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BULLETIN
OF THE AMERICAN PHYSICAL SOCIETY

Vol. 49, No. 5, September 2004

GEC Meeting 2004

TABLE OF CONTENTS

57th Annual Gaseous Electronics Conference

September 26–29, 2004

Queen's University Belfast and Dublin City University

GENERAL INFORMATION

Failte. Welcome to Ireland and to the Fifty-Seventh Annual Gaseous Electronics Conference (GEC) of the American Physical Society (APS). The GEC 2004 program will address a broad range of topics at the forefront of Gaseous Electronics. The program includes the Will Allis Prize Talk, the GEC Student Award for Excellence Talks, 18 invited talks and over 250 contributed papers presented in oral and poster sessions. The conference will be headquartered at the Conference Centre at the Fitzpatrick Bunratty Hotel, Bunratty, County Clare, Ireland.

SPECIAL SESSIONS AND EVENTS

The GEC Executive Committee is pleased to announce that the Will Allis Prize Lecture at the 2004 GEC will be given by Professor Bill McConkey of the University of Windsor, Canada. His talk is entitled ''Colliding electrons–Workhorses of gaseous electronics''. The Will Allis Prize of the American Physical Society for the Study of Ionized Gases was established in 1989 in recognition of Will's outstanding contributions to this field of study. The talk will cover both introductory material, to guide students and newcomers, as well as cutting edge work from the speaker's own experience, to engage the expert.

The GEC Executive Committee seeks to encourage student attendance and participation in the Gaseous Electronics Conference. In order to recognize the important contributions students make to the GEC, the Committee annually invite applications for the GEC Student Award for Excellence, a prize for the best paper presented by a student at that year's conference.

The GEC Executive Committee has reviewed this year's nominated abstracts and have selected the following students to compete for the 500 Euro prize. They are listed in the order of their appearance in the program.

Sergey Belostotsky (Skobeltsyn Nuclear Physics Institute of Lomonosov, Moscow State University), ''Investigation of negative ion destruction by $O(^3P)$ atoms and $O_2(a^{1\Delta}{}_g)$ molecules in oxygen plasma'' [AS1.005], Sunday, 9:30.

Matt Foster (University of Missouri–Rolla), ''Fully Differential Cross Section for Charged Particle Impact Ionization of Helium'' [CS2.002], Sunday, 14:30.

Milica Jelisavcic (Australian National University), ''Electron Scattering from Plasma Processing Gases–C_2F_4 and c-C_4F_8'' [DS2.003], Sunday, 16:45.

Nicholas Plihon (LPTP, Ecole Polytechnique, France), ''Instabilities in electronegative ICP-type discharges'' [KM1.001], Monday, 14:00.

Members from the GEC Executive Committee will serve as judges. They will attend all the finalists' talks and select the award winner. The recipient of the GEC Student Award for Excellence will be announced at the Conference Lunch. You are encouraged to attend these talks and session details are given in the listing above.

SESSION TOPICS

A1:	Registration and Reception
AS1:	Glows
AS2:	Plasma Chemistry
BS1:	Plasma Applications for Nanotechnology I
BS2:	Lighting I
CS1:	Particle and Electrical Diagnostics
CS2:	Ionization
DS1:	Optical Emission Diagnostics
DS2:	Interactions with Molecules
ES1:	Poster Session I –Recombination –Other plasma topics –Glows –Electron-atom scattering –Atomic lifetimes –Heavy particle interactions –Capacitively coupled plasmas
ES2:	Poster Session II –Materials processing in low temperature

plasmas
–Plasma chemistry
–Diagnostics I

FM1: Plasma Applications

FM2: Electron-Molecule Interactions

GM: Plenary Lecture: The Will Allis Prize Lecture

HM: Business Meeting

JM1: Plasma Applications for Nanotechnology II

JM2: Dissociative Attachment/Dissociative Recombination

KM1: Negative Ions and Instabilities

KM2: Material Processing in Low Pressure Plasmas I

LT1: Biological and Emerging Applications of Plasmas

LT2: Plasma Surface Interactions

MT1: Plasma Boundaries

MT2: Capacitively Coupled Discharges

NT1: Laser Diagnostics

NT2: Cold Collisions

PT1: Poster Session III
–Inductively coupled plasmas
–Magnetically enhanced plasmas
–Electron-molecule interactions
–Ionization
–Distributions and transport coefficients
–Photoionization

PT2: Poster Session IV
–Dielectric barrier discharges, Displays
–Thermal plasmas
–Lighting plasmas
–Diagnostics II
–Innovative plasma applications
–Dusty Plasmas
–Plasma applications for nanotechnology
–Environmental applications
–Biological and emerging applications of plasmas
–Coronas, breakdown and sparks
–Laser media-processes
–High pressure glow discharges

QW1: Pulsed Plasmas

QW2: Lighting II

RW1: High Pressure Discharges

RW2: Material Processing in Low Pressure Plasmas II

SW: Conference Lunch

PRESENTATION FORMATS AND AUDIOVISUAL EQUIPMENT

Papers that have been accepted for presentation are listed in the technical program. Invited papers are allotted 25 minutes with 5 additional minutes for questions and discussion. Oral contributed presentations are allotted 12 minutes with 3 additional minutes for questions and discussion. If you are making an oral presentation please arrive at least fifteen minutes before the beginning of your session and report to the session chair.

The poster presentation board area is 1 m high and 1.2 m wide. Posters can be put up two hours before the beginning of the session and must be removed immediately after the session ends.

REGISTRATION

The registration desk is located in the Conference Centre at the Fitzpatrick Bunratty Hotel. It will be open during session times commencing 19:00 on Saturday, 25 September to noon on Wednesday, 29 September. The on-site registration fee is 285 Euros for regular registrations and 160 Euros for students and retirees.

RECEPTION AND CONFERENCE LUNCH

An opening reception will be held on the evening of Saturday, 25 September 2004 in the Conference Centre at the Fitzpatrick Bunratty Castle starting at 19:00.

A conference lunch will be held on 29 September 2004 in the Bunratty Castle Hotel. This will be a table-served lunch and will be an opportunity for the presentation of prizes and Executive Committee announcements. Some tickets may still be available from the conference registration desk at a cost of 21 Euro.

E-MAIL AND OTHER BUSINESS SERVICES

Free internet access will be available to the conference participants in the computer room behind the con-

ference registration desk (see plan). There is a wireless service available in the conference centre. Wireless access cards will be for sale at the registration desk for those who have wireless capability. The conference registration desk will try to help you find any other business services you require.

DINING AND SIGHTSEEING

Information on dining opportunities is provided in your Conference Pack. We would like to point out that some restaurants, even in hotels, require advance booking and that in Ireland many restaurants close on Sunday night so please make arrangements for dinner early that evening.

On the night of Monday, 27 September 2004, we have seats reserved at the medieval banquets at Bunratty Castle, located adjacent to the Fitzpatrick Bunratty Hotel, and Knappogue Castle, about 15 miles from Bunratty Village (buses provided). Check with the Conference Registration desk for availability; tickets cost 45 Euros.

Members of the local committee will be on hand, at the registration desk, throughout the conference to help participants and accompanying guests organize bookings for sightseeing tours.

CALL FOR NOMINATIONS FOR GEC GENERAL AND EXECUTIVE COMMITTEES

The GEC Executive Committee (ExComm) is the governing body of the GEC. It is the responsibility of the ExComm to oversee all aspects of the conference. This includes selection of meeting sites, budgetary decisions, selection of special topics and invited speakers, accepting and rejecting abstracts, and arranging of the program. The General Committee and the ExComm meet during the GEC, and the ExComm meets again during the summer to plan the program of the next GEC. There are numerous communications between members of the ExComm (usually e-mail) during the year to insure the successful completion of their duties. We have been fortunate over the years to have a dedicated group of volunteers who have been willing to take on these very necessary roles.

The bylaws of the Gaseous Electronics Conference describe the process whereby members of the ExComm are elected. At the GEC Business Meeting (to be held on Monday, September 27, at 11:45 in the Belfast Room of the Conference Centre at the Fitzpatrick Bunratty Hotel), nominations are accepted for members of the GEC General Committee (GenComm).

The GenComm consists of the ExComm and 6 at-large members elected at the Business Meeting. The eligible voting membership of the GEC (defined as those attending the Business Meeting) elects 6 at-large members. The GenComm then meets to fulfill its only duty: to elect new members of the ExComm.

The ExComm membership consists of the Chair, Treasurer, Past-Secretary, Secretary, Secretary-elect, past or incoming Chair, and 4 at-large members. The Chair is a 4-year term (1 year incoming, 2 years Chair, and 1 year past-Chair), the Secretary is a 3-year term (1 year incoming, 1 year Secretary, 1 year past-Secretary), and all other ExComm members serve 2 years. The Secretary is the person who manages the local arrangements for the meeting and is usually ''recruited'' and appointed to the ExComm.

The ExComm welcomes nominations, including self-nomination, for both the GenComm and the ExComm. Becoming a GenComm and/or ExComm member provides a unique opportunity to see both how the GEC is run and to influence its future direction by helping to define the programs and choosing future sites.

Please submit your nominations to the GEC Chair to any member of the ExComm. The ExComm also welcomes inquiries on hosting future GECs.

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PLEASE NOTE

The APS has made every effort to provide accurate and complete information in this *Bulletin*. However, changes or corrections may occasionally be necessary and may be made without notice after the date of publication. To ensure that you receive the most up-to-date information, please check the meeting Corrigenda distributed with this *Bulletin*.

Epitome of the 57th Gaseous Electronics Conference of the American Physical Society

19:00 SATURDAY EVENING 25 SEPTEMBER 2004

1A **Reception and Registration**
Belfast Room, Bunratty Conference Centre

8:30 SUNDAY MORNING 26 SEPTEMBER 2004

AS1 **Glows**
Belfast Room, Bunratty Conference Centre

AS2 **Plasma Chemistry**
Dublin Room, Bunratty Conference Centre

10:30 SUNDAY MORNING 26 SEPTEMBER 2004

BS1 **Plasma Applications for Nanotechnology I**
Winter, Tomohiro
Belfast Room, Bunratty Conference Centre

BS2 **Lighting I**
Haverlag
Dublin Room, Bunratty Conference Centre

14:00 SUNDAY AFTERNOON 26 SEPTEMBER 2004

CS1 **Particle and Electrical Diagnostics**
Belfast Room, Bunratty Conference Centre

CS2 **Ionization**
Ullrich
Dublin Room, Bunratty Conference Centre

16:00 SUNDAY AFTERNOON 26 SEPTEMBER 2004

DS1 **Optical Emission Diagnostics**
Bowden
Belfast Room, Bunratty Conference Centre

DS2 **Interactions With Molecules**
Williams
Dublin Room, Bunratty Conference Centre

19:30 SUNDAY EVENING 26 SEPTEMBER 2004

ES1 **Poster Session I**
Clonmoney, Fitzpatrick Bunratty Hotel

ES2 **Poster Session II**
Cork, Bunratty Conference Centre

8:30 MONDAY MORNING 27 SEPTEMBER 2004

FM1 **Plasma Applications**
Belfast Room, Bunratty Conference Centre

FM2 **Electron-Molecule Interactions**
Huo
Dublin Room, Bunratty Conference Centre

10:30 MONDAY MORNING 27 SEPTEMBER 2004

GM **The Will Allis Prize Lecture**
McConkey
Belfast Room, Bunratty Conference Centre

11:45 MONDAY MORNING 27 SEPTEMBER 2004

HM **Business Meeting**
Belfast Room, Bunratty Conference Centre

14:00 MONDAY AFTERNOON 27 SEPTEMBER 2004

JM1 **Plasma Applications for Nanotechnology II**
Belfast Room, Bunratty Conference Centre

JM2 **Dissociative Attachment/ Dissociative Recombination**
Hotop
Dublin Room, Bunratty Conference Centre

16:00 MONDAY AFTERNOON 27 SEPTEMBER 2004

KM1 **Negative Ions & Instabilities**
Belfast Room, Bunratty Conference Centre

KM2 **Material Processing in Low Pressure Plasmas I**
Dublin Room, Bunratty Conference Centre

8:30 TUESDAY MORNING 28 SEPTEMBER 2004

LT1 **Biological and Emerging Applications of Plasmas**
Bowen, Burrow
Belfast Room, Bunratty Conference Centre

LT2 **Plasma Surface Interactions**
Dublin Room, Bunratty Conference Centre

10:30 TUESDAY MORNING 28 SEPTEMBER 2004

MT1 **Plasma Boundaries**
Belfast Room, Bunratty Conference Centre

MT2 **Capacitively Coupled Discharges**
Dublin Room, Bunratty Conference Centre

14:00 TUESDAY AFTERNOON 28 SEPTEMBER 2004

NT1 **Laser Diagnostics**
Hancock
Belfast Room, Bunratty Conference Centre

NT2 **Cold Collisions**
Stwalley
Dublin Room, Bunratty Conference Centre

16:00 TUESDAY AFTERNOON 28 SEPTEMBER 2004

PT1 **Poster Session III**
Clonmoney, Fitzpatrick Bunratty Hotel

PT2 **Poster Session IV**
Cork, Bunratty Conference Centre

8:30 WEDNESDAY MORNING 29 SEPTEMBER 2004

QW1 **Pulsed Plasmas**
Belfast Room, Bunratty Conference Centre

QW2 **Lighting II**
Collins, Whang
Dublin Room, Bunratty Conference Centre

10:30 WEDNESDAY MORNING 29 SEPTEMBER 2004

RW1 **High Pressure Discharges**
Kono, Ebert
Belfast Room, Bunratty Conference Centre

RW2 **Material Processing in Low Pressure Plasmas II**
Benjamin, Economou
Dublin Room, Bunratty Conference Centre

12:30 WEDNESDAY AFTERNOON 29 SEPTEMBER 2004

SW **Conference Lunch**
Castle Suite, Bunratty Castle Hotel

MAIN TEXT

SESSION AS1: GLOWS
Sunday morning, 26 September 2004
Belfast Room, Bunratty Conference Centre at 8:30
Ed Barnat, Sandia National Laboratory, presiding

8:30

AS1 1 Novel Giant-Size Plasmas Produced by Microwave Discharge with Slot Antenna Array H. SUGAI, Y. NOJIRI, K. TAKASU, T. ISHIJIMA, E. STAMATE, *Nagoya University, Japan* There is a growing need for giant-scale high-density plasma sources for manufacturing a meter-size flat panel display and for surface modification of large-area various materials. Capacitive discharges at frequencies in VHF range have been studied to meet this demand, however standing wave effect and edge effect significantly degrade the plasma uniformity. Here, we present a new technology for generation of large-area flat high-density plasma based on surface wave excitation at 2.45 GHz. A critical challenge to avoid huge atmospheric pressure acting on a microwave window was dodged by fully filling a waveguide, which is directly inserted in a low-pressure discharge vessel. The second challenge is a discharge antenna construction to attain the plasma uniformity over meter-scale. This issue was solved by a careful design of slot antenna array. Surface waves propagating along the dielectric-plasma interface were investigated in FDT simulation. A surface wave mode was observed in plasma by a movable antenna, indicating the mode number predicted in the simulation. In a discharge vessel, 1 m long and 0.3 m wide, we obtained the plasma density of 5×10^{11} cm^{-3} with 10 and 50 mTorr Ar. Three-dimensional profiles of plasma density in different conditions measured by a Langmuir probe will be presented.

8:45

AS1 2 WITHDRAWN

9:00

AS1 3 Investigation of Axially Flowing He/O_2 Plasmas for Oxygen-Iodine Lasers* D. SHANE STAFFORD, *Dept. Chem. and Biomolecular Engr., University of Illinois at Urbana-Champaign* MARK J. KUSHNER, *Dept. Elect. and Comp. Engr., University of Illinois at Urbana-Champaign* Current trends in pumping chemical oxygen-iodine lasers (COIL) involve producing the $O_2(^1\Delta)$ donor in axially flowing rf or pulsed electric discharges, thereby circumventing the hazards and complexity of conventional liquid-phase $O_2(^1\Delta)$ production. Previous global-plug-flow modeling focused on developing reaction mechanisms and determining the specific energy deposition required to achieve high $O_2(^1\Delta)$ yields. Recent experimental efforts have achieved positive laser gain with these energy depositions and have demonstrated the importance of upstream and downstream penetration of the plasma. In this work, we have examined the effects of axial transport (mass, momentum, and energy) on $O_2(^1\Delta)$ yields in flowing He/O_2 plasmas at a few to 10 Torr using a compressible 1D hydrodynamics and plasma kinetics model. Experimentally observed extension of short lived excited states upstream and downstream of the excitation zone is explained by electron thermal conduction and flow-induced extension of the plasma zone

*Work supported by Air Force Research Labs and National Science Foundation

9:15

AS1 4 On "Helicon Antennas" and the role of the different current elements A. R. ELLINGBOE, *Dublin City University, Ireland* Over the last 35 years numerous antenna geometries have been employed in in helicon-wave plasma sources. Helicon waves propagate nearly parallel to the axial magnetic field, and in cylindrical geometry have a preference for the $M = +1$ (right-hand-circularly-polarized) wave structure. Spatially, this results in a left-handed-circularly polarized wave, and helically twisted antennas have been used to improve coupling between the antenna and the helicon wave. The amplitude of the resultant helicon wave can be represented by the power spectrum (k_z, M) of the antenna divided by the plasma response (k_z, M). A detailed analysis of the power spectrum of the various antennas, broken down into their primary elements will be presented.

9:30

AS1 5 Investigation of negative ion destruction by $O(^3P)$ atoms and $O_2(a^1\Delta_g)$ molecules in oxygen plasma SERGEY BELOSTOTSKY,* DMITRIY LOPAEV, TATYANA RAKHIMOVA, *Skobeltsyn Nuclear Physics Institute of Lomonosov Moscow State University, 119992, Moscow, Russia* It is well-known that negative ions play an important role in plasmas of electronegative gases. They affect a lot of processes. E.g. reactions of associative detachment on active particles (radicals, metastable atoms and molecules) cause changes in a charge composition, thereby directly influencing on the electric field distribution and EEDF. Furthermore, negative ions take an active part in various plasma-chemical reactions, such as plasma etching, polymerization and dusty particles formation. The dynamics of negative ions N^- in oxygen dc glow discharge in a wide range of pressure and current density of the discharge (P=0.16-2 Torr, I=5-25 mA/cm2) was investigated. The N^- concentration was measured by the laser photodetachment technique. As experimentally shown by using the discharge modulation, the N^- concentration varies with the characteristic times of evolution of oxygen atoms $O(^3P)$ and metastable molecules $O_2(a^1\Delta_g)$. To investigate the dynamics of atomic

oxygen density the actinometry technique was applied. The dynamics of $O_2(a^1\Delta_g)$ molecules was investigated by the IR spectroscopy at 1.27 μm. Moreover, the photodetachment technique was also applied for studying the spatial distribution of negative ion density. It has been shown that O^- ion is the main negative ion in low pressure plasma. The analysis of the data of O^- ion dynamics allowed to determine the rate constants of the associative detachment on $O(^3P)$ atoms and $O_2(a^1\Delta_g)$ molecules in plasma for the first time: $O^- + O(^3P) \rightarrow O_2 + e$; $O^- + O_2(a^1\Delta_g) \rightarrow$ products + e.

*Student fo Faculty of Physics, Lomonosov Moscow State University

9:45

AS1 6 Experimental evidence of a charge reduction during one on/off period of VHF source in holes on a SiO_2-wafer exposed to etching in a pulsed two frequency CCP. TAKESHI OHMORI, TAKUMI AKAIKE, TAKESHI KAMATA GOTO, TOSHIAKI MAKABE, *Keio University* It will be essential to develop in-situ diagnostics for charging damage of a surface exposed to etching under close and complementary cooperation between optical and electric procedure in a top-down nanoscale etching. In our previous papers[1], we have applied an emission selected computerized tomography(CT) close to the wafer during plasma etching, in order to investigate the polarity and the phase of high energy charged particles incident on the wafer, biased by a LF source. A reduction in charging voltage on a contact hole bottom of SiO_2 was validated in a pulsed 2f-CCP in CF_4/Ar, by using a temporal emission CT and a contact hole charging. Correlational results of the reduction in the charging voltage are elucidated as a function of phase and amplitude of the single bias pulse[1]. In the present work, discussion is focused on the temporal change of a SiO_2 hole charging during one on/off period of VHF source. The injection mechanism of energetic negative charges to the wafer is discussed from the temporal changes of CT images, total flux to the wafer, and bottom charging voltage. [1] T. Ohmori, T. K. Goto, T. Kitajima, and T. Makabe, Appl. Phys. Lett. 83, No. 22, pp.4637-4639 (2003), J. Vac. Sci. Technol. (submitted)

SESSION AS2: PLASMA CHEMISTRY
Sunday morning, 26 September 2004
Dublin Room, Bunratty Conference Centre at 8:30
Pascal Chabert, LPTP-UMR Ecole Polytechnique, presiding

8:30

AS2 1 ECR PLASMA MODIFIED POLYSULFONE MEMBRANES ESENGUL KIR, *T.C. Süleyman Demirel Üniversitesi* LUTFI OKSUZ, *T.C. Süleyman Demirel Üniversitesi* AYSEGUL GOK, *T.C. Süleyman Demirel Üniversitesi* SELCUK HELHEL, *T.C. Süleyman Demirel Üniversitesi* This study considers ion transport properties of membranes modified by action of ECR nitrogen plasma. The membranes are a kind of polysulfone membrane. They generally used for ion transportation and recovery. These membranes were pretreated to remove impurities. We showed that ECR nitrogen plasma changes various kinds of surface functionalities. Ion transport properties of membranes were taken into consideration. IR measurements of both non plasma modified and plasma modified membranes were taken between 4000-400cm-1 scale. Additionally, they were characterized by scanning electron microscopy (SEM). During laboratory experiments, plasma treated membranes react much more better than their untreated analogues to ion transportation.

8:45

AS2 2 Cavity Ringdown Spectroscopy Measurements of a DC Arcjet Reactor and Associated Computational Modelling CHRISTOPHER RENNICK, *School of Chemistry, University of Bristol* RICHARD ENGELN, *Eindhoven University of Technology* MICHAEL ASHFOLD, *School of Chemistry, University of Bristol* ANDREW ORR-EWING, *School of Chemistry, University of Bristol* Absolute concentrations of carbon radicals have been measured in a 10 kW diamond chemical vapour deposition (CVD) plasma jet system by cavity ringdown spectroscopy (CRDS), a highly sensitive absorption spectroscopic technique particularly suited to the detection of radicals under the harsh conditions presented in a plasma jet. The measurements have revealed the absolute number density of $C_2(X^1\Sigma_g^+)$ radicals to be of the order 3.0×10^{11} cm^{-3}, and that of $C_2(a^3\Pi_u)$ to be 3×10^{12} cm^{-3}. This ratio is close to that predicted by a Boltzmann weighting of the two states at 4000 K (as determined by Doppler widths and the comparison of rotational and vibrational populations) despite the higher reaction rates of the X state with hydrogen and hydrocarbons. Work is currently in progress to determine electron densities in the plasma by measurements of the hydrogen Balmer lines in absorption by CRDS. Results of these investigations will be presented, with comparison to a 2 dimensional computational model of the system.

9:00

AS2 3 Non-Thermal Ignition of Hydrocarbon-Air Mixtures by Nonequilibrium Plasmas NAVEEN CHINTALA, AINAN BAO, GUOFENG LOU, J. WILLIAM RICH, WALTER LEMPERT, IGOR ADAMOVICH, *Ohio State University* The paper presents results of nonequilibrium RF plasma assisted ignition and combustion experiments in premixed methane-air, ethylene-air, and CO-air flows. The results show that large volume ignition of these mixtures by a uniform, diffuse RF plasma can be achieved at high flow velocities (up to u=25 m/s) and low pressures (P=60-130 torr), as compared to either a spark discharge or a DC arc discharge. FT-IR measurements show that ignition occurs at temperatures below that of equilibrium autoignition by as much as 350o C. Spontaneous emission in the discharge detected presence of radical species such as CN, CH, C2, and OH, as well as O and H atoms. CO2 emission was also detected in the flame downstream of the RF plasma. FTIR absorption of the combustion products shows that up to 80burned in ethylene-air mixtures and 50mixtures. Further experiments at higher test section flow velocities and higher RF discharge powers are underway.

9:15

AS2 4 PLASMA PROCESS ANALYSIS USING QUANTUM CASCADE LASER-ABSORPTION SPECTROSCOPY J. ROEPCKE, *INP-Greifswald, F.-L.-Jahn-Str. 19, 17489 Greifswald, Germany* S. GLITSCH, F. HEMPEL, S. SASS, H. ZIMMERMANN Tuneable infrared diode laser absorption spectroscopy (TDLAS) in the mid infrared spectral region is a well known technique for the monitoring of molecular plasma reaction products in their ground state. Information on absolute concentrations of plasma species can be used for improvements of process pa-

rameters. Quantum cascade lasers (QCL), a new type of mid infrared lasers, have become available recently. QCLs operate at room temperature and can have similar spectroscopic properties, in comparison with TDLs. Quantum cascade laser absorption spectroscopy (QCLAS) methods can be applied for the measurements of concentrations of molecular species as well. In combination with thermoelectrically cooled infrared detectors, QCLAS is well suited for industrial applications, in particular for in-situ process monitoring. Recently a itnew QCL based system, the Q-MAX-System, has been developed and used to study dissociation processes of several precursor gases, as e.g. hydrocarbons and B_2H_6 or BCl_3, in industrial CVD reactors. The applicability of this type of diagnostic for on-line process monitoring has been proofed successfully. Recent results of measurements are presented.

9:30

AS2 5 Theoretical Analysis of Plasma Spraying Particle Chemistry DAVID KOLMAN, *Technical University Ilmenau, Germany* Particle chemistry, namely oxidation and reduction in case of metallic particles, is an important and often critical phenomenon in plasma spraying, and as such it has to be paid close attention thereto. When the chemistry changes are considered at all, the reaction rates are taken from a molten drop measurement or modeled by a Wagner-like formula neglecting the complex interplay of various diffusion and chemical processes. The incorporation of the complex oxidation patterns known to occur in case of alloy oxidation is to our knowledge not readily attempted either. The present paper sets as its goals just that to outline briefly the approaches to oxidation/reduction modeling, to develop a comprehensive quantitative model for particle oxidation/reduction and to discuss the tremendous difficulties in collecting the physico-chemical data needed for such a modeling. A comparison of the results for Fe-Cr oxidation in water-stabilized plasma spraying with experimental data and a discussion of the crucial modeling parameters conclude the talk.

9:45

AS2 6 Plasma Chemistry in remote Ar/C_2H_2 plasma and hydrocarbon growth precursors JAN BENEDIKT, *Dep. of Appl. Phys., Eindhoven Univ. of Tech., Eindhoven, The Netherlands* SUMIT AGARWAL, *Dep. of Chem. Eng., Univ. of Massachusetts, Amherst, MA 01003* RICHARD VAN DE SANDEN, *Dep. of Appl. Phys., Eindhoven Univ. of Tech., Eindhoven, The Netherlands* Threshold ionization mass spectrometry (TIMS), an ultra high sensitive radical detection technique, is successfully applied to the remote Ar/C_2H_2 expanding thermal plasma in order to study the C_2H_2 chemistry and the growth mechanism of hydrogenated amorphous carbon films (a-C:H). The radicals such as C_2H or C_3H_y (y=0..2) are measured. A plasma chemistry model is created in order to reveal dominant plasma chemistry channels. The film growth rate and film properties are determined additionally by different experimental techniques. It is shown that C, CH, C_2 and C_2H radicals formed in the primary decomposition of C_2H_2, usually suggested as depositing species, play a minor role in the film growth due to their high reactivity in the gas phase with C_2H_2. Radicals such us C_3 and C_3H, which are produced in secondary reactions involving C_2H_2, are the probable growth precursors. These radicals are resonantly stabilized, which allows them to survive in the C_2H_2-rich environment. The results provide valuable information about possible radical growth precursors and they can help to understand the a-C:H formation e.g. in future fusion reactors where the tritium redeposition will be one of the major research issues.

SESSION BS1: PLASMA APPLICATIONS FOR NANOTECHNOLOGY I

Sunday morning, 26 September 2004; Belfast Room, Bunratty Conference Centre at 10:30
Alan Hynes, Dow Corning Plasma Solutions, presiding

Invited Papers

10:30

BS1 1 Nanoparticles in Process Plasmas: Growth, Diagnostics, Applications.
JÖRG WINTER, *Institute of Experimental Physics II, Ruhr-University Bochum, D-44780 Bochum, Germany*

Process plasmas for thin film deposition and for etching often tend to form nanoparticles. In semiconductor processing particle formation has to be avoided because particle incorporation may lead to a lethal defect of the device. The ever decreasing feature size sets a size limit for such killer particles to a few nanometres for the next generation of devices. In other applications, however, plasma grown nanoparticles are used to advantage. Examples are innovative dispersion materials, chemical catalysis, pharmacology, etc. Understanding the growth mechanisms and the complex plasma-particle interactions are challenging questions. In situ particle diagnostics are instrumental for tackling these problems. In this contribution, the growth of carbonaceous nanoparticles from Ar-CH_4 and from Ar-C_2H_2 plasmas and the mutual interaction of particles and plasma will be discussed. The growth occurs via homogeneous nucleation involving negative ion-molecule-reactions, followed by rapid nucleation of protoparticles and further growth by accretion. It will be shown, that also in the case of Ar-CH_4 the existence of C_2H_x precursors triggers the particle growth. When the particles are larger than a few nm, they are charged negatively on average and confined in the plasma. Small particles occupy essentially the whole plasma volume, heavy particles are suspended against gravity at the sheath edge with its high electric field. The in-situ diagnostics of nanoparticles is an important issue. Some examples will be presented using multipass FTIR absorption spectroscopy, Rayleigh-Mie Ellipsometry, laser light scattering, and the analysis of the complex impedance of the discharge. The latter method, though yielding a global information of the discharge, appears to be suited for industrial use. A big challenge is the detection of particles with diameters of a few nanometres light scattering gets increasingly difficult because of the r^{-6} dependence of the scattering cross section. Finally, examples for the use of nanoparticles in thin film deposition will be discussed.

11:00

BS1 2 Generation of atmospheric pressure radio-frequency discharge without dielectric barrier and application to nanotubes deposition.

NOZAKI TOMOHIRO, *Tokyo Institute of Technology, Mechanical and Control Engineering*

This talk will present carbon nanotubes/nanofibers (CNs) deposition using an atmospheric pressure radio-frequency discharge (APRFD). Unlike medium frequency operation of atmospheric pressure glow discharge (10-100 kHz), high frequency (13.56 MHz) operation is expected to generate continuous plasma and will be able to grow vertically oriented carbon nanotubes in atmospheric pressure PECVD. In addition, operating voltage is significantly reduced due to electron and ion trapping in the discharge gap which minimizes the formation of filamentary discharges. In fact, stable glow discharge is maintained between two metallic electrodes without dielectric barrier. The plasma structure and related chemistry is strongly influenced by H2/CH4 admixture. Operating voltage and discharge current significantly increased with increasing admixture. A uniform discharge transits to arc discharge if applied voltage exceeds a curtain value. In addition, emission from helium and atomic hydrogen are significantly weakened even though discharge power is increased. Carbon-based fine particles tend to form in gas phase because of atmospheric pressure condition. Up to now, the author suggests that lower amount of precursor (less than 2-5% of H2/CH4) and higher growth temperature seems to grow well-oriented nanotubes, but reproducibility of results depend strongly on gas flow pattern and substrate temperature. Not only plasma operation, but also heat and mass transport must be well understood and controlled for further improvement of atmospheric pressure PECVD.

Contributed Papers

11:30

BS1 3 Modeling the Growth of Nanostructures in Plasmas HELEN HWANG, *NASA Ames Research Center* DEEPAK BOSE, *Ames Center for Nanotechnology* T. R. GOVINDAN, *NASA Ames Research Center* As semiconductor circuits shrink to CDs below 0.1 nm, it is becoming increasingly critical to replace and/or enhance existing technology with nanoscale structures, such as nanowires for interconnects. Nanowires grown in plasmas are strongly dependent on processing conditions, such as gas composition and substrate temperature. Growth occurs at specific sites, or step-edges, with the bulk growth rate of the nanowires determined from the equation of motion of the nucleating crystalline steps. Traditional front-tracking algorithms, such as string-based or level set methods, suffer either from numerical complications in higher spatial dimensions, or from difficulties in incorporating surface-intense physical and chemical phenomena. Phase field models have the robustness of the level set method, combined with the ability to implement surface-specific chemistry that is required to model crystal growth, although they do not necessarily directly solve for the advancing front location. We have adopted a phase field approach and will present results of the adatom density and step-growth location in time as a function of processing conditions, such as temperature and plasma gas composition.

11:45

BS1 4 Remote Plasma Synthesis of Highly Oriented Silicon Nanoparticles and Single-Nanoparticle Electronic Devices AMEYA BAPAT, CURTIS ANDERSON, UWE KORTSHAGEN, *Mechanical Engineering, University of Minnesota* DING YONGPING, YING DONG, STEPHEN CAMPBELL, *Electrical and Computer Eningeering, University of Minnesota* Crystalline semiconductor nanoparticles can be used for the manufacture of novel electronic devices such as vertical Schottky barrier transistors. Remote plasma synthesis of such particles may enable the manufacture of such devices on a wide spectrum of substrates that may be flexible or that require low processing temperatures. Furthermore, directed deposition of remotely produced crystalline particles may enable 3-dimensional integration of electronic devices. In this presentation we discuss a plasma process based on a constricted mode capacitive discharge which is capable of producing single-crystal, virtually defect-free, cube shaped silicon nanoparticles. Particles are between 20-50 nm in diameter with a highly monodisperse particle size distribution. Particles are extracted from the discharge through an orifice, formed into a particle beam, and deposited on metallized or doped silicon wafers. Metal-semiconductor-metal devices as well as Schottky barrier vertical transistors have been built from these particles. Electrical characterization of these devices provides insight into the electronic properties of the silicon nanoparticles as well as the importance of interface effects. This work is supported by NSF under NIRT grant DMI-0304211.

12:00

BS1 5 Direct particle temperature measurements in dusty plasmas GREG HEBNER, *Sandia National Laboratories* C. FLEDDERMANN, *University of New Mexico* Particle temperature, the random thermal motion of particles immersed in a plasma, has a strong influence on the structure and binding of plasma crystal assemblies. For example, the formation of stable, well ordered dust arrangements is not possible under conditions where the thermal energy is larger than the binding or confining potential energy. To characterize the thermal temperature, we have employed two different techniques. The first was based upon traditional image analysis of the particle motion using digitized images from cameras and post processing. The second used a laser interferometer system to measure the motion of individual particles. The laser interferometer has significant advantages over the traditional image analysis techniques including higher velocity resolution and good spatial discrimination. We will compare temperature measurements obtained using the two systems and discuss the experimental challenges associated with using a laser interferometer with a 6 um target. The particle temperature as a function of number of particles and structure as well as the implications for particle heating mechanisms will also be discussed. This work was supported by the Division of Material Sciences, BES, Office of Science, U. S. Department of Energy and Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energys National Nuclear Security Administration under contract DE-AC04-94AL85000.

12:15

BS1 6 Vertical wave packets observed in a crystallized hexagonal monolayer complex plasma DMITRY SAMSONOV, SERGEI ZHDANOV, GREGOR MORFILL, *Max-Planck-Institute for Extraterrestrial Physics* Propagation of vertical wave packets was observed experimentally in a hexagonal monolayer complex plasma. The complex plasma was formed of monodisperse plastic microspheres suspended above an electrode in a capacitively coupled radio-frequency discharge. Vertical oscillations were excited by a short electrostatic pulse applied to a wire stretched below the lattice. The lattice was illuminated by a laser sheet and observed with a top view video camera. A new method of vertical motion diagnostics based on particle visible brightness was used. Wave packets with constant width propagating away from the excitation source were observed. It was found that the phase velocity of the vertical waves exceeded its group velocity by a factor 70 and had the opposite direction as expected for an optical-like dispersion relation (backward wave). The theory describing the lattice motion is based on three-dimensional equations of motion and uses a long wavelength weak dispersion weak inhomogeneity aproximation. It is not limited by the nearest neighbour approximation (takes all particles into account). It was found that the constant wave packet width is provided by a balance of dispersion (spreading the packet) and lattice inhomogeneity (focusing the packet).

SESSION BS2: LIGHTING I

Sunday morning, 26 September 2004; Dublin Room, Bunratty Conference Centre at 10:30
Robert Piejak, Osram, presiding

Invited Papers

10:30

BS2 1 Modeling of the energy balance and transport processes in metal halide lamps using PLASIMO.
MARCO HAVERLAG,* *Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands*

Metal halide lamps are being used in many applications where a compact light source producing a large amount of light with good colour properties is necessary. Despite the fact that these light sources have already been around for a number of years, many aspects of the plasma energy balance and transport processes (segregation) are not understood on a quantitative level, and therefore a number of groups in the world are working on numerical models that describe these plasmas. In a co-operation between the Eindhoven university and Philips Lighting CDL the plasma modelling toolkit PLASIMO is used to construct a 2-D LTE model of metal halide lamps which describes the following aspects: transport of plasma species by diffusion and convection in combination with the local chemical equilibrium between different species in this multi-component plasma, transfer of energy by different mechanisms (gas conduction, radiation transport, ethalpy transport, convective energy transport), and the local electric field which governs the Joule power that is injected in the plasma. Since these plasma are efficient in the generation of radiation, the treatment of radiation is paramount in understanding the energy balance. In the presentation the different sub-models that have been developed are treated and some first results with metal halide lamps will be discussed.

*D. Benoy (Philips Lighting), B. Hartgers, M. Beks, J. van Dijk, J. van der Mullen.

Contributed Papers

11:00

BS2 2 Modeling of multi filament discharges in dielectric barrier discharge excimer lamp HARUAKI AKASHI, *National Defense Academy of Japan* AKINORI ODA, *Nagoya Inst. Technol.* YOSUKE SAKAI, *Hokkaido Univ.* Filamental discharges in Dielectric Barrier Discharge(DBD) excimer lamp has been simulated using two dimensional fluid model. 300Torr Xe gas was used and the gap length of 1cm, the thickness of 0.2cm dielectric barriers, radial length of 1cm and 200kHz driving frequency are used. And periodical boundary condition is taken for the radial direction boundary. A small electron-ion density cluster is provided in the middle of the gap for initial condition. At the beginning, the discharge starts from one filament, then the number of filaments becomes three. These filaments are formed self-consistently, and found to be stable in the present condition. In this discharge, there are two discharge modes in the filament discharge development, streamer discharge and surface discharge. In the streamer discharge period, the filaments are formed in the bulk region. And the streamer heads reached at the cathode at the same time. Then, the discharge expands toward radially by the surface discharge. The surface discharge stops expanding by colliding with other surface discharges of other filaments. This surface discharge influence on the current waveform significantly and this makes flat part in the discharge current.

11:15

BS2 3 Two-dimensional Numerical Study of a Uniform Atmospheric Pressure Glow Discharge in Helium with Nitrogen Impurities PENG ZHANG, UWE KORTSHAGEN, *Mechanical Engineering, University of Minnesota* Uniform Atmospheric Pressure Glow Discharges (APGD) are widely considered for applications in plasma processing including etching and deposition at atmospheric pressure. A two-dimensional numerical model has been developed for the study of an APGD in helium with nitrogen impurities. The simulation successfully reproduces several features observed in experiments. The results show that the breakdown first appears in the central region of the discharge volume, followed by the axial and radial propagation of the ionization wave. The space charge electric field is believed to be the main reason for the radial propagation. Penning ionization is the dominant ionization mechanism in the discharge. It increases the pre-

ionization before the next breakdown which appears to be essential for obtaining a homogeneous discharge. The influence of the driving frequency on the discharge behavior is also studied. At low frequencies the discharge is found to be filamentary. On increasing the driving frequency, an increasing number of filaments are observed. At even higher frequency, the filaments merge to give the discharge a uniform appearance. This work is supported by DOE under grant DE-FG02-00ER54583.

11:30

BS2 4 Long time-scale transient phenomena in dielectric barrier atmospheric pressure glow discharge JICHUL SHIN, *The University of Texas at Austin* LAXMINARAYAN RAJA, *The University of Texas at Austin* Dielectric barrier controlled atmospheric-pressure glow discharges (APG) can potentially provide new approaches for large-scale, vacuum-chamber-free materials processing. A good understanding of APG phenomena is however a prerequisite to realizing successful applications. Here, we report fundamental studies of long time-scale transient phenomena in APG discharges. APG discharges are observed to have irreproducible V-I characteristics for nominally similar discharge conditions. Also long-term drift in V-I characteristic are observed with time-scales spanning 10's of minutes to hours. We explain these phenomena as a consequence of variation of dielectric surface condition that effectively causes variations in the secondary electron emission coefficient. Asymmetric pulses are also often observed and can be explained by variations in the secondary emission coefficient. We rule out impurities as a cause of variations through a set of experiments involving flow through the APG discharge. Our studies and conclusions are supported through detailed time-resolved imaging of discharge structures as well as zero-dimensional modeling.

11:45

BS2 5 Singlet Oxygen Generation in a High Pressure Non-Self-Sustained Electric Discharge ADAM HICKS, SETH NORBERG, PAUL SHAWCROSS, WALTER LEMPERT, J. WILLIAM RICH, IGOR ADAMOVICH, *Ohio State University* We present results of an experimental effort to develop an electric discharge based efficient singlet oxygen generator for an electrically excited oxygen-iodine laser. The non-self-sustained electric discharge is generated by a high voltage (15-20 kV), short duration (20 nsec), high repetition rate (40 kHz) pulser and sustained using a low-voltage, high current (2 kV, up to 3 A) DC discharge, both of which are transverse to the flow. In a 10% O2 ~ 90% Ar mixture at 120 torr, I-V measurements have demonstrated time averaged power coupling of 400 W at E/N equal to 0.6cm2, corresponding to energy loading per O2 molecule of 0.13 eV. These values of E/N, which are normally inaccessible to self-sustained electric discharges, are in the range where a significant fraction of the input power goes to excitation of the desired O2(a1D) state. Experiments using AC and RF sustainers are also underway, with the objective of increasing the power loading, as are emission spectroscopy measurements to quantify O2 a (singlet delta) and O2 b (singlet sigma) state populations.

12:00

BS2 6 Effect of metal halides on stability of the diffuse discharge on thermionic cathodes* M. S. BENILOV, *Departamento de Fisica, Universidade da Madeira, 9000 Funchal, Portugal* M. D. CUNHA, *Departamento de Fisica, Universidade da Madeira, 9000 Funchal, Portugal* G. V. NAIDIS, *Institute for High Temperatures RAS, Moscow 127412, RF* The model of interaction of a high-pressure plasma with a thermionic cathode is generalized in order to take into account the presence of multiple plasma species. A number of effective coefficients has been introduced, which are calculated by means of averaging the corresponding individual coefficients over plasma composition evaluated at the plasma edge of the ionization layer. The composition is found by solving equations of local balance of production and loss of every plasma species in volume reactions. The model obtained in such way is employed for calculation of a diffuse discharge on tungsten cathodes in mercury plasmas with metal halide additives. It is found that although the current-voltage characteristic of the near-cathode plasma region is not appreciably affected by the presence of metal halides, stability of the diffuse mode may be considerably improved.

*The work was supported by the projects 32411/99 of the program POCTI of FCT and FEDER and NumeLiTe of the 5th Framework programme ENERGIE of the EC

12:15

BS2 7 Temperature determination in metal-halide arc lamps using Bartels' method* H. SCHNEIDENBACH, ST. FRANKE, H. SCHÖPP, R. METHLING, H. HESS, *INP Greifswald, Jahn-Str. 19, D-17489 Greifswald, Germany* Self-reversed lines are intensively used for diagnostics of high-pressure lamp plasmas. Under LTE conditions the temperature profile of a plasma column can be determined by Bartels' method [1] from the reversal maxima of the side-on measured line intensities. For non-LTE a method has been developed in [2]. Bartels' method implies some additional conditions like constant partial pressures and exclusion of lines with near-zero lower level excitation energy. The exact expressions of the Bartels parameters have been analyzed for cases without these limitations. With the knowledge of the density distributions, the effects of demixing and ionization can be taken into account and resonance lines can be considered. The latter was also done elsewhere before [3]. The analysis has been applied to Hg/TlI discharges. It has been shown that for resonance lines the Bartels parameters are appreciably influenced by the densities in the near-wall region, i.e. far away from the region with measurable line radiation. [1] H. Bartels, Z. Physik 128 (1950) 546. [2] D. Karabourniotis, J. Phys. D: Appl. Phys. 16 (1983) 1267. [3] E. Drakakis, PhD thesis, Univ. Toulouse, 1988.

*Supported by German BMBF. Cooperation with OSRAM Munich.

SESSION CS1: PARTICLE AND ELECTRICAL DIAGNOSTICS

Sunday afternoon, 26 September 2004
Belfast Room, Bunratty Conference Centre at 14:00
Alec Goodyear, The Open University, presiding

14:00

CS1 1 Real-time, Nonintrusive Monitoring of Time-varying Ion Energy and Flux in Inductively Coupled Plasmas MARK SOBOLEWSKI, *N.I.S.T.* Energetic ion bombardment plays an important role in plasma processing. To obtain optimal results, ion bombardment energies must be carefully controlled. Unfortu-

nately, directly measuring ion energy distributions in situ, at a wafer surface during plasma processing, is difficult or impossible. Ion energy distributions can be indirectly monitored, however, by measuring the radio-frequency (rf) voltage and current applied to a plasma reactor and analyzing these measurements with plasma sheath models [1]. In this study, performed in rf-biased inductively coupled Ar and Ar/CF_4 discharges, rf electrical measurements were used to monitor changes in ion energy distributions and total ion flux that were caused by simulated faults in gas flow and rf power delivery and by drift in plasma conditions due to deposition on reactor surfaces. In some cases, changes in ion energies as large as 100 eV were observed. Three different mechanisms that explain how changes in plasma density or total ion flux result in changes in ion energies were identified. Implications of this work for assuring more stable ion energies in plasma reactors will be discussed. [1] M. A. Sobolewski, J. Appl. Phys. 95, 4593 (2004).

14:15

CS1 2 Particle-In-Cell Modelling of RF transients in low-pressure discharges LAURA LAUROTARONI, ALEC GOODYEAR, NICHOLAS BRAITHWAITE, *The Open University, Oxford Research Unit, Boars Hill, Oxford OX1 5HR, UK* Investigation of perturbative, transient phenomena is a powerful tool to unravel information on the physical properties of plasmas. In many situations transient phenomena arise through internal instabilities or during sudden changes in external parameters. RF transients applied to small surface-mounted probes have been used to measure the ion flux and electron temperature in low to medium pressure plasmas[1]. This uses a simple analysis without a full model of the transient sheath. To include displacement current the full transient analysis has been done by numerical simulation. A 1-D PIC code (by M. Turner, DCU) has been used in the present work, in planar geometry. The numerical model has been tested by comparing results with the analytical model and with experiments. The simulations reproduce various features that are observed experimentally but which are not accounted for by the analytical approach, such as non-Maxwellian EEDFs and perturbed ionization/heating near the transient sheath. [1] N.St.J.Braithwaite et al, J.Phys.D, 36 (2003) 2837-2844

14:30

CS1 3 Harmonic butterflies as a plasma diagnostic tool V. J. LAW, D. GAHAN, F. SOBERON, L. OKSUZ, *Dublin City University, Ireland* F. GARCIA, *The Queen's University of Belfast, Northern Ireland* A. R. ELLINGBOE, *Dublin City Unversity, Ireland* W. G. GRAHAM, *The Queen's University of Belfast, Northern Ireland* Inductively coupled plasma-tools have three power-coupling modes:capacitive (E-mode), inductive (H-mode) and Helicon wave (W-mode). These vary in light output intensity and rf behaviour depending on the system parameters. Here the particular interest is in the rf fundamental and its plasma-generated harmonic amplitudes and the relative phase between them. For the DCU ARIS II and the QUB GEC reference cell we have observed that the rf fundamental and its plasma generated harmonic(s) vary in amplitude and relative phase with the mode of discharge coupling. The rf information is captured using either a non-invasive dual-direction coupler and/or a surface-wave probe, and is displayed as a Lissajous figure on an oscilloscope. Experiments show that this technique delineates the mode change both in time and space for argon, chlorine and oxygen discharges. In the case of self-pulsing the Lissajous figure forms a time-varying Butterfly image that follows the pulse period thus allowing the time varying discharge to be monitored in real-time. Partially funded by the HEA North-South Programme for Collaborative Research and by SFI under grant number 02/IN.1/I147.

14:45

CS1 4 Oxygen plasma harmonic stability in a RIE plasma tool AMEDEO PAGLIARANI, ANTHONY KENYON, NINA THORNHILL, EHANTHA SIRISENA, KEVIN LEE, *Department of Electronic & Electrical Engineering, University College London* VICTOR LAW, *School of Physical Sciences, Dublin City University* We report the results of a study in which the detailed RF harmonic response of capacitively-coupled technological plasmas to the fundamental drive frequency of 13.56 MHz has been monitored. Using a dual-directional coupler (DDC) inserted at the 50 Ohm input port of the matching network to detect, in real time, the incident and reflected power in the travelling waves propagating along its through line, we have studied the behaviour of plasma-generated harmonics during etch processes. Two sets of experiments were performed: in the first, the output of the DDC sampling line was connected to a very high resolution digital spectrum analyser that allowed the frequencies and amplitudes of the plasma-generated harmonics to be monitored individually. The second experiment sampled the DDC output into a digital oscilloscope, from which the harmonic amplitude and phase relative to the incident fundamental were measured. The instrument has been used for the end-point detection of 1.8 micron thick Microposit S1818 photoresist etching on a 50 mm diameter silicon wafer using an oxygen plasma. Our results show that all three measurements harmonic amplitude, harmonic relative phase, and harmonic frequency yield valuable process-specific information. Selected harmonics exhibit a step-change in their amplitude and/or relative phase at etch end-points. However, although the harmonic frequencies also shift due to the changing complex impedance of the plasma loading the output of the RF generator, the frequency shift is a gradual one, moving asymptotically to a stable value as the process end-point is reached. We postulate that the two classes of measurement yield qualitatively different information.

15:00

CS1 5 Measurement of High-Energy Neutral Atoms in Rare Gas Magnetron Discharge HIROTAKA TOYODA, YOHEI SAKASHITA, JUNSI GAO, KOICHI SASAKI, SATOSHI IWATA, TAKESHI KATO, SHIGERU TSUNASHIMA, HIDEO SUGAI, *Department of Electrical Eng. Computer Sci., Nagoya University* In sputtering film deposition process, energetic species incident on the depositing film surface is considered to play an important role for the film crystallinity, surface roughness and so on. Existence of energetic rare gas atoms in magnetron plasmas is predicted but no experimental observation is reported so far. In this work, energetic Ar ions and atoms are measured by a mass spectrometer with an energy analyzer. In the case of energetic Ar atom detection, an extra-ionization cell with electron beam reflector is installed between the magnetron target and an extraction orifice of the mass spectrometer, in order to enhance ionization efficiency of energetic argon neutrals by electron impact. By using this technique, Ar atoms hiving the energy as high as 150 eV are detected at a magnetron discharge voltage of 600 V and an Ar pressure of 3 mTorr using Permalloy target. Origin of energetic Ar atoms is considered to be backscattering of Ar ions incident to the target surface. Production of high-energy Ar atoms is simulated

using TRIM code. The simulation result indicates backscattered Ar has maximum energy of 150 eV for 600 eV incident energy on the Permalloy target, showing the consistency with the experimental result. Flux density of energetic Ar atom from the target will also be discussed.

15:15

CS1 6 Investigations of a pulsed plasma doping (PLAD) system by time resolved mass and energy spectrometry LUDOVIC GODET, SVETLANA RADOVANOV, ZIWEI FANG, JIM BUFF, *Varian Semiconductor Equipment Associates, Gloucester, MA01930, USA* CHRISTOPHE CHRISTOPHE CARDINAUD, GILLES CARTRY, *Nantes University, France* DAMIEN LENOBLE, ANDRE GROUILLET, *ST Microelectronics, Crolles Cedex, France* Time resolved measurements of ion mass and energy distributions were carried out in a pulsed, plasma doping system (PLAD). In PLAD, the glow discharge is created by a negative pulsed voltage (0.3 to 1 kV) applied to a wafer in the presence of low pressure (10-40 mTorr) gas. The spectrometer was placed behind the biased wafer and configured to measure the mass and energy of ions striking the wafer during the pulse on and off periods. The operation of the spectrometer was modeled using 3-D ion optics simulation software to obtain key parameters such as ion transit time and transmission efficiency under various bias voltages. This enabled an accurate measure of the time resolved ion energy distribution as a function of plasma operating parameters. Results from Ar and BF3 plasma operation with bias voltages from -0.1 to -0.65kV, and pressure from 10 to 40mTorr are reported.

SESSION CS2: IONIZATION

Sunday afternoon, 26 September 2004; Dublin Room, Bunratty Conference Centre at 14:00
Steve Buckman, ANU, presiding

Invited Papers

14:00

CS2 1 "Reaction Microscopes": The "Cloud Chambers" of Atomic and Molecular Physics.
JOACHIM ULLRICH, *Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany*

Reaction-Microscopes, developed 10 years ago in order to investigate fast ion-atom collisions [1], allow to determine the complete vector momenta of several electrons and ions emerging as a result of the fragmentation of single atoms, molecules or clusters interacting with electrons, ions, single photons or intense laser pulses. Thus, the complete final-state many-particle wave function in momentum space becomes observable for single and multiple ionisation of atoms as well as for the dissociation of molecules [2]. In the talk the working principle of these machines will be described. Illustrative examples will be given demonstrating the ability of the method to identify the "mechanisms" of single and multiple ionisation for electron and ion impact. Its potential for the investigation of single photon as well as of intense laser-pulse induced fragmentation will be highlighted. Future possibilities to investigate ultra-low-energy electron atom or molecule collisions, laser assisted ionisation, using few-cycle phase controlled laser pulses or future free-electron lasers are envisaged. [1] R. Moshammer et al., Phys. Rev. Lett. 73 (1994) 3371 [2] J. Ullrich et al., Rep. Prog. Phys. 66 (2003) 1463.

Contributed Papers

14:30

CS2 2 Fully Differential Cross Section for Charged Particle Impact Ionization of Helium M. FOSTER, *University of Missouri - Rolla, Rolla, MO USA* D. H. MADISON, *University of Missouri - Rolla, Rolla, MO USA* J. L. PEACHER, *University of Missouri - Rolla, Rolla, MO USA* JOACHIM ULLRICH, *Max-Planck-Insitut für Kernphysik, Heidelberg, Germany* We have studied fully differential cross sections (FDCS) for single ionization of helium by a variety of projectiles ranging from 2 MeV/u C^{6+} to 3.6 MeV/u Au^{Q+} (Q =24, 53). Theoretical FDCS have been calculated for the entire three-dimensional distribution of the ionized electron. These absolute experimental FDCS, in the scattering plane, are not in very good agreement with standard CDW-EIS (continuum-distorted-wave-eikonal-initial-state) calculations which are normally in excellent agreement with doubly differential cross section measurements. We have recently introduced the 3DW-EIS (three-distorted-wave-eikonal-initial-state) approach which is a fully quantum mechanical approach similar to the CDW-EIS except that the usual approximations of the CDW-EIS are not made. The 3DW-EIS results have been shown to be in better agreement with absolute experimental data than the CDW-EIS for 2 MeV/u C^{6+} single ionization of helium. We have now extended these calculations to higher energy and different projectiles. The 3DW-EIS results will be compared with other theoretical calculations and absolute experimental measurements.

14:45

CS2 3 4-Body Treatment of Single Ionization of He by Proton Impact D. H. MADISON, *University of Missouri - Rolla* M. FOSTER, *University of Missouri - Rolla* J. L. PEACHER, *University of Missouri - Rolla* We have studied the effects of a four-body treatment for fully differential cross sections (FDCS) for single ionization of helium by 75 keV proton-impact. Previous CDW-EIS (Continuum-Distorted-Wave-Eikonal-Initial-State) calculations for this collision system are in very poor agreement with absolute experimental measurements. The CDW-EIS treats the four-body problem as an effective three-body problem in which the passive electron does not participate in the collision. The model that we have developed is a full four-body approach in which the passive electron participates fully in the collision. The importance of the passive electron for the FDCS will be examined.

15:00
CS2 4 Model Sensitivity of Theoretical Results for Ionization-Excitation of Helium* OLEG VOROV, *Drake University* KLAUS BARTSCHAT, *Drake University* The absolute value of the total cross section for simultaneous ionization-excitation of helium by electron impact has been revisited several times recently, leading to a renormalization of previously measured data (for details, see [1] and references therein). We have started a systematic study on the sensitivity of theoretical results to the details of the approximation applied, such as first- and higher-order effects in the interaction between the projectile and the initial bound state, the two outgoing electrons and the residual ion, and the quality of the bound-state description. [1] H. Merabet, R. Bruch, S. Fülling, K. Bartschat and A.L. Godunov, J. Phys. B **36** (2003) 3383.

*Work supported by the NSF under grant PHY-0244470.

15:15
CS2 5 Scattering amplitudes from time-dependent density functional theory ADAM WASSERMAN, *Department of Chemistry and Chemical Biology, Rutgers University, USA* FAN ZHANG, *Department of Physics and Astronomy, Rutgers University, USA* NEEPA T. MAITRA, *Department of Physics and Astronomy, Hunter College of CUNY, USA* KIERON BURKE, *Department of Chemistry and Chemical Biology, Rutgers University, USA* The linear response formalism of time-dependent density functional theory is adapted to study low-lying electronic continuum states of atoms. Exact novel formulas to extract transmission amplitudes from the susceptibility are derived for one dimensional scattering, and exemplified on a simple model. Continuum states of the ground-state Kohn-Sham potential of an N-electron system can provide a good approximation to scattering from the corresponding $(N-1)$-electron system, as shown here for the case of electron-He^+ and electron-H scattering.

SESSION DS1: OPTICAL EMISSION DIAGNOSTICS
Sunday afternoon, 26 September 2004; Belfast Room, Bunratty Conference Centre at 16:00
Vince Donnelly, University of Houston, presiding

Invited Papers

16:00
DS1 1 Temporally and spatially resolved measurements of plasma breakdown.
MARK BOWDEN, *Dept. of Applied Physics, Eindhoven University of Technology, Netherlands*

Breakdown is an important process in plasma science but is difficult to study because of its highly transient nature. It depends greatly on the discharge parameters such as geometry, gas pressure and applied voltage. The goal of this research is to study breakdown processes experimentally with sufficiently high spatial and temporal resolution for the features of breakdown to be observed. In the first stage of the project, emission measurements were used to characterize the main features of breakdown into a glow-like discharge. Three different experimental systems were studied: a simple system with two metal electrodes, a planar dielectric barrier discharge, and a straight discharge tube. Although the three experimental systems differed greatly in pressure and geometry, breakdown in each case was characterized by ionization waves traveling between the electrodes. The differences between the breakdown processes for the three systems could be understood as being related to the different way in which these ionization waves were generated. This study showed clearly that simple measurements of the plasma emission could be used effectively to understand the main features of the breakdown process.

Contributed Papers

16:30
DS1 2 The use of multiple helium line ratios as a plasma diagnostic tool PATRICK McCARTHY, RICHARD ARMSTRONG, CATHLEEN O'NEILL, *Department of Physics, University College Cork, Association EURATOM DCU, Cork, Ireland* MARTIN O'MULLANE, *Department of Physics, University of Strathclyde, Glasgow G4 ONG, U.K.* The determination of electron temperature and density from line intensity ratios is an established diagnostic technique in both laboratory and astrophysical plasmas. The neutral helium line ratios 668/728 nm and 728/706 nm, which are predominantly sensitive to Ne and Te, respectively, are of particularly interest for the edge profiles of tokamak plasmas where they complement other diagnostic techniques. Benchmarking of Te and Ne values derived from theoretically calculated line ratios with data from, say, Langmuir probes suffers from systematic errors and other cross-diagnostic problems. However, inclusion of additional line ratios would allow an internal validation check using only spectroscopic data. We observe 10 prominent He I lines in the range 388 < lambda < 728 nm visible in a filament discharge helium plasma, with Te in the range of several eV and Ne in the range 1E8-1E11/cm**3, generated in a Double Plasma device. Spectral data has been acquired for a range of plasma densities and temperatures using an Ocean Optics UV-vsible spectrometer with 1 nm resolution and the purpose of the present work is to determine how consistently the 9 independent line ratios determine a unique Te and Ne value for each plasma state using predictions from the ADAS package. For a consistent Te, Ne result, the dimensionality of the line ratios must not clearly exceed two, with allowances for measurement errors.

16:45
DS1 3 WITHDRAWN

17:00
DS1 4 Fluorine and Oxygen Monitoring in Plasma CVM Etching Process for Silicon Wafer by Argon Actinometry Technique YASUSHI OSHIKANE, *Grad. School of Eng., Osaka Univ.* AKIHIKO NAGAO, *Grad. School of Eng., Osaka Univ.* KAZUYA YAMAMURA, *Grad. School of Eng., Osaka Univ.* AKINORI ODA, *Grad. School of Eng., Nagoya Inst. of Technol.* KATSUYOSHI ENDO, *Grad. School of Eng., Osaka Univ.* Relative changes in the density of atomic fluorine and oxygen in plasma chemical vaporization machining (CVM) process is determined from the intensity ratios of the argon λ = 750 nm line, the atomic oxygen lines λ = 777 nm and 844 nm, and the atomic fluorine lines λ = 733 nm and 740 nm. The relative density change which depends on the position in the plasma is compared with an etched pattern on a silicon wafer surface. A rotational cylindrical electrode creates high speed shear flow of the plasma gas in a sub-millimeter gap between electrode and wafer. The plasma generation condition is controlled by changing VHF electric power and the rotation speed of electrode. The plasma gas composition is fixed at $He/CF_4/O_2$=99.89/0.1/0.01 and the total gas pressure is an atmosphere. The density profiles of fluorine and oxygen are different. In the basic experiment, the fluorine density profile has a maximum value around the narrowest plasma gap. On the other hand, the oxygen density profile has a peak up the gas flow. These results are compared with the etched pattern on the siliconsubstrate.

17:15
DS1 5 Radially Resolved Rotational Temperature Profiles in a Hydrogen Inductively Coupled Plasma V. SCHULZ-VON DER GATHEN, M. ABDEL-RAHMAN, T. GANS,* H.F. DÖBELE, *Universität Duisburg-Essen, Inst. f. Experimentelle Physik, 45117 Essen, Germany* Rotational temperatures of hydrogen in an inductively coupled RF- discharge are measured by optical emission spectroscopy using the rotational Q-Branch of the Fulcher-α (v=2) system. Radially profiles are obtained by Abel inversion of 5 Fulcher line intensities measured with a stepper-motor controlled mirror. The temperatures are subsequently calculated from the emissivities. The discharge is operated at 15 Pa and transceiver powers between 150 and 350 W at 13.56 MHz. Time dependences obtained in H- and in E-mode are discussed. An increase of the rotational temperature as a function of power is observed. This is compared with translational temperatures determined by Fabry-Perot interferometry. On the central axis the temperature decreases from a maximum near the coil towards the lower grounded electrode. Radially a nearly constant temperature plateau of about 40 mm radius is obtained in the area close to the coil. Beyond this distance from the discharge axis the rotational temperature falls off rapidly.

*Ruhr-Universität Bochum, Inst. f. Experimentalphysik V, 44780 Bochum, Germany

SESSION DS2: INTERACTIONS WITH MOLECULES
Sunday afternoon, 26 September 2004; Dublin Room, Bunratty Conference Centre at 16:00
Michael Brunger, Flinders University, presiding

Invited Papers

16:00
DS2 1 Ionization in Strong Electric Fields.
IAN WILLIAMS, *Queen's University Belfast*

The ionization of atoms due to single photon, electron and heavy particle impact has been studied for many years, and as a result there is a good understanding of the underlying processes. There is also a wealth of data available for plasma applications. More recent studies have focussed on the ionization process in strong electric field, where new processes are observed. The talk will provide background information, and concentarte on recent advances.

Contributed Papers

16:30
DS2 2 3DW and DWIA Calculation of Electron-Impact Ionization of Molecules JUNFANG GAO, *Physics Department of University Missouri-Rolla* DON H. MADISON, *Physics Department of University Missouri-Rolla* JERRY L. PEACHER, *Physics Department of University Missouri-Rolla* The Highest Occupied Molecular Orbital (HOMO) is important for chemical reactions and some biological processes. Electron impact ionization of molecules (e,2e) is an effective probe for studying the important molecular interactions. Recently the interference effect in diatomic molecules has also received considerable attention. For high incident-energy (keV range) electron-impact ionization, the Plane Wave Impulse Approximation (PWIA), which was developed in the 1970s, provided a good understanding of the experimental differential cross section data. However for lower incident-electron energies, no accurate theory exists to describe the ionization process. We have developed a Three-body Distorted Wave (3DW) approach which treats all continuum electrons as distorted waves and which also includes the final state electron-electron interaction (correlation) to all orders of perturbation theory. In

addition, we have developed the Distorted Wave Impulse Approximation (DWIA) which is a distorted wave version of the PWIA. Both theories will be used to calculate triple differential cross sections and to study the interference effects for electron-impact ionization of the nitrogen molecule.

16:45

DS2 3 Electron Scattering from Plasma Processing Gases: C2F4 and c-C4F8 MILICA JELISAVCIC, RADMILA PANAJOTOVIC, STEPHEN BUCKMAN, *Australian National University, Canberra* Fluorocarbons like C_2F_4 and C_4F_8 are very common processing gases in the plasma etching of silicon dioxide, which is an important step in the manufacture of semiconductor microelectronics. Understanding the reaction chemistry of these molecules is crucial for achieving production efficiency and stability of the etched surfaces. In order to explain, and model, the complex collision processes in such low temperature plasmas, a good knowledge of the absolute cross sections for these processes is essential. We have measured elastic and inelastic (vibrational excitation) electron scattering from C_2F_4 and C_4F_8 using a crossed electron-molecule beam apparatus. The experimental results consist of absolute differential, integral and momentum transfer cross sections in the energy range 1.5-20 eV and angular range $10^o - 130^o$. In order to investigate the role of intermediate negative ions (resonances) in the scattering process we have also measured excitation functions for elastic scattering and vibrational excitation of the ground electronic state of both molecules. These results are compared with recent theoretical calculations and the limited amount of experimental data available in the literature.

17:00

DS2 4 Density functional theory for low-energy electron-molecule scattering KIERON BURKE, ADAM WASSERMAN, *Department of Chemistry and Chemical Biology, Rutgers University, USA* Time-dependent density functional theory (TDDFT) is becoming popular as an approach to time-dependent electronic problems[1]. In the weak field regime, TDDFT predicts electronic transition frequencies and optical spectra of atoms, molecules, clusters, and solids, with an accuracy comparable to high-level wavefunction calculations at a fraction of the computational cost[2]. For large systems, TDDFT is the method of choice. Given the importance of correlation effects in low-energy electron-molecule scattering, extracting scattering amplitudes from TDDFT appears desirable. I will review this background, and outline how this can be done[3]. Detailed results will be shown by Wasserman in another talk. [1] *Time-Dependent Density Functional Theory*, M.A.L. Marques and E.K.U. Gross, Annu. Rev. Phys. Chem. **55**, 427 (2004). [2] *Time-dependent density functional theory in quantum chemistry*, F. Furche and K. Burke, to appear in 1st vol. of Annu. Rev. of Computational Chemistry (2004) [3] *Electron-molecule scattering from time-dependent density functional theory* A. Wasserman, N.T. Maitra, and K. Burke, submitted (see http:dft.rutgers.edu/pubs/publist.html).

17:15

DS2 5 Electron and Positron Scattering from C3H6 Isomers* CASTEN MAKOCHEKANWA, *Graduate School of Sciences, Kyushu University, Fukuoka 812-8581, Japan, and Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* OSAMU SUEOKA, MINEO KIMURA, *Graduate School of Sciences, Kyushu University, Fukuoka 812-8581, Japan* MASAMITSU HOSHINO, TAKAHIRO TANAKA, MASASHI KITAJIMA, HIROSHI TANAKA, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* Hydrocarbons play an important role in high temperature plasmas in Tokamak fusion devices in plasma processing and many other fields [1]. In this paper we report experiments for 0.4-1000 eV electron and 0.2-1000 eV positron total cross sections (TCS) measured using a linear time-of-flight apparatus [2], and electron differential cross sections (DCS) for elastic, vibrational and electronic excitations covering the ranges 1.5 to 100 eV and 15 deg to 130 deg, measured using the crossed beam and relative flow method [3]. The continuum multiple scattering (CMS) [4] calculations have also been performed for the theoretical analysis of the observed features in our cross sections. We observe the isomer effect in both electron and positron TCSs and DCSs. The presence of a dipole moment in propene molecules shows up in enhanced forward scattering in DCSs, leading to larger TCSs and integral cross sections compared to cyclopropane at energies less than 20 eV. However, both electron and positron TCSs for these two molecules nearly equal each other above 100 eV, i.e. the molecular size effect. [1] W. L. Moragn, Adv. At. Mol. Opt. Phys. 43, 79 (2000). [2] O. Sueoka, S. Mori and A. Hamada, J. Phys. B 27, 1453 (1994). [3] H. Tanaka, L. Boesten, D. Matsunaga and T. Kudo, J. Phys. B 21, 1255 (1988). [4] M. Kimura and H. Sato, Comments At. Mol. Phys. 26, 333 (1991).

*The authors would like to acknowledge the Japan Atomic Energy Research Institute, Ministry of Education, Sport, Culture and Technology, the Japan Society for Promotion of Science, and the Collaborative Research Grant by the National Institute for Fusion Science, for financial support.

SESSION ES1: POSTER SESSION I
Sunday evening, 26 September 2004
Clonmoney, Fitzpatrick Bunratty Hotel at 19:30

ES1 1 RECOMBINATION

ES1 2 A New Photoion Method for Electron-Ion Recombination Studies O. NOVOTNY, B. SIVARAMAN, C. REBRION-ROWE, D. TRAVERS, J.B.A. MITCHELL, B.R. ROWE, *Universite de Rennes I* A new method has been developed for the measurement of the recombination of complex ions with electrons. The ions are produced by ionizing a very small amount of vapour of the parent molecule using a pulsed UV laser (157nm). This ionization takes place in a chamber along which is flowing an

argon- helium plasma, generated by a microwave discharge. The purpose of this plasma is to provide a source of electrons with which the complex ions can recombine. Full details of the technique and results for the recombination of anthracene ions will be presented.

ES1 3 Recombination and detachment in oxygen discharges diluted with argon: The role of metastables J. T. GUDMUNDSSON, *Department of Electrical and Computer Engineering, University of Iceland, Reykjavik, Iceland* A global (volume averaged) model of oxygen discharge is used to study how argon dilution affects the dissociation of oxygen molecules and the electronegativity of the discharge. Furthermore we study the transition from recombination dominated discharge to detachment dominated discharge. The model includes the metastable oxygen molecules $O_2(a^1\Delta_g)$ and $O_2(b^1\Sigma_g^+)$ and the three Herzberg states $O_2(A^3\Sigma_u^+, A'^3\Delta_u, c^1\Sigma_u^-)$ as well as metastable argon atoms. Dissociative attachment of the oxygen molecule in the ground state $O_2(^3\Sigma_g^-)$ and the metastable oxygen molecule $O_2(a^1\Delta_g)$ are the dominating channels for creation of the negative oxygen ion O^-. At high pressure dissociative attachment of the Herzberg states contributes significantly to the creation of the negative oxygen ion O^-. The detachment by a collision of the metastable oxygen molecule $O_2(b^1\Sigma_g^+)$ with the oxygen ion O^- is a significant loss process for the O^- at pressures above 10 mTorr. Detachment by collision with $O(^3P)$ is also an important loss mechanism for O^-. We find that ion-ion recombination is the dominating loss process for negative ions in oxygen discharge at low pressures and calculate the critical pressure where the contributions of recombination reactions and detachment reactions are equal.

ES1 4 Dissociative Recombination of CF_3^+ * G. ANGELOVA, J.L. LEGARREC, C. REBRION-ROWE, B.R. ROWE, J.B.A. MITCHELL, *Universite de Rennes I* PALMS TEAM, CF_3^+ is the dominant positive ion in a CF_4 plasma and at low pressures is destroyed primarily by dissociative recombination with electrons. A value of 9.6×10^{-7} cm^3s^{-1} for this process has been used in a number of modeling studies[1] but the origin of this value is obscure[2]. A new measurement of this reaction has been performed using a (FALP-MS) apparatus with CF_4 as the parent gas for CF_3^+. The fact that CF_4 does not attach electrons rapidly at room temperature is critical for this measurement for such a process would dominate over electron ion recombination as the neutral density is orders of magnitude greater than the ion density. We find a value of $2.8 \pm 0.8 \times 10^{-7}$ cm^3 s^{-1} for the recombination rate. References 1. D. Edelson and D.L. Flamm 1984 J. Appl. Phys. **56** 1522 2. M.A. Biondi (Private communication).

*UMR NO. 6627 du CNRS

ES1 5 Branching Ratios for the Dissociative Recombination of Hydrocarbon Ions C. REBRION-ROWE, G. ANGELOVA, J.L. LEGARREC, *Universite de Rennes I* J.B.A. MITCHELL, O. NOVOTNY, *Charles University, Prague* H. BLUHME, K. SEIERSEN, A. SVENDSEN, L.H. ANDERSEN, *Aarhus University* Branching ratios for the recombination of hydrocarbon ions $C_2H_3^+$, $C_3H_m^+$ (m=1-8) and $C_4H_m^+$ (m=1-9) have been measured[1-3]. The detector used did not have sufficient resolution to distinguish hydrogen atoms so the relative distributions of carbon atoms among the dissociation products were measured. For most of the ions in linear isomeric form, the fragmentation patterns were predictable from the structure of the parent. For cyclic isomers however, this was not so clear and indications are that ring opening occurs prior to dissociation.
A. 1. J.B.A. Mitchell et al. Int. J. Mass Spec. 227, 273, 2003 2. G. Angelova et al Int. J. Mass Spec. 232, 195, 2004 3. G. Angelova et al Int. J. Mass Spec. 235, 7, 2004.

ES1 6 Dissociative Recombination of NeH^+ ANCA FLORESCU, *Universite de Rennes I* A.E. OREL, *UC Davis* J.B.A. MITCHELL, O. NOVOTNY, G. ANGELOVA, J.L. LEGARREC, C. REBRION-ROWE, *Universite de Rennes I* A. SVENDSEN, L.H. ANDERSEN, *Aarhus University* The dissociative recombination of NeH^+ has been measured using the ASTRID storage ring. NeH^+ does not have a curve crossing with the ion ground state but recombination can occur at higher energies via excitation to neutral rydberg states lying below excited ion states. These have been modeled theoretically using a wave packet method and preliminary results show good agreement with experiment.

ES1 7 OTHER PLASMA TOPICS

ES1 8 Effect of ultrasound waves on electrical characteristics of hollow needle to plate electrical discharge in air or in mixture of air with VOC STANISLAV PEKAREK, RUDOLF BALEK, *Czech Technical University in Prague, Technick 2, 166 27 Prague 6, Czech Republic* MILAN POSPISIL, *Institute of Chemical Technology, Technick 5, 166 278 Prague 6, Czech Republic* The results of study of ultrasound waves influence on V-A characteristics of the DC hollow needle to plate electrical discharge enhanced by the flow of air or flow of the mixture of air with 2-propanol-izopropanol or n-heptane, through the needle are described. It was found that the application of ultrasound substantially influences V-A characteristics of the discharge in air. From the standpoint of application of ultrasound on the discharge in the mixture of air with VOCs the V-A characteristics can be divided into two parts: the low current region and the high current region. For the low current region the application of ultrasound for a constant current decreases the discharge voltage. On the other hand for the high current region the application of ultrasound increases for a constant current discharge voltage. This work was supported by the Grant Agency of the Czech Republic under contract 202/04/0728.

ES1 9 Secondary Plasma Formation in Neutralization Cells associated with High Energy Neutral Beam Injectors N. J. FITZGERALD, *Dublin City University, Ireland* A. R. ELLINGBOE, *Dublin City University, Ireland* M. M. TURNER, *Dublin City University, Ireland* B. CROWLEY, *Culham Science Centre, England* Neutral-beam injection is one of the more important techniques employed to heat the plasma in magnetically confined nuclear fusion experiments. Energetic neutral-beams are produced by accelerating charged particles, which are then neutralized in collisions with a low density gas in a neutralizer cell. The efficiency of such neutralizer cells is less in practice than is expected in theory on the basis of the expected gas target density and in-

teraction cross sections. This deficit is thought to be caused by heating of the gas in the neutralizer cell as a side effect of the neutralization process. The heating effects include direct interaction of the gas with the beam and the formation of a secondary low temperature plasma inside the neutralization cell. In this paper we will present results from a modeling investigation of these effects using a particle-in-cell simulation with Monte Carlo collisions. The simulation treats self-consistently the interaction of the beam with the background gas, and the formation of the secondary plasma. The primary aim is to evaluate the magnitude of the gas heating effect for inclusion in gas transport models.

ES1 10 GLOWS

ES1 11 Power Transfer Efficiency of Plasma Sources VALERY GODYAK, *Osram Sylvania* There are many devices to produce gas discharge plasmas. They differ by the method of plasma coupling to the electrical energy source. In order to create self-sustained gas-discharge plasma with given gas pressure and plasma density, a certain amount of power P_p has to be delivered to plasma electrons to compensate for electron energy losses. As shown in this presentation, this power does not depend on the specifics of electron interaction with electromagnetic field and is basically the same for all types of discharges. Some additional power loss P_c associated with power dissipation in the plasma supporting means (like thermionic cathode, cathode fall, rf antenna and matching network) is unavoidable to maintain self-sustained plasma. That is accounted for by the power transfer efficiency $\eta = P_p/(P_p + P_c)$. Efficiency analysis of different plasma sources is given in this presentation. It is shown that the largest values of efficiency are found in the plasma sources for lighting and the lowest in the plasma for processing of materials. The presentation explains this disparity and challenges some wide spread mythology about unique efficiency of some plasma sources.

ES1 12 Comments on experiments supporting a novel energy source from atomic hydrogen A. V. PHELPS, *JILA, U. of Colorado and NIST* More than 20 papers have been published since 2000 in which R. L. Mills and collaborators have interpreted their observations of discharges in mixtures of hydrogen and ''catalyst'' gases as evidence for a novel energy source. We show that most of their experiments can be explained using conventional electric discharge processes with no novel energy source. We suggest models for their other experiments using accepted processes. For example, we propose that the ''excess Doppler broadening'' of H_α lines they observe[1] in intense microwave discharges in mixtures of H_2 and He or Ar is the result of a pulsating, high-voltage sheath similar to those studied in detail in rf discharges[2]. Such a high-voltage sheath and the resultant sputtering would also explain erosion by intense microwave discharges[3] in He. Recent experiments[4] that failed to observe the excess H_α broadening did not reproduce the highly non-uniform microwave excitation conditions of Mills et al.

[1]R. L. Mills et al., J. Appl. Phys. **92**, 7008 (2002).
[2]S. B. Radovanov et al., J. Appl. Phys. **78**, 746 (1995).
[3]P. Baltzer and L. Karlsson, Phys. Rev. A **38**, 2322 (1988).
[4]S. Jovičević et al., J. Appl. Phys. **95**, 24 (2004).

ES1 13 Glow discharges in low pressure hollow cathode geometries T.H. CALLEGARI, F. GEGOT, J. GALY, L. PITCHFORD, J.-P. BOEUF, *CPAT, Univ. P. Sabatier, Toulouse, France* We present electrical and optical measurements in xenon/neon discharges in a hollow cathode geometry with a cathode diameter of 1 cm and for gas pressures from 0.5 to 6 torr. The geometry and pd (gas pressure x cathode dimensions) are similar to the micro-hollow cathode discharges (MHCDs) used to generate atmospheric pressure plasmas. Many properties of the low pressure hollow cathode discharges are the same as those observed in the MHCDs with pressures above 100 torr and hole diameters in the 100 micron range. In particular, we find a region where the voltage-current characteristic is negative. We show that the negative slope of the characteristics is correlated with a transition between a discharge localized inside the cathode hole to one in which electron emission from the outer cathode surface is important. It is not correlated with the onset of the classical hollow cathode effect. Optical diagnostics have been used quantify the conditions for which the classical hollow cathode effect is present.

ES1 14 Glow discharges in high pressure microhollow cathodes J.-P. BOEUF, L.C. PITCHFORD, *CPAT, CNRS and Univ. P. Sabatier, Toulouse, France* K.H. SCHOENBACH, *Old Dominion Univ, VA* We have developed a model of high-pressure, microhollow cathode discharges (MHCDs) which has been used to predict the electrical characteristics and other properties of these discharges for comparison with experiment. The configuration studied here is an anode/dielectric/cathode sandwich in which a cylindrical hole with a diameter of some 100's of microns is pierced in the dielectric and in the cathode. Results from the model calculations in xenon at 100 torr and higher pressures show that the positive V-I (voltage-current) characteristic observed experimentally at low current corresponds to an abnormal glow discharge inside the cathode hole. At higher current, the V-I characteristic is that of a normal to slightly abnormal glow discharge between the anode and the outer face of the cathode. The change in slope of the V-I characteristic is consistent with experiment (provided metastables are taken into account). This shape was previously attribed to the onset of the classical hollow cathode effect, but we find no hollow cathode effect for pressures above about 30 torr and for 200 micron hole diameters.

ES1 15 Influence of Electron and Excited States Densities on the Electron Energy Distribution Function of Argon Microwave Plasmas A. YANGUAS-GIL, J. COTRINO, *ICMSE, CSIC - Univ. Sevilla, Spain* L. L. ALVES, *CFP, IST, Portugal* A new set of electron cross-sections for argon has been compiled from a review of former sets and by using results published up to date (2004). The new set proposed has been tested by comparing calculated argon transport coefficients and swarm parameters with experimental values available, and has been used to develop a 32 level collisional-radiative model for argon. This model has been solved coupled to the homogeneous electron Boltzmann equation for microwave low-pressure plasmas, by taking into account both

electron-electron collisions and the influence of inelastic and superelastic electron collisions with argon excited states. Results obtained for pressures ranging between 10^{-2} and 10 mbars, electric fields up to 10^5 V/m and ionization degrees up to 10^{-4} are influenced by the populations of either electrons or excited states for ionization degrees higher than 10^{-5}. The electron density plays an essential role in the dynamics of the 4s states, as these levels present a different ordering depending on the value of that plasma parameter.

ES1 16 Gas Thermal Model for Low-pressure Microwave Discharges L.L. ALVES, *CFP, IST (Portugal)* J. COTRINO, *ICMSE, CSIC (Spain)* The paper models gas heating mechanisms, with the main purpose of calculating self-consistent gas temperature profiles in low-pressure microwave discharges: First, the power balance equation for neutral gas species is obtained by analysing the global power budget of a discharge, by taking into account the creation, destruction and transport of electrons, ions and neutral gas species. Second, the wall boundary condition adopted, in solving the energy transport equations for the neutral gas, is deduced by equating its inward and outward thermal energy fluxes with respect to the discharge wall, and by introducing a thermal accommodation coefficient, instead of just imposing a surface temperature assumed equal to the gas temperature near the wall. Third, the gas energy transport equations, subject to appropriated boundary conditions, are self-consistently solved within the framework of a plasma discharge fluid model, which includes the transport equations for the charged particle and the electron mean energy, Poisson's equation for the electrostatic space-charge field, and Maxwell's equations for the electromagnetic propagative fields. The model is applied to the study of cylindrical discharges created and maintained by TM_{00} surface-waves at frequency $\omega/2\pi = 2.45$ GHz, pressures $p = 10 - 500$ mTorr and average electron densities $\bar{n}_e \simeq 5 \times 10^{11} - 5 \times 10^{12}$ cm^{-3}.

ES1 17 Two-dimensional simulation of surface wave discharges GERJAN HAGELAAR, *Centre de Physique des Plasmas et Applications de Toulouse (CPAT), France* Surface wave discharges (SWDs) are sustained by electromagnetic waves propagating along the interface of the plasma and the glass tube containing it. Most models of SWDs describe the surface waves by an approximate semi-analytical solution of Maxwell's equations, neglecting axial variations of the plasma and the tube geometry. Here we present an alternative, fully two-dimensional approach to SWD modeling. We solve Maxwell's equations numerically, self-consistently coupled with a set of fluid equations for the plasma particle species, the electron energy, and the gas temperature. This makes it possible to investigate the effect of geometrical details. As an example, we show simulation results of a SWD in argon (3 Torr), generated by a surfatron launcher (2.45 kHz, 50 W) in a narrow tube (5 mm diameter) and propagating into a wider tube (18 mm). These results reproduce and explain experimentally observed light emission patterns due to the partial reflection of the surface waves against the tube diameter transition.

ES1 18 On Characterization of a Subcritical Microwave Discharge* S. POPOVIC, L. VUSKOVIC, A. MASON, *Department of Physics, Old Dominion U., Norfolk, Virginia* Sub-critical microwave discharges [1] generated near the tip of a sharp half-wavelength long cylindrical conductor are characterized by using highly non-uniform plasma at a pressure ranging from 1 Torr to atmospheric. The presence of a strong electric field and substantial heat flux gradients lead to complex properties of the discharge. We will present a quantitative description of the discharge that will be used for studies of the interaction between weak shock waves and weakly ionized gas at atmospheric conditions. We will also present observations of Balmer line profiles, which have received a renewed interest [2] due to unconventional interpretations of their Doppler broadening component, in addition to their use as a simple tool for electron density diagnostics. Detailed observations in highly non-uniform subcritical microwave discharges in Ar/H2 mixtures did not reveal any excessive increase of the Doppler broadening component of Balmer line profiles. [1] S. Popovic, L. Vuskovic, I.I. Esakov, L.P. Gratchev, and K.V. Khodataev, Appl. Phys. Lett. 81, 1964 (2002). [2] S. Jovicevic, M. Ivkovic, N. Konjevic, S. Popovic, and L. Vuskovic, J. Appl. Phys. 95, 24 (2004).

*Supported by NASA Langley Research Center.

ES1 19 Ion flux energy and mass distributions at the cathode surface of DC discharges of $H_2/CH_4/N_2$ mixtures A. M. ISLYAIKIN,* *Instituto de Estructura de la Materia (CSIC), Madrid, Spain* V. J. HERRERO, *Instituto de Estructura de la Materia (CSIC), Madrid, Spain* I. ITANARRO, *Instituto de Estructura de la Materia (CSIC), Madrid, Spain* F. L. TABARES, *Association Euratom/Ciemat, Madrid, Spain* D. TAFALLA, *Association Euratom/Ciemat, Madrid, Spain* The energy and mass distributions of the ions bombarding the cathode surface in low pressure ($\approx 10^{-2}$ mbar) DC discharges of gas mixtures of H_2 with small amounts (up to 5%) of CH_4 and/or N_2 are determined under different experimental conditions by means of a quadrupole mass spectrometer equipped with a cylindrical mirror energy analyzer. A relationship between the ion flux and the source gas compositions is under discussion. Analysis of the detailed shapes of the recorded ion energy distributions is shown to allow, in some cases, a discrimination of particles having the same *m/e* ratio, but different chemical nature. The possible relevance of the bombarding ions for the formation or suppression of amorphous hydrogenated carbon films is under discussion as well.

*Present address: Dublin City University, Ireland

ES1 20 Characterization of Low-pressure Microwave Discharges in Argon S. LETOUT, *CFP, (Portugal)* C. BOISSE-LAPORTE, *LPGP, (France)* A. YANGUAS, *ICMS, (Spain)* L.L. ALVES, *CFP, (Portugal)* The paper investigates low-pressure microwave discharges in argon, produced by TM_{00} surface-waves (SW) within a coaxial structure (corresponding to the following media sequence: inner metal - dielectric - plasma - outer metal), at frequency $\omega/2\pi = 2.45$ GHz, pressures $p = 10^{-2}$ to 1 Torr and average electron densities $\bar{n}_e \simeq 10^{11} - 10^{12}$ cm^{-3}. A moment-method simulation tool is used to model the discharges, by solving the continuity and the momentum transfer equations for electrons and positive ions and the electron mean energy transport equations, coupled to Poisson's equation for the dc space-charge electric field and the appropriated Maxwell equations for the propagative SW field. The latter set of equations is self-consistently solved together with a 32 levels collisional-radiative model for argon gas, which takes into account the diffusion of the $3p^5 - 4s$ metastables towards discharge walls. Simulation results of the electron density and temperature radial profiles are compared to experimental probe measurements. The calculated radial distribution of the argon $3p^5 - 4p$ and $3p^5 - 5p$ excited states densities, are compared to spectroscopic measurements of line intensities at [3950 − 4700] Å and [6700 − 10.000] Å, respectively.

ES1 21 Dynamics of the breakdown in a discharge gap at high overvoltages. A. SHVYDKY, *University of Toledo* V.N. KHUDIK, *Plasma Dynamics Corp., MI* V.P. NAGORNY, *Plasma Dynamics Corp., MI* C.E. THEODOSIOU, *University of Toledo* The dynamics of the breakdown of the discharge in a gap between two plane electrodes at high overvoltage is studied via 3D Monte Carlo/PIC kinetic simulations. In these simulations, the negative and positive macroparticles represent their physical counterparts (which cannot in principle be attained in 1- or 2-D Monte-Carlo simulations, since macroparticles there are planes or rods rather than point particles). The breakdown is initiated by a single seed electron, and then an ionization region formed at the anode spreads toward the cathode. The velocity of this spreading (as well as the ionization region structure) at different voltages applied to the gap is compared with those predicted by the 1D analytical theory. Such realistic simulations allow the elucidation of the role of fluctuations in microdischarges, when the gap width is small and the number of particles is relatively low.

ES1 22 Self-consistent field profiles in surface wave-produced plasma columns BABAK SHOKRI, *Laser Research Institue* MOHAMMAD GHORBANALILU, *Laser Research Institue* ALIREZA NIKNAM, *Laser Research Institue* Studying the surafce wave produced plasmas, in the present work, we obtain the radial surface wave field profile on a weakly ionized and fully collisional- unmagnetized-nonisothermal plasma column under considered conditions in a self-consistent way. Since for non-magnetic media with the cylindrical symmetry, surafce waves are often E-type with field components E_z, E_r and H_φ if the axis of symmetry is z axis, obtaining the general formulas, we solve them numerically for a surface-wave-sustained plasma column in the RF frequency region when a radial electron density profile is given by a Bessel function and the radial variation of electron temperature is given by a two-order polynomial. Furthermore, we study the influence of main physical parameters such as electron temperature, SWs frequency, wavelength, inhomogeneity parameter, electron density, and electron neutral collision frequency on the electric and magnetic field profiles in the plasma column.

ES1 23 Modelling Inductively Coupled Hydrogen Discharges VIKTOR KADETOV, UWE CZARNETZKI, *Institute for Plasma and Atomic Physics, Ruhr-University Bochum, Bochum, Germany* Inductively coupled plasma (ICP) discharges in molecular gases are complex systems where relationship between the physical and chemical processes is unclear and complicated. We investigated a hydrogen ICP with different diagnostics like Langmuir probe, ion mass and energy spectroscopy, laser electric field measurement, laser spectroscopic temperature measurement, and phase and space resolved emission spectroscopy. In order to better understand the discharge physics, an analytical model of the low-pressure ICP that includes the mechanisms of the power coupling, plasma generation and the sheath formation was developed. Input parameters are the plasma cell geometry, the neutral gas pressure, the neutral gas temperature, the incident RF power, and the antenna resistance. The model allows the calculation of the electron density, the electron temperature, and the effective electron-neutral collision frequency. It also relates the incident RF power to the power dissipated in the discharge either capacitively or inductively by calculating the respective currents in the plasma. Integrating Poissons equation numerically with boundaries obtained from the ICP model allows us to find the fields, potentials and currents in the plasma sheath. The ion energy distribution function is inferred by simulating the ion trajectories in the sheath. The model is consistent with measurements.

ES1 24 Ion Injected IEC Discharge Physics GEORGE MILEY, *NPRE Dept., University of Illinois, U-C Campus* YANG YANG, NIE LUO, YASSER SHABAN We present recent progress in inertial electrostatic confinement discharge physics using a unique external ion source, ILLIBS, which employs a RF-driven plasma in a graded magnetic field configuration. Use of this external source allows initiation of the plasma discharge below the normal (Paschen relation) discharge breakdown region. This study provides the first experimental data on this important new discharge regime where losses due to charge exchange are greatly reduced, improving the neutron production efficiency and allowing higher yields. Wide ranges of sub-breakdown deuterium pressures (0.4 to 2 mTorr) were studied. With 100 Watt input RF power, ILLIBS provided a high ion current extraction efficiency and a deuterium ion flux of 6 x 10^{18} ions/(cm2-sec) at 65 mA with a well collimated beam diameter of 3 mm. With the ion gun on, a deuterium fusion rate of 2 x 10^7 rx/sec was achieved with grid voltage and current at 75 kV and 15 mA respectively, at 1.2 mTorr. This represents a significant improvement in discharge production efficiency, reducing power handing problems associated with high yield operation.

ES1 25 Electron impact excitation of fine-structure levels in O IV and S X* SWARAJ TAYAL, *Clark Atlanta University* Electron impact excitation collision strengths and rates for inelastic transitions among the 71 fine-structure levels of the $2s^22p$, $2s2p^2$, $2p^3$, $2s^23s$, $2s^23p$, $2s^23d$, $2s2p3s$, $2s2p3p$, $2s^24s$, and $2s2p3d$ configurations in O IV and 72 fine-structure levels of the $2s^22p^3$, $2s2p^4$, $2p^5$, $2s^22p^23s$, $2s^22p^23p$, and $2s^22p^23d$ configurations in S X are calculated using the Breit-Pauli R-matrix approach. The target levels are represented accurately by configuration-interaction wave functions. The calculated excitation energies and oscillator strengths obtained with these wave functions agree very well with measured and other calculated values. The relativistic effects in the scattering equations are included through mass correction, Darwin, and spin-orbit operators of the Breit-Pauli Hamiltonian. The collision strengths in the threshold energy regions are dominated by complicated resonance structures. The resonance structure in O IV is confirmed by experiment[1]. [1] Smith et al., Phys. Rev. A 68, 062708 (2003).

*Supported by NASA grant NAG5-11434 from the SARA program.

ES1 26 2DRMP-G: A 2-dimensional R-matrix propagator to study electron collisions with atoms and ions, using grid computing A. CARSON, V. FARO-MAZO, T. HARMER, P. PRESTON, M.P. SCOTT, N.S. SCOTT, P.G. BURKE, *Queen's University Belfast* The 2-dimensional R-matrix propagator, which was developed to study electron impact excitation and ionisation of hydrogen-like atoms and ions, has recently been modified to run across the UK Level 2 Grid (UK L2G). The calculations involved consist of a number of independent steps which are farmed out to various processors on the grid. 2DRMP-G contains software to monitor the resources that are available in the grid and dynamically to allocate available tasks to available resources. Where there are no real-time constraints on a problem, a grid environment can

provide a useful alternative to supercomputer resources. In connection with 2DRMP-G, a visualisation tool, VisRes-G is also being developed for grid application. This is a comprehensive visual tool which facilitates the graphical display, manipulation and analysis of resonance data produced in atomic physics calculations. Latest results and developments using these codes will be presented at the conference.

ES1 27 B-Spline Breit-Pauli R-matrix calculations for electron collisions with heavy noble gases* OLEG ZATSARINNY, *Drake University* KLAUS BARTSCHAT, *Drake University* We used the B-Spline R-matrix method [1,2] to calculate electron-impact excitation of the heavy noble gases Ne − Xe. Relativistic effects were accounted for through the most important terms of the Breit-Pauli hamiltonian in the inner region of the R-matrix box. A variety of non-orthogonal valence orbitals was employed to account for the strong term dependence in the one-electron orbitals. Using non-orthogonal basis sets avoids the need for pseudo-orbitals to improve upon the target description and virtually eliminates pseudo-resonance problems. The agreement between our predictions and experiment [3] is much better than obtained in previous calculations based on the standard R-matrix approach with strictly orthogonal orbitals, particularly in details such as resonance positions and widths. Consequently, the new results should represent a major improvement of the current database for electron collisions with noble gases. [1] O.I. Zatsarinny and C. Froese Fischer, J. Phys. B **33** (2000) 313. [2] O.I. Zatsarinny and K. Bartschat, J. Phys. B **37** (2004) 2173. [3] S.J. Buckman and C.W. Clark, Rev. Mod. Phys. **66** (1994) 539.

*Work supported by the NSF under PHY-0311161 and PHY-0244470.

ES1 28 B-Spline R-matrix calculations for electron collisions with quasi-two-electron atoms* KLAUS BARTSCHAT, *Drake University* OLEG ZATSARINNY, *Drake University* We extended our recent work on benchmark calculations for electron scattering from magnesium atoms [1] to the Zn and Hg targets that are currently of high interest for lighting applications. We used the B-Spline R-matrix method [2], with a recent extension [3] to account for relativistic effects through the most important terms of the Breit-Pauli hamiltonian in the inner region of the R-matrix box. An important feature of our method is the possibility of employing different sets of non-orthogonal valence orbitals, which can efficiently represent the term dependence in the one-electron orbitals as well as short-range correlation effects in resonances, without the typical problems associated with expansions in a fully orthogonal basis containing both physical and pseudo-orbitals. A comparison of our most recent predictions with experimental and other theoretical data will be presented. [1] K. Bartschat, O.I. Zatsarinny, I. Bray, D.V. Fursa, and A.T. Stelbovics, J. Phys. B **37** (2004) 2617.[2] O.I. Zatsarinny and C. Froese Fischer, J. Phys. B **33** (2000) 313. [3] O.I. Zatsarinny and K. Bartschat, J. Phys. B **37** (2004) 2173.

*Work supported by the NSF under PHY-0244470 and PHY-0311161.

ES1 29 Electron impact excitation of iron peak elements P.G. BURKE, A. HIBBERT, B.M. McLAUGHLIN, C.A. RAMSBOTTOM, M.P. SCOTT, *Queen's University Belfast* V.M. BURKE, C.J. NOBLE, A.G. SUNDERLAND, *CLRC, Daresbury Laboratory* One of the major outstanding problems in atomic physics is the accurate calculation of collision data for low ionization stages of iron peak elements such as iron, nickel and cobalt. There are two main difficulties which arise from open d-shells in the target states of these ions. Firstly, a large CI expansion is required to adequately represent electron correlation effects within the target ion, and secondly, the open d-shells give rise to a large number of target states, and in turn to a large number of coupled channels. In addition, in order to resolve low-lying Rydberg resonances, calculations must be carried out over a very fine energy mesh. Recently results for electron impact excitation of FeII, FeIII and FeIV, which are of crucial importance in the interpretation of astrophysical spectra, have been obtained using a new parallel R-matrix code. Latest results will be presented at the conference.

ES1 30 WITHDRAWN

ES1 31 Electron collisions with quasi one-electron atoms and ions using an IERM method ANGELA KINNEN, PENNY SCOTT, *Queen's University Belfast* The intermediate energy R-matrix method (IERM) is an established technique for studying electron collisions with a variety of one-electron target atoms and ions. Recent advances in this area have included the addition of a 2-dimensional R-matrix propagator, which enables us to extend the R-matrix boundary considerably, and it is this development that has given the impetus for the current work. The method has been adapted to include a core potential, enabling the study of electron impact excitation and ionization of quasi one-electron targets; that is, target atoms or ions with a series of closed inner shells and a single outer electron. This model of the target makes it similar to a one-electron hydrogenic target, and so we have been able to modify the existing IERM computer codes. Initial tests were made with an atomic sodium target and the results proved to be in excellent agreement with those from different sources. Work is currently being conducted on CaII, results of which will be presented at the conference. We are also extending this approach to study photoionisation and photo-double-ionisation.

ES1 32 Accurate *r*-ratios for the Electron Impact Excitation of Argon STEPHANIE PROCTOR, J. G. CHILDERS, MURTADHA A. KHAKOO, *California State University, Fullerton, CA 92834, USA* The ratio of the differential cross sections for the electron impact excitation of the $4s[3/2]^o_2$ and $4s'[1/2]^o_0$ levels of the first excited $3p^5 4s$ configuration of argon, designated the *r*-ratio, has been more accurately measured at 15 eV, 17.5 eV, 20 eV, and 30 eV incident energies. Earlier measurements[1] found a surprising deviation from the *LS*-coupling limit of 5 at higher incident energies and small scattering angles, a region quite susceptible to systematic error. A more accurate measurement technique was used predominately at small scattering angles to verify this deviation, a result which would indicate the effects of second-order couplings during the electron impact excitation process. The measured values of the ratio are close to the *LS*-coupling limit of 5 indicating that second-order effects in the excitation of the target can be considered negligible. The results will be presented. This work is funded by the National Science Foundation under grant # NSF-RUI-PHY-0096808.

[1]M. A. Khakoo *et al.*, *J. Phys. B* **37**, 247 (2004)

ES1 33 ATOMIC LIFETIMES

ES1 34 Measurement of the $6P_{1/2,3/2}$ Atomic Lifetimes of Cesium using a Mode-Locked Laser B.M. PATTERSON, T. TAKEKOSHI, R.J. KNIZE, *Laser and Optics Research Center, United States Air Force Academy, CO 80840 USA* G. BROOKE, *Department of Physics, Virginia Military Institute, Lexington VA 24450 USA* We will present a technique that employs a mode-locked Ti:Sapphire laser to measure the lifetimes of the $6P_{1/2}$ and $6P_{3/2}$ levels of cesium. A single pulse from the laser is used to excite atoms to the desired level in a thermal beam. A subsequent laser pulse is frequency-doubled and used to ionize the excited atoms. The ions are then counted using an electron multiplier. This process is repeated for various pump-probe pulse separations allowing the decay curve to be plotted and the lifetime to be determined. The fixed pulse separation of the mode-locked pulses provides an extremely accurate time base for the experiment. The National Science Foundation (Grant No. 9988100) and the United States Air Force Academy provided financial support for this work.

ES1 35 HEAVY PARTICLE INTERACTIONS

ES1 36 THE MOBILITY OF XE+ AND NE+ IONS IN XE/NE GAS MIXTURES JASMINA V. JOVANOVIC, *Faculty of Mechanical Engineering, 11000 Belgrade, Serbia and Montenegro* ZORAN LJ. PETROVIC, *Institute of Physics, P.O.Box 68, 11080 Zemun, Belgrade, Serbia and Montenegro* The ion mobility data important for modeling glow discharges in rare gas mixtures are not generally available. The Xe+ and Ne+ mobilities at 300 K over the range 10 T E/n0 (Td) T 2000 in 5compared with Monte Carlo calculations. Those mixtures are of interest for plasma display panels (PDPs). Results from MTT (momentum transfer theory) calculations of Xe+ and Ne+ mean energies and mobilities in pure gases are used to obtain the predictions of Blanc's Law, Blanc's Law that include effects of elastic collisions proposed by Robson and common mean energy procedure. Common mean energy method obtained by momentum balance equation in MTT are very accurate in all cases.

ES1 37 TOWNSEND DISCHARGES IN NEON AT VERY HIGH E/N ZELJKA D. NIKITOVIC, *Institute of Physics, P.O.B. 68, 11080 Belgrade, Serbia and Montenegro* ALEKSANDRA I. STRINIC, *Institute of Physics, P.O.B. 68, 11080 Belgrade, Serbia and Montenegro* VLADIMIR D. STOJANOVIC, *Institute of Physics, P.O.B. 68, 11080 Belgrade, Serbia and Montenegro* GORDANA N. MALOVIC, *Institute of Physics, P.O.B. 68, 11080 Belgrade, Serbia and Montenegro* ZORAN LJ. PETROVIC, *Institute of Physics, P.O.B. 68, 11080 Belgrade, Serbia and Montenegro* We have analyzed experimental transport data and in particular the spatial profiles of excitation coefficients for 2p levels. Monte Carlo Simulations (MCS) that include transport of electrons ions and fast neutrals were used. At moderate E/Ns, from 10 Td to 1000 Td, electron excitation dominates and it was possible to determine the electron ionization and excitation coefficients. At higher E/Ns the excitation growth towards the cathode is observed and attributed to fast neutral excitation. It was possible to determine the effective fast neutral excitation cross sections that fit the experimental emission profiles normalized to the excitation rates. It was necessary to make significant modifications to the available cross sections for excitation by fast neutrals in order to fit the experimental data.

ES1 38 CAPACITIVELY COUPLED PLASMAS

ES1 39 Design and modeling of a planar probe for power measurements in a capacitive plasma sheath D. GAHAN, *Dublin City University, Ireland* M. B. HOPKINS, *Dublin City University, Ireland* A. R. ELLINGBOE, *Dublin City University, Ireland* The design and modeling of a planar probe for power measurement in a capacitive RF sheath is described. The probe is to be biased negatively, using a DC power supply, while simultaneously being driven with an RF voltage. A simple model has been developed which describes the voltage, current and impedance from the generator to the probe surface incorporating the transmission line. A conventional method to determine the power through such a probe would be to measure the voltage, current and their phase relationship very close to the probe surface. This can be very difficult to do with much accuracy since the load is almost purely reactive. An alternative method is discussed. The model shows that for certain lengths of transmission line there exists a point on that transmission line where the imaginary impedance goes to zero. If the power is measured at this point where the current and voltage are almost in phase the result should be more accurate. A brief description of the model is given along with some results for its validation. The operation of the power sensor used is also explained.

ES1 40 Manipulating charged particle distributions in multiple frequency capacitively coupled discharges JAFAR AL-KUZEE, ALEC GOODYEAR, NICHOLAS BRAITHWAITE, *The Open University, Oxford Research Unit, Boars Hill, Oxford OX1 5HR, UK* Plasma processing is essential to the manufacture of ultra scale integrated circuits. As specifications increase and tolerances tighten greater control over the individual plasma parameters is necessary. Active plasmas are complicated by the interdependence of many parameters. Effective control requires either exact models or a broad range of possible control actions in conjunction with real-time measurements. For capacitively coupled discharges dual frequency excitation has been shown to facilitate decoupling of ion bombardment energy from plasma density. Experiments have been conducted in a capacitively coupled parallel plate plasma system at 50 - 200 mTorr in argon. Voltage waveforms consisting of multiple frequencies (e.g. 1 and 80 MHz) have been applied to the powered electrode. We have directly measured ion flux and dc bias demonstrating independent control of both. Measurements will also be reported of the tail of the electron energy distribution for a range of excitation conditions that are based on the same nominal ion flux.

ES1 41 Measurements and simulations of ion energy distribution functions in a dual-frequency capacitively-coupled discharge in hydrogen D. O'CONNELL,* M. M. TURNER, A. R. ELLINGBOE, *Dublin City University, Ireland* Hydrogen discharges typically contain at least three species of positive ion: H^+, H_2^+ and H_3^+ . In the sheaths, where the mean ion energy may be tens of eV or more, a large number of ion-molecule reactions are energetically permitted, and all three ion species may be present in substantial numbers. The dynamics of ion motions in the sheath are of course considerably complicated by the presence of two superposed driving frequencies, in the present case 2 MHz and 27 MHz. In this paper we will present measurements of the ion energy distribution functions at the electrodes using an energy resolved mass spectrometer. Data will be presented for a range of discharge pressures and amplitudes of the driving voltages. The measured distribution functions have features associated with both driving frequencies. These results will be compared with calculations performed with a particle-in-cell simulation with Monte Carlo collisions. We will show that such comparison requires careful attention to the acceptance angle of the mass spectrometer.

*Present Address: Ruhr-Universität Bochum, Germany

ES1 42 Transport and Maintenance of RF-Generated Plasma Through Slots or Tubes M.A. LIEBERMAN, *UC Berkeley* A.J. LICHTENBERG, *UC Berkeley* SUNGJIN KIM, *UC Berkeley* The transport of rf-generated plasma through gaps, slots, or tubes is both of physical interest and has important technological applications. We consider a capacitive discharge with the main discharge connected to a peripheral (pumping) region through an insulating annular slot within the discharge gap. We determine the conditions for which ignition occurs, in order to prevent it, i.e., to confine the discharge to the central region. The two issues that we examine are: (1) Plasma transport in the slot. What conditions are necessary for the diffusion of plasma from the main discharge through the slot into the periphery? (2) Breakdown and maintenance of a discharge. What conditions are necessary to breakdown or to maintain a discharge in the slot and in the periphery? We develop models describing these situations and compare their predictions to experimental results.

ES1 43 Characteristics of VHF capacitively coupled plasmas in a 300 mm chamber G. A. HEBNER, P. A. MILLER, E. V. BARNAT, *Sandia National Laboratories* A. PATERSON, J. HOLLAND, T. LILL, *Applied Materials* We have investigated the characteristics of VHF capacitively coupled plasmas produced in a modified Applied Materials chamber. The chamber had a 14-inch diameter upper electrode (source) that was driven at 10 to 160 MHz and a 300 mm diameter electrostatic chuck with a ceramic process kit that was driven at 13.56 MHz (bias). Diagnostics employed include rf diagnostics to measure the voltage and current, Bdot probes to measure the spatial magnetic fields, a microwave interferometer to measure the line-integrated electron density, a hairpin microwave resonator to measure the spatially resolved electron density, absorption spectroscopy to determine the argon metastable temperature and density, laser induced fluorescence (LIF) to determine the spatial distribution of the excited species, and spatially resolved optical emission. Scaling of the plasma parameters with frequency, power and pressure, and implications to energy deposition models will be discussed. This work was supported by Applied Materials and Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energys National Nuclear Security Administration under contract DE-AC04-94AL85000.

ES1 44 Plasma non-uniformities in VHF capacitive discharges P. CHABERT, A. PERRET, J.-L. RAIMBAULT, J.-M. RAX, *LPTP, Ecole Polytechnique, France* The standing wave effect in high frequency capacitive discharges causes non-uniform plasma excitation when the electrode size is not considerably smaller than the excitation wavelength. It was theoretically predicted [1] using a self-consistent non-linear transmission line model that the presence of a plasma significantly shortens the excitation wavelength compared to the vacuum case. This prediction was experimentally verified by Perret et al. [2] which shows that the ion flux measured by planar electrostatic probes is strongly non-uniform. We have also measured the ion energy uniformity using three retarding field energy analyzers inserted at the centre, the side and the corner of the grounded electrode. The ion energy was found to be uniform although the rf voltage across the electrode is not. [1] Chabert et al., Phys. of Plasmas, 11 (2004) 1775 [2] Perret et al., Appl. Phys. Lett., 83 (2003) 243

ES1 45 Attachment cooling of electrons in oxygen-argon and SF6-argon mixtures NATALIA BABAEVA, SUNG JIN KIM, GAN YOUNG PARK, JAE KOO LEE, *Department of Electronic and Electrical Engineering, Pohang University of Science and Technology, Pohang, Korea* In e-beam sustained plasma different electron temperature can be obtained. Thus, in plasma of capacitive RF discharges in inert gases typical electron temperature is of the order of 23 eV. At certain conditions, in plasma of electronegative gases electron temperature can approach ion/neutral temperature. We consider e-beam sustained plasma of electronegative gases and their mixtures with argon where the main mechanism of plasma neutralization is connected with electron-molecule attachment. In such plasma, due to retardation of fast electrons of e-beam secondary electrons are created which loose their energy due to attachment. It is shown, that at certain conditions (in dependence of the e-beam intensity and spectrum of secondary electrons) electron temperature can obtain the values comparable or even less than temperature of neutral component. The effect can be explained by the increase of attachment rate coefficient with the increase of electron temperature (mean electron energy). Such a dependence leads to attachment of the fastest plasma electrons and selective loss of electrons whose energy exceeds the mean electron energy and, as a result, to effective electron cooling. The theoretical and numerical analysis of the problem has been conducted. The numerical results obtained using ELENDIF code are compared with Particle-in-cell/Monte Carlo simulations under similar conditions.

ES1 46 MATERIALS PROCESSING IN LOW PRESSURE PLASMAS

ES1 47 Surface Modification of Hydroxyapatite Crystal Using IR Laser Induced plasma Plume WEIMIN GUAN, NOBUYA HAYASHI, SATOSHI IHARA, SABURO SATOH, *Faculty of Science and Engineering, Saga University* CHOBEI YAMABE, *Faculty of Science and Engineering, Saga University* GOTO MASAAKI COLLABORATION,* YAMAGUCHI YOSHIMASA COLLABORATION,† DANJYO ATSUSHI COLLABORATION‡ Calcium hydroxyapatite is the major inorganic component of animal hard tissues (teeth and bones). It is also used as adsorbent for protein separation, catalyst, bioceramics

and coatings of implants. Since performance of these materials is mostly determined by their surfaces, and the physical properties of this crystalline material are directly dependent on its atomic arrangement. It is of great interest to develop methods to control the surface functionality of calcium hydroxyapatite. So far, the application of laser technology to the process of calcium hydroxyapatite surface material have been concentrated on methods such as electroplate, chemical deposition and plasma spray etc. However, ever since reports of pulse laser deposition (PLD) on improvement of hydroxyapatite surface were emerged, much attention has been focused on the lasers potential to enhance mechanical and chemical properties of hydroxyapatite. Whereas, most of the previous reports concentrated on the between hydroxyapatite and metal material. Few researches have pursued the improvement of the surface of hydroxyapatite itself. In order to develop a creative method to modify the surface condition of hydroxyapatite, the authors innovated a novel procedure with plasma plume induced by IR lasers.In this study, artificial hydroxyapatite pellet, CELLYARD HA (PANTAX, Japan) were used as both target and substrate. Laser irradiation were performed with 10.6 micron CO2 laser and 1.06 micron Nd: YAG laser separately. X-ray diffraction analyses in combination with FTIR spectroscopy have been used for identification of the new crystal structure and compounds. The combination of these techniques has been particularly effective to observe the crystal phases and molecular energy change of the deposited surface. The crystal structures were refined from X-ray diffraction data, which show that the (002) reflection was increased significantly. It indicates the crystal growth in c-axis. Significant mineralization occurred for hydroxyl enhanced the pH value evidently. At the same time, photo-chemical and thermal-chemical reactions occurred on the junction of liquid and solid. In the vaporized plasma plume atmosphere, collisions of atoms (calcium ion) and molecule (phosphate molecule) are prosperous. Thermal effect and excited particles contained in the plasma plume can enhance the mineralization when the excited particles arrived at the surface of substrate. As a consequence of the interactions described above, the surface energy of hydroxyapatite will be changed. We can suppose that it might be possible to manipulate the hydroxide ion ordering on the surface to achieve predominant characteristic for various applications. This hypothesis should be confirmed by further experiments.

*Department of Oral and Maxillofacial Surgery, Saga University
†Department of Oral and Maxillofacial Surgery, Saga University
‡Department of Oral and Maxillofacial Surgery, Saga University

ES1 48 Measurements and Modelling of Plasma Ashing Equipment C. HAYDEN, *Dublin City University, Ireland* A. R. ELLINGBOE, *Dublin City University, Ireland* M. M. TURNER, *Dublin City University, Ireland* Ashing is an important step in plasma-aided manufacturing processes, such as dry surface cleaning, de-scum and photo-resist removal. The process may also change the chemical character of the surface in desirable ways. The ashing equipment under consideration consists of two plasma chambers separated by a diffuser plate or showerhead. A mixture of oxygen and nitrogen gases flows into the upstream chamber where a plasma is excited by a microwave source with a power of about 1 kW. The efflux from this microwave discharge flows though a showerhead into the downstream chamber containing the work-piece, which is attached to radio-frequency powered electrode with an excitation frequency of 13.56 MHz and a power of approximately 200 W. The work-piece is therefore exposed to energetic ions produced by the downstream capacitive discharge and a flux of radicals produced predominantly in the upstream source. In this paper we will present an experimental characterisation of the downstream plasma using Langmuir probes, mass spectrometry and optical emission spectrometry. We will also discuss a global model representation of this equipment, in which the problem of transport through the showerhead will be addressed.

ES1 49 Decomposed Fragment Identification in C_8F_{18} RF Plasma for a-C:F Film Production YOSUKE SAKAI, SHOTA TAZAWA, MARIA BRATESCU, YOSHIYUKI SUDA, HIROTAKE SUGAWARA, *Hokkaido University* Amorphous fluorocarbon polymer (a-C:F) film shows excellent insulation properties such as low dielectric constant (< 2.5), high dielectric strength (> 2 MV/cm), low surface energy, and chemical inertness. Therefore, we have studied this film for a purpose of an additional insulator to enhance the breakdown voltage in an alternative to a SF_6 gas insulation system. The films are prepared using a C_8F_{18} vapor RF plasma. When per-fluorocarbon, such as C_8F_{18} as source gases, then the deposition rate becomes roughly two orders of magnitude higher than that obtained from conventional low molecular-weight source monomers (CF_4, C_2F_6, C_3F_6, and C_4F_8) [1]. The breakdown voltage (V_s) of N_2, Ar and He gases between the a-C:F film coated Al sphere-sphere electrodes for a gas pressure (p) times gap length (d), pd=0.1-100 Torrcm, was studied as well. Then, V_s between the a-C:F film coated electrodes was a several times higher than that between the Al electrodes in the present pd range[2]. In this work, the decomposed species of C_8F_{18} in the plasma were identified using emission spectra from the plasma and Quadra-pole mass spectrograph, and the reason why the high deposition rate was obtained was discussed. The physical and chemical properties of a-C:F film was analyzed. [1] C.P.Lungu, et.al., Jpn. J. Appl. Phys. 38 (12B) L1544 - L1546 (1999) [2] C.Biloiu, et.al., Jpn. J. Appl. Phys. 42 (2B) L 201- L203 (2003) Work supported by Grant-in-Aid for Scientific Research (B), JSPS.

ES1 50 Plasma properties during pulsed DC sputter-deposition of TiO2 photocatalytic thin films WEIDONG ZHU, JOSE LOPEZ, ABE BELKIND, KURT BECKER, *Stevens Institute of Technology, Hoboken, NJ, USA* Thin films of TiO2 are very attractive for photocatalytic applications to decompose organic pollutants. Photocatalytically active thin films of TiO2 can be deposited by pulsed DC reactive sputtering. The performance of the films as catalysts is strongly determined by the thin film crystalline structure and, therefore, by the deposition conditions. In this work, time-resolved optical emission spectroscopy is employed to investigate and control the pulsed DC magnetron plasma used to reactively deposit TiO2 films. Depositions are carried out using a pulsing frequency of 60 kHz and off-times of 3 and 5 us. Optical measurements were done employing a fast intensified CCD (ICCD) camera. Work supported by the U.S. Army.

ES1 51 Harmonics of the driving frequency and their use as a plasma processing diagnostic in radio-frequency plasmas RAOUL FRANKLIN, *The Open University, Oxford Reseaerch Unit, Oxford OX1 5HR, U.K.* NICHOLAS BRAITHWAITE, *The Open University, Oxford Research Unit, Oxford OX1 5HR, U.K.* It was suggested five years ago that the higher harmonics of the driving frequency were sensitive to the conditions in the plasma and that monitoring them might enable better process control (Law et al.(1999)). They found that the relative magnitudes of the har-

monics were not monotonic with order n. We have examined two particular models of the r.f. plasma-sheath for their harmonic content–(i) the Lieberman (1990) model, and (ii) a more sophisticated model that allows for ''field reversal''. In case (i) even and odd harmonics behave differently but both decrease monotonically with order n. Whereas in case (ii) there is a sensitivity to the length of the period of field reversal that cuts across any simple relationship with order n. This points to a usefulness in process control, even if the signals are interpreted on an empirical basis in the practical situation.

ES1 52 Deposition of DLC coatings using a combined microwave and hollow cathode plasma source DENIS DOWLING, FERGAL O'REILLY, PAUL DUGGAN, *University College Dublin* GLYNN DYSON, DENIS TEER, *Teer Coatings* TEER COATINGS COLLABORATION A critical issue for the commercial exploitation of plasma deposited coatings is the deposition rate. In this paper the performance of a hybrid plasma source, which combines an Electron Cyclotron Resonance (ECR) microwave plasma with a radio frequency (rf) hollow cathode plasma, is reported. This combined source has already been shown to produce high plasma densities. Within this hybrid source a magnetic field is used to form the ECR plasma, which is located at the outlet of a linear hollow cathode. This paper reports on the use of this source to deposit diamond-like carbon (DLC) films. These films were deposited from acetylene / argon gas mixtures at a pressure of 10^{-1} Pa on glass slide and silicon substrates. The coatings exhibited good adhesion on both substrates. The influence of rf power on DLC film growth rates and properties at constant microwave power and pressure is evaluated. The deposited coatings are examined using Raman spectroscopy and their refractive index is determined using ellipsometry. Optical profilometry is used to measure step heights on the coating to determine film thickness. Maximum film growth rates of up to 20 μm / hour were obtained, which is considerably higher than typical growth rates with conventional capacitively coupled rf systems.

ES1 53 Optical and electrical diagnostics of fluorine- and chlorine-containing plasmas during etching of high dielectric constant HfO_2 films KAZUO TAKAHASHI, KOUICHI ONO, YUICHI SETSUHARA, *Department of Aeronautics and Astronautics, Kyoto University, Kyoto, Japan* Plasma etching of high dielectric constant (k) materials is required for integration of these materials as gate dielectrics in device fabrication. The etch selectivity of high-k materials over Si substrate is a key issue in the fabrication, being dependent largely on composition of reactive species and on energy of incident ions. This paper presents optical and electrical diagnostics of high-density plasmas with fluorine- and chlorine-containing gases during etching of HfO_2 thin films on Si substrate, as a function of gas composition and rf bias power. Experiments were performed by employing inductively coupled plasma (ICP) and electron cyclotron resonance (ECR) plasma sources with $Ar/C_4F_8/H_2$ and $Ar/Cl_2/BCl_3$ chemistries at a gas pressure of 10-20 mTorr. Several diagnostics were employed to characterize the plasma around the wafer position, including optical emission spectroscopy, microwave interferomery, Langmuir probe, and quadrupole mass spectrometry. The measurements, compared with etching characteristics, indicated that the higher concentration of halogen atoms and the higher ion energy increase the HfO_2 etch rate; moreover, the higher concentration of species for passivation layer formation on Si decreases the etch rate of Si, which results in an increase in the etch selectivity. We discuss the etch mechanisms for HfO_2 on Si in high-density fluorine- and chlorine-containing plasmas, with emphasis of the effects of small additives on plasma and surface chemistries.

ES1 54 A prediction of thermal device damage during plasma etching M. OSAKA, T. YAGISAWA, T. SHIMADA, T. MAKABE, *Keio University at Yokohama, Japan* Device heating during plasma etching for ULSI circuits fabrication will become one of the practical issues under the recent trend of the shrinkage of chips. Especially, the application of Low-k materials,which have poor thermal conductivity and thermal instability, for interlayer dielectrics makes it more serious. Wafer surface is locally etched reactively by incident ions with high energy, and the released thermal energy diffuses to the inside of the device. As a result, gate dielectrics and Low-k materials are thermally damaged, and the quality of semiconductor devices deteriorate. The present work aims to predict thermal device damage during plasma etching. We have developed a numerical model to investigate thermal behavior in device. Local surface potential by charging and trajectories of ions and electrons are first computed[1] by using the ion energy and angle distribution in a two-frequency capacitively coupled plasma(2f-CCP)[2]. Thermal profile inside a device has been solved with the heat equation. We discuss the temperature of gate dielectric and the thermal distribution in device during plasma etching.

[1]J.Matsui *et al*; J. Phys. D, **34**, 2950 (2001)
[2]T.Yagisawa *et al*; IEEE Trans. Plasma Sci., **32**, 90 (2004)

ES1 55 Chemistry and Physics of Amorphous Silicon Device Production WENGANG ZHENG, *JILA, Univ. of Colorado, Boulder, CO 80309-0440* PETER HORVATH, ALAN GALLAGHER, Hydrogenated amorphous silicon (a-Si:H), and its carbon and germanium alloys, is used for most large-area semiconductor devices, such a liquid crystal displays and photovoltaics. These thin-films are deposited from the hydrogenated molecular gases of Si, C and Ge, and dopants P and B. The molecular dissociations that yield this chemical vapor deposition are initiated by a DC, RF, VHF or microwave discharge, or a high-temperature (hot-wire) surface. Neutral radicals, cations and an occasional Si particle deposit on the chamber surfaces, yielding the growth and semiconductor properties of the device. The continual quest for improved device properties motivates studies of the discharge physics and deposition chemistry. Here we will report studies of the cation and neutral-radical species depositing from hot-wire and RF-discharge deposition of a-Si:H, from primarily SiH4 vapor. We utilize threshold-ionization mass spectrometry to measure the neutral radicals, since this can identify all (SixHn) radicals in the presence of the stable parent gases (SixH2x+2). We use ion deflectors for a rough measure of ion bombardment energy versus species. The hot-wire system utilizes lower SiH4 and H2 pressures, resulting in more Si and H at the surface compared to the RF discharge. This work is supported by The National Renewable Energy Laboratory and the DOE.

ES1 56 Plasma Diagnostics for the RF Physical Vapour Deposition of CuCl Thin Films GOMATHI NATARAJAN, *National Centre for Plasma Science and Technology, Dublin City University* STEPHEN DANIELS, *National Centre for Plasma Science and Technology, Dublin City University* LISA O'REILLY, *Research Institute for Networks and Communications Engineering,*

Dublin City University DAVID CAMERON, *National Centre for Plasma Science and Technology, Dublin City University* PATRICK McNALLY, *Research Institute for Networks and Communications Engineering, Dublin City University* CuCl thin films have interesting properties which make it a potential material for silicon based optoelectronic devices. This study investigates the rf pvd deposition of CuCl thin films from compound targets using non-invasive optical, chemical and electrical process diagnostics. The use of these diagnostic techniques for process optimisation and the control of film properties are investigated. Results are presented which explain some of the plasma induced fundamental underlying mechanisms affecting the optoelectronic and structural properties of the as deposited thin films.

ES1 57 An investigation of the structural changes of ta-C and ta-C:N nano films as a function of thickness and arc current RICHARD McCANN, SUSANTA S. ROY, PAGONA PAPAKONSTANTINOU, PAUL MAGUIRE, JIM McLAUGHLIN, *NRI, School of Electrical and Mechanical Engineering, University of Ulster, Shore Road, Newtownabbey, N. Ireland* A double bend off-plane filtered cathodic vacuum arc system was used to produce tetrahedral amorphous carbon (ta-C) and tetrahedral amorphous carbon nitride (ta-C:N) films on silicon substrates at room temperature. The magnetic filter employed in this method was mainly to guide the ionized plasma as well as to prevent the macroparticles reaching the substrates. An investigation has been carried out to optimize the film structure under different arc current, which directly control the plasma efficiency. Two sets of experiments were carried out to investigate the structural changes that take place within the films. The first experiment investigated the structural changes that took place within ta-C and ta-CN films as the film thickness was increased from 10nm to 100nm. In the second experiment the arc current varied over the range of 30A to 100A. XPS, Raman and XRR spectroscopies were utilised to establish the relationship between film thickness, deposition arc current, chemical bonding structure and density. The effect of thickness on ta-C and ta-C:N films were totally different. With the increase of arc currents, the films became more and more disordered due to the energy enhancement of species in the plasma. For films prepared as a function of arc current the Raman D-peak to G-peak intensity ratio (ID/IG) exhibited a decreasing trend. The G peak positions and the FWHM for both films showed similar trends as they all shifted to higher wavenumbers as a function of arc current. The ta-C films deposited at arc current 80 A displayed the lowest level of sp2 configurations and the highest density.

ES1 58 Species Densities and Temperatures in an Argon-Acetylene RF Plasma using Mass Energy Analysis C.M.O. MAHONY, G.L. McPEAKE, P.D. MAGUIRE, *Nanotechnology Research Institute, N.I. Bio-Engineering Centre, University of Ulster, BT37 0QB, Northern Ireland* We report species measurements made with a Hiden EQP Mass Energy Analyser in a Diamond like Carbon Plasma Enhanced Physical Vapour Deposition system. Argon/acetylene fractions of 0% to 100% argon, pressures from 3 to 20 mTorr and RF powers up to 180 W (~ 500 V d.c. bias), were used, concentrating near optimum DLC deposition conditions (10 sccm argon, 20 sccm acetylene, 7 mTorr, 150 W, 450 V dc bias). Initial neutral species results show, for all RF powers, at constant chamber pressure, altering the argon fraction causes the expected linear variation in argon and acetylene count rate. For a 33% argon fraction at near constant pressure (~ 7 mTorr), however, acetylene count rates fall significantly as RF power is raised, argon count rates are almost constant. If the drop in total count rate (and thus number density) at constant pressure is due to a neutral temperature rise, it implies a temperature of 300 C at 160 W. Ionic species/energy measurements and comparison of species density with deposition rate will also be presented.

SESSION ES2: POSTER SESSION II
Sunday evening, 26 September 2004
Cork, Bunratty Conference Centre at 19:30

ES2 1 DIAGNOSTICS I

ES2 2 CF_2 density and temperature profiles in an $Ar/C_4F_8/O_2$ dual frequency capacitive discharge determined by UV absorption NICOLAS BULCOURT, JEAN-PAUL BOOTH, GARRETT CURLEY, *Laboratoire de Physique et Technologie des Plasmas, Ecole Polytechnique, Palaiseau, France (CNRS UMR 7648)* The radical CF_2 was detected using broad-band UV absorption spectroscopy in a dual RF frequency (2 and 27 MHz) capacitive discharge in $Ar/C_4F_8/O_2$. The objective was to obtain the radial and axial profiles of the CF_2 density and temperature for different discharge conditions. Absorption spectra were taken at different radial chords: the absorption spectra at different radii were then obtained by Abel inversion. The densities and temperatures were then obtained by comparing the experimental CF_2 spectra to spectrum simulations. These simulations used recently calculated values of the Franck-Condon factors and rotational constants calculated [1]. The results showed that the CF_2 rotational and vibrational temperatures at the center of the reactor are high (up to 500 K and 1000 K respectively). Radical production and gas heating mechanisms will be discussed. We acknowledge financial support from the Lam foundation. [1] N. Bulcourt, J.-P. Booth, E. A. Hudson, J. Luque, D. K. W. Mok, E. P. Lee, F.-T. Chau, J. M. Dyke. Chem. Phys. 120, 9499 (2004).

ES2 3 Phase and Space Resolved Rotational Temperature Measurements in Hydrogen RF Discharges V. SCHULZ-VON DER GATHEN, M. ABDEL-RAHMAN, T. GANS,* H.F. DÖBELE, *Universität Duisburg-Essen, Inst. f. Experimentelle Physik, 45117 Essen, Germany* Rotational temperatures of hydrogen in a capacitively and an inductively coupled RF- discharge are measured by optical emission spectroscopy using the first 5 lines of rotational Q-Branch of the Fulcher-α (v=2) system. The dimensions of both of the discharge systems are similar to those of the GEC reference cell. The CCRF discharge is operated at about 100 Pa and powers of up to 100 W while the ICP is operated at about 15 Pa and transceiver powers between 150 and 350 W. Both discharges are excited at an rf frequency of 13.56 MHz. In this contribution phase and space variations of Fulcher line emission and rotational temperature are compared. While both discharges show clear phase variations of the emission a prominent time variation

of the rotational temperature is observed only for the CCRF. The differences in the modulation of emission and temperature are discussed on basis of a simple model incorporating effects of population cascades from energetically higher states.into the upper states of Fulcher emission.

*Ruhr-Universität Bochum, Inst. f. Experimentalphysik V, 44780 Bochum, Germany

ES2 4 Spatial structure and temporal evolution of fields around dissimilar surfaces present on an rf powered electrode E. V. BARNAT, *Sandia National Laboratories* G. A. HEBNER, *Sandia National Laboratories* Both the spatial structure and temporal evolution of electric fields in an rf sheath of an argon discharge had been measured using laser-induced fluorescence-dip (LIF-dip) spectroscopy. Electric fields are measured by experimentally calibrated Stark-induced shifts of the 13d[3/2]1 level of the argon atom. Both the experimental setup as well as the technique employed to calibrate the Stark-induced shifts are discussed in detail. Knowing the Stark induced shifts, we examined the distribution of the electric fields present in the sheath above various configurations of an rf powered electrode. We illustrate how the structure of the rf electrode influenced both the structure of the fields around the electrode as well as the excitation in discharge. This work was supported by the Division of Material Sciences, BES, Office of Science, U. S. Department of Energy and Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energys National Nuclear Security Administration under contract DE-AC04-94AL85000.

ES2 5 Electric field measurement methods based on xenon spectroscopy MARK BOWDEN, TAO JIANG, ERIK WAGENAARS, GERRIT KROESEN, *Dept. of Applied Physics, Eindhoven University of Technology, PO Box 513, 5600 MB, Eindhoven, Netherlands* Laser spectroscopic methods of measuring electric fields provide non-intrusive measurements of field strength with good spatial and temporal resolution. Recently, we have been developing such methods based on the spectroscopy of xenon, methods that are specifically aimed at measurements in lighting plasmas. We report the development of two complementary techniques. The first uses a single laser to excite atoms from a metastable level to a Rydberg level. The second uses two lasers in a 2+1 photon scheme to excite atoms from the ground state to a Rydberg level. Examples of spectra measured with both techniques will be presented. These spectra will be compared with theoretical spectra determined from a calculation of Stark effects in xenon. Applications of the techniques for measurements of electric fields in lighting discharges will be briefly discussed.

ES2 6 Measurement of rf-phase resolved plasma parameters in an RF plasma using an uncompensated Langmuir probe S. LINNANE, M. B. HOPKINS, A. R. ELLINGBOE, *Dublin City University, Ireland* In rf plasmas, compensation is used to allow the probe tip to follow the oscillating plasma potential, thus giving undistorted time-averaged parameters. Here, a new technique, using an uncompensated probe, measuring the rf oscillation while applying a sweeping dc bias to the tip, is used to obtain characteristics similar to compensated probes, while also resolving parameters within the rf cycle. This uncompensated technique should allow the measurement of time dependent plasma potential oscillation which is impossible with standard Langmuir probe techniques.

ES2 7 Interpretation of Langmuir Probe Characteristics in Unmagnetized Flowing Plasma P. SHEERIN, *Dublin City University, Ireland* B. DOGGETT, *Trinity College, University of Dublin, Ireland* M. M. TURNER, *Dublin City University, Ireland* J. G. LUNNEY, *Trinity College, University of Dublin, Ireland* The behaviour of planar Langmuir probes in stationary low-temperature plasmas is well understood, but the theory of such probes when the plasma is flowing relative to the probe is not so satisfactory. In this paper we show that when the flow velocity is almost in the plane of the probe, the problem has certain formal similarities with the situation arising when a voltage pulse is suddenly applied to an electrode in a stationary plasma. Theory applicable to the latter situation has been considerably developed [1,2], and we will show how this theory can be adapted to describe the current-voltage characteristic of a planar Langmuir probe in a flowing plasma. There are many practical situations where such a description is useful, including examples in laboratory and astrophysical contexts, but we will discuss a particular instance relevant to experiments involving a plasma produced by ablating silver using a high power laser. [1] M. A. Lieberman, J. Appl. Phys. 66 2926 (1989) [2] K.-U. Riemann and Th. Daube, J. Appl. Phys. 86, 1202 (1999)

ES2 8 Time-resolved double probe measurements in a pulsed magnetron discharge SHANTANU KARKARI, JAMES. W BRADLEY, *Department of Physics, UMIST, Sackville Street, P.O.Box-88, M60 1QD, Manchester, U.K.* Pulsed magnetron discharges are very popular in plasma manufacturing of oxide films, as they provide better quality of the film property deposited on a substrate. Therefore, accurately determining the plasma properties will help to a better understanding of the sputter-deposition process. In this work, we have investigated the time-resolved plasma properties of a mid-frequency range (100 kHz) bi-polar pulsed magnetron discharge using double Langmuir probe techniques. The main advantage using a double probe is that both the probes follow the variation in plasma potential. Therefore, the transient sheaths between the probe and the plasma, which could lead to a distortion in measured probe characteristics are eliminated. However, application of double probe technique in pulsed plasmas has several other challenges, which must be addressed. This relates to (1) the frequency response of the probe, which is determined by the dynamic sheath impedance (2) a small difference in capacitive coupling of the plasma potential at each probe tips gives a displacement current at zero bias voltage between the probes (3) problems in measuring small floating current. To address these problems, we have developed two different sets of double probes: a) one set has a large physical area in the form of two semi circles sampling the plasma at one fixed radial position and b) the other set are a pair of two closely placed cylindrical probes with each probe tips capacitively coupled to a large electrode. This technique has improved the frequency response of the probe and hence better time-resolved probe characteristics are possible to obtain.

ES2 9 Time-Resolved Measurements in Pulsed DC Sputtering Magnetron IAN SWINDELLS, *UMIST* JAMES BRADLEY, *UMIST* Time-resolved Langmuir probe and optical emission spectroscopy (OES) have been used in a pulsed DC magnetron deposition system. The probe results show typically a decrease in electron temperature and density of around 30% and 20%, respectively, during the 1 - 5 μs reverse phase of the pulse. OES, however, shows the decay of line intensities to be on a much

quicker timescale of about 0.5 - 1 μ, with the reason for the difference discussed. The effect on the Langmuir probe results of changing the frequency (25kHz 350kHz) and duty (50% - 90%) of the pulse is also to be looked at.

ES2 10 An active probe compensation technique for time-resolved Langmuir probe measurements on pulsed RF discharges SERGEY A. VORONIN, *Department of Physics, UMIST, PO Box 88, Sackville Street, Manchester M60 1QD, UK* JAMES W. BRADLEY, *Department of Physics, UMIST, PO Box 88, Sackville Street, Manchester M60 1QD, UK* MORGAN R. ALEXANDER, *School of Pharmacy, University of Nottingham, University Park, Nottingham, NG7 2RD, UK* A three-harmonic active probe compensation technique has been developed to obtain time-resolved measurements in pulsed RF plasmas. The amplitude and phase of the RF compensation signals at the harmonic frequencies are tuned at each desired time point of measurements by obtaining the maximum value of the probe floating potential. The method allows accurate probe results to be obtained in transient phases (when the RF exciting voltage ramps up between off and on periods), not possible when the feedback signals are tuned for CW operation. Comparison between the point-wise and CW tuning has been carried out in a 1.3 Pa pressure Ar discharge pulsed at 200-2000 Hz and 30 W power. With tuning made in CW operation, the floating potential is 10 V underestimated in the beginning of a pulse, while the electron temperature is 2 eV overestimated. At times after the rise of the RF excitation (100 ms) the two of these methods give the same results.

ES2 11 A DC Biased Hairpin Resonator Probe ROBERT PIEJAK *Osram Sylvania, Inc.* A hairpin resonator probe has been constructed whose potential can be varied with respect to plasma potential. This construction has considerable practical advantage over a (normally) floating or a grounded probe. At low electron density (n_e) where the sheath is relatively large, a numerically calculated correction[1] (based on a step-front ion sheath) requires knowledge of the electron temperature (T_e) to accurately determine n_e. A biasable hairpin probe no longer requires an independent measurement of T_e. Moreover, if biased near plasma potential, it can determine n_e without knowledge of T_e! Data are presented here showing the hairpin probe's resonant frequency versus probe potential in an argon discharge. Minute changes in the resonant frequency are clearly observable. As the probe nears plasma potential, the ''raw'' n_e found directly, without sheath correction, reaches a plateau. This density plateau is in excellent agreement with that predicted by the sheath correction[1] applied to the resonant frequency measured at the floating potential. It is found that n_e can be determined by simply biasing the hairpin probe near plasma potential without a sheath correction. It is also found that a biased hairpin probe can be used as a Langmuir probe to determine T_e (and n_e!) as well as a resonant structure to determine n_e (independently) based on plasma permittivity.
R. Piejak, V. Godyak, R. Garner, B. Alexandrovich and N. Sternberg, JAP **95**, 3785, (2004).

ES2 12 Mass-spectrometry measurements in an rf asymmetric capacitively-coupled oxygen discharge MAGDALENA AFLORI, *Department of Plasma Physics, Al. I. Cuza University, Iasi, Romania* CEZAR-MIHAI GAMAN, *Department of Plasma Physics, Al. I. Cuza University, Iasi, Romania and Plasma Research Laboratory School of Physical Sciences Dublin City University Dublin, Ireland* LILIANA-MIHAELA IVAN, MIHAELA MIHAI-PLUGARU, DAN-GHEORGHE DIMITRIU, *Department of Plasma Physics, Al. I. Cuza University, Iasi, Romania* DEPARTMENT OF PLASMA PHYSICS, AL. I. CUZA UNIVERSITY, IASI, ROMANIA TEAM, PLASMA RESEARCH LABORATORY SCHOOL OF PHYSICAL SCIENCES DUBLIN CITY UNIVERSITY DUBLIN 9 IRELAND COLLABORATION. This article intend to present kinetic energy distributions for positive ions and neutrals from a 13.56 MHz oxygen plasma for different values of rf power(10 - 150 W) and pressure (10 90 mTorr) in an asymmetrical industrial OPT Plasmalab 100 system for semiconductor etching, by using a Hiden EQP Plasma probe. The ions density / neutrals density ratio is increasing with the rf power and decrease with the increase of the pressure. With increasing of the pressure, the mean free path is decreasing and becomes of the order of the sheath thickness. The elastic collisions of ions with neutral gas dominate and form the low energetic part. When a fast ion passes close to an oxygen atom or molecule, an electron from the atom or molecule transfers to the ion, neutralizing it. After the interaction, the original ion continues as atom along its previous trajectory but is no longer accelerated in the sheath potential. What was from the beginning a neutral is now an ion that is drifting instantaneously at thermal equilibrium with the bulk gas and will be accelerated in the sheath potential. These ions having energies different from that of the original fast-moving ion are expected to create multiple peaks in the ion energy distribution (observed at 90 mTorr).

ES2 13 Effect of Admixture of Rare Gases on Microwave-Excited Oxygen Plasma TAKESHI SAKAMOTO, *Tokyo Institute of Technology* KOUICHI NAOI, *Tokyo Institute of Technology* NAOHISA KITAMURA, *Tokyo Institute of Technology* HARUAKI MATSUURA, *Tokyo Institute of Technology* HIROSHI AKATSUKA, *Tokyo Institute of Technology* We examine the effect of admixture of noble gases with oxygen discharge on its vibrational and rotational temperatures (T_v, T_r) by using optical emission spectroscopy (OES). In the present study, we chose helium, neon, argon, krypton and xenon as admixtures with oxygen. We generated microwave discharge oxygen plasma in a cylindrical quartz tube (26 mm i.d.) with its discharge pressure 0.5 – 2.0 Torr. The microwave frequency was 2.45 GHz and the output power was set at 600 W. The gas flow rate was set at about 40 – 320 ml/min. In order to obtain the T_v and T_r, we measured the band spectra of radiative transition $A\,^2\Sigma^+ \rightarrow X\,^2\Pi$ of OH radical and $b\,^4\Sigma_g^- \rightarrow a\,^4\Pi_u$ of O_2^+ ion. First, we calculate the above band spectra for given T_v, T_r. After that, we compare the experimentally measured spectrum with the calculate one to determine the real T_v and T_r of the generated plasma. When the mixture ratio was larger than about 80%, T_v and T_r changed very much, and they depended on the species of mixed noble gas. The difference in the temperature change is discussed from several physical viewpoints.

ES2 14 A SEERS Model for Magnetically Enhanced Discharges T. MUSSENBROCK, J. REINELT, R. P. BRINKMANN, *Theoretische Elektrotechnik, Ruhr-Universität Bochum, D-44780 Bochum, Germany* SEERS (self-excited electron resonance spectroscopy) provides a robust and contamination-free in-situ diagnostic method of important parameters in capacitively coupled plasmas like the averaged electron density, the averaged electron collision rate, or the plasma bulk power. It employs a sensor which is integrated into the reactor wall. The RF current detected by the sensor is analyzed with respect to its harmonics

which excites the so called plasma series resonance. A model-based evaluation technique then determines from its frequency and damping the plasma parameters. The goal of this contribution is to provide an enhancement of the improved SEERS model, which already allows for the spatial resolution of the plasma and the electrodynamic effects [1]. This enhanced model takes into account an external dc magnetic field, e.g. as in magnetically enhanced reactive ion etchers (MERIEs). It is found that the excited resonance modes are considerably depending on the magnetic field, so that it has to be taken into account for a reliable diagnostics in magnetically enhanced discharges. [1] T Mussenbrock, Thesis, Ruhr-Universität, 2004

ES2 15 The Resonances of a Bounded Plasma and their Relation to SEERS R. P. BRINKMANN, T. MUSSENBROCK, *Theoretische Elektrotechnik, Ruhr-Universität Bochum, D-44780 Bochum, Germany* The behavior of bounded plasmas differs strongly from that of their unbounded counterparts. In the analysis of their RF response one can no longer apply the concept of a continuous dispersion relation $\omega = \omega(k)$ but finds isolated modes $\omega = \omega_n$. The frequency/damping of these modes depends on the spatial distribution of the plasma parameters. Diagnostics that study the resonances to find the properties of a plasma must solve a complex inverse problem. This holds also for SEERS (self-excited electron resonance spectroscopy), which observes the lowest resonances of a plasma. The first (so-called series) resonance lies at $\omega = (d/L)^{1/2}\omega_{pe}$ (L: reactor diameter, d: sheath width), but it was shown that also higher resonances play a role [1]. This contribution analyses the system of resonances with the help of two different models. The first model describes the plasma in terms of an infinitesimally thin sheath and a quasi-neutral bulk [1], while the second model allows also for a displacement current in the bulk. A comparison of the two models for a spherical symmetric plasma with constant parameters is conducted. It is found that the method of [1] gives reliable results for the lowest resonances, but leads to considerable deviations for higher modes. [1] T Mussenbrock, Thesis, Ruhr-Universität, 2004

ES2 16 Simple Estimation Method of RF Current in Inductively Coupled Plasmas KAWATA HIROAKI, YASUDA MASAAKI, HIRAI YOSHIHIKO, *Osaka Prefecture University* The antenna coil impedance for Ar inductively coupled plasma is measured at the pressure of 13Pa. Both the current and the voltage waveforms are measured. One turn antenna coil is used in our experiments. A large current flows through the self inductance of the antenna coil even at no discharge. The current through the self inductance is canceled by a newly developed cancellation circuit. The relation between the antenna coil impedance measured by the new method and the plasma impedance is derived based on a simple equivalent circuit model. It is found that the RF current in the plasma is directly proportional to the measured current. A simple equation is given for obtaining the coupling coefficient between the antenna coil and the plasma. The RF power is ranged between 150W and 300W. The measured current is directly proportional to the RF power. The coupling coefficient slightly increases as the RF power increases and the values are ranged between 0.4 and 0.5 in our experiments.

ES2 17 Atmospheric Plasma Analysis By Molecular Beam Mass Spectrometry Y. ARANDA GONZALVO, *Hiden Analytical Ltd.* J.A. REES, C.L. GREENWOOD, T.D. WHITMORE, D.L. SEYMOUR, I.D. NEALE The use of atmospheric plasmas is growing in interest due to their advantage in processing materials, mainly organic, which are not suitable for high vacuum. Such discharges are commonly studied by optical emission spectroscopy but, to understand the surface properties of the treated material, it is important to know the energy and identity of the impinging species. Atmospheric discharges from a number of gas mixtures have been studied using a Hiden EQP mass/energy analyser. The discharges were generated by a radio frequency driven atmospheric plasma source* and sampled using a multi-stage differentially pumped molecular beam inlet system. Results for gas mixtures containing different percentages of O_2, N_2, N_2O and CO_2 in Helium are compared. Energy distributions of the ionic species are reported as a function of the discharge power and the distance between the plasma source and the entrance to the analyser. Additionally, the pathways for producing radical species in the various mixtures are identified by electron attachment and appearance potential methods. * Stoffels et al., Plasma Sources Sci. Technol. 11 (2002) 383-388

ES2 18 Ionization processes of Ti atoms in magnetron sputtering plasmas studied by laser-induced fluorescence imaging spectroscopy N. NAFARIZAL, N. TAKADA, *Nagoya University, Japan* K. NAKAMURA, *Chubu University, Japan* M. KOBAYASHI, *ANELVA Corp., Japan* K. SASAKI, *Nagoya University, Japan* Recently, the ionized physical vapor deposition (IPVD) technique, which can deposit barrier and seed layers on the surfaces of narrow trenches and holes of LSI, has been developed. To optimize this technique, understanding of ionization processes of metal atoms in sputtering plasmas is essential. We measured the spatial density distributions of Ti, Ti^+ and Ar at a metastable state (Ar^M) in magnetron Ti sputtering plasmas by laser-induced fluorescence imaging spectroscopy. In addition, we also measured the plasma density and the electron temperature by using a Langmuir probe. We observed that the Ti^+ density increased drastically with the gas pressure, and the ratio of Ti^+ density to Ti density was maximum at several centimeters from the target. Hence, ionization processes of Ti are available in the gas phase with a low electron temperature. A possible ionization process in this region is collision with Ar^M (Penning ionization). However, we found that the Ar^M density was localized in the adjacent region to the target surface. In addition, we also found that the Ti^+ density and the plasma density were nearly equal at a distance of several centimeters from the target.

ES2 19 Transport of oxygen radicals in a slender glass tube of a microwave remote plasma source K. SASAKI, K. TAKIZAWA, *Nagoya University, Japan* A remote plasma processing tool is composed of a glow discharge source, a processing chamber, and a slender glass tube. An important point in the remote plasma processing tool is the transport of active species in the slender glass tube that connect the glow discharge region to the processing chamber. In the present work, we examined the transport of oxygen radicals in a slender glass tube by measuring the oxygen radical density using TALIF. We measured the oxygen radical density at various distances from the glow discharge region. As a result, the oxygen radical density was almost constant with the distance. We observed the temporal variation of the oxygen radical density in the afterglow. The oxygen radical density in the initial afterglow was almost constant, and the constant density was followed by the exponential decrease in the late afterglow. The duration of the constant oxygen radical density was dependent on the pumping speed and the gas pressure, and was proportional to D/v_g with v_g and D being the flow velocity of oxygen gas and the distance between the glow discharge region and the observa-

tion point, respectively. According to these results, it has been known that the loss of oxygen radicals on the wall of the glass tube is negligible, and oxygen radicals are transported efficiently toward the processing chamber with the gas flow.

ES2 20 PLASMA CHEMISTRY

ES2 21 Kinetics of OH radicals involved in the removal of acetaldehyde by a photo-triggered discharge in N2/O2/CH3CHO mixtures L. MAGNE, *LPGP, Univ. Paris-Sud, CNRS, France* J. AMORIM, *ITA-CTA Sao Jose Dos Campos, Brasil* V. EDON, S. PASQUIERS, *LPGP* F. JORAND, *LPGP* C. POSTEL, *LPGP* Acetaldehyde is a VOC responsible for offensive odors and suspected to be carcinogen. Therefore its abatement is attracting many interests, in particular using non-thermal plasmas created by dielectric barrier or corona discharges. However, such reactors are characterized by highly non-homogeneous plasmas for which diagnostics of radicals and modeling are very difficult. In order to avoid problems in connection with density and temperature gradients, we used a homogeneous pre-ionized discharge. Removal of acetaldehyde was studied at a total mixture pressure of 460 mbar and for oxygen and acetaldehyde concentration values in the range 5-10 percent and 250-5000 ppm respectively. Temporal evolutions of the OH radical density was measured by time-resolved laser induced fluorescence in the afterglow. CH3CHO density was measured by gas chromatography as a function of the number of accumulated discharges in the mixture. Comparisons between experimental results and predictions of a self-consistent 0D model were made, which allowed us to validate a kinetic scheme for acetaldehyde oxidation.

ES2 22 Interaction between hollow needles electric field, light emission and ozone generation study in multineedle to plate electrical discharge* VITEZSLAV KRIHA, *Czech Technical University Prague* Multi hollow needle to plate electrical discharges in air are studied as ozone sources. Dependence of ozone concentration as an function of applied voltage, discharge current, mutual hollow needles position and electrical connection, working gas flow rate, distances between needles tips and plate electrode, visible light emission was measured experimentally in these systems. Electric field was numerically modeled. Light emission and electrical field distributions were compared. Coming from light emission and electric field a model of energy density spatial distribution was built. This model was finally compared with ozone generation.

*This research is supported by Grant Agency of the Czech Republic under contract No. 202/02/P139

ES2 23 Production and loss kinetics of SiClx (x<3) etch products in high density HBr/Cl2/O2 plasmas GILLES CUNGE, *Laboratoire des Technologies de la Microélectronique, 17 rue des Martyrs, 38054 Grenoble, France* MARTIN KOGELSCHATZ, NADER SADEGHI, *Laboratoire de Spectrométrie Physique, 38402 St Martin d'Héres, France* Absolute $SiCl_x$ (x=0-2) and $SiCl_X^+$ densities are determined by UV broad band absorption spectroscopy and mass spectrometry during silicon etching in $HBr/Cl_2/O_2$ plasma at different RF source powers and O2 gas flows. These measured densities are compared to densities calculated with a simple model which uses electron impact cross sections for ionisation and dissociation of $SiCl_x$ (x=0-2) radicals and the measured etching rate. From these calculations it is concluded that neutralisation of ions on the reactor walls is an important production mechanism for Si and SiCl. At the same time these radicals are lost on the chamber walls with a large probability (between 0.1 and 0.5). Finally, our results show that most of the radicals that have chemisorbed on the reactor walls are etched back into the plasma as $SiCl_{2-4}$species. Silicon that is not cycled back into the plasma is oxidized and incorporated in the SiOCl film that is growing on the reactor walls.

ES2 24 Lumped circuit model of a plasma system grounded through a lossy dielectric T. ABU SHEMALA, M. M. TURNER, M. B. HOPKINS, A. R. ELLINGBOE, *Dublin City University, Ireland* In some modern plasma processing reactors, the rf current path to ground may be difficult to establish in the presence of dielectric materials with unusual properties. We present a 2-D time-dependent model of the plasma interface to ground. The plasma is in contact with a lossy dielectric that, in turn, is backed by a spatially-non-uniform ground plane. The first dimension is from the plasma boundary through the sheath to the ground reference plane. The second dimension is along the non-uniform lossy dielectric. The 2-D system is divided spatially, and each location is described by a lumped circuit, with either linear or non-linear components. The computational technique used is a fusion of transient network analysis methods and circuit theory resulting in a system of differential equations which are solved numerically. Results show that the plasma sheath voltage varies across the plasma dielectric. This results in net ion current in some locations, and net electron current in others, with current reconnection along the dielectric.

ES2 25 Dimensions of Plasma Boundary Region in Collisionless and Collisional Plasmas AKIHIRO KONO, *Nagoya University* In the boundary region in low-pressure plasmas, there exists a considerable distance (many Debye lengths) from the ''point'' where spontaneous charge separation begins to the ''point'' where the electron density becomes significantly lower than the ion density. Thus it seems appropriate to call the two points by different names. Here we call the former point the ''plasma edge'' which we define specifically as the edge of the space where quasineutral plasma solution exists in the fluid model treatment of the problem. We call the latter point the ''sheath edge,'' which we define specifically as the edge of the space where electron-free ion sheath equation has a solution. Based on this concept, accurate closed formulas for the distance between the plasma edge and the sheath edge and that between the sheath edge and the wall are derived in the collisionless and collisional limits. To what extent the formulas are accurate in the intermediate conditions between the collisional and collisionless limits are also discussed.

ES2 26 Streaming Instabilities in Negative Ion Plasmas* GLENN JOYCE, *Icarus Research Inc., Washington DC* RICHARD F. FERNSLER, STEVEN P. SLINKER, *Plasma Physics Division, Naval Research Laboratory, Washington DC* Positive ions in discharge plasmas stream toward the plasma walls while negatively charged ions stream toward the plasma core. This counter-streaming may lead to the cold two-stream instability. The

instability is quenched by ion collisions with neutrals, so the streaming instability should be observed at low pressures. The two-stream instability has been suggested as the source of dust heating in dusty plasma experimentss[2]. We have investigated this phenomenon using a one-dimensional fluid simulation code developed at NRL for studies of the LAPPS and for rf-plasmas. The code is time dependent, can be run in the electrostatic mode. The electrons are treated in the collision approximation in which inertial terms are neglected, but the ion equations include all inertial terms, so we can use this model to study streaming instabilities. Using this code, we have determined the properties of the two-stream instability for a negative ion plasma, including the stability boundaries as a function of the neutral pressure. We present the results of these studies. 2. G. Joyce, M. Lampe, G. Ganguli, Phys. Rev. Lett., 88, 095006, (2002)

*Work supported by ONR

ES2 27 Stable and unstable operation of a chlorine-based ICP C.S. CORR, *LPTP, Ecole Polytechnique, France* P.G. STEEN, *School of Physical Sciences, DCU, Ireland* W.G. GRAHAM, *Queen's University Belfast, Northern Ireland* Chlorine-based inductively coupled discharges are characterized using optical emission, electrostatic probes and probe-based photodetachment. Measurements of the negative ion fraction, the charged particle densities and the electron probability functions are presented. Instabilities are observed in the form of periodic modulations in the light output, floating potential, negative ion fraction and charged particle densities. When the discharge is tuned for zero reflected power instabilities are observed only in argon-chlorine mixtures and occur over limited operating conditions of input power, gas pressure and chlorine content. By variation of the matching conditions, an apparent pulsed plasma environment in a pure chlorine discharge is observed. Time-resolved measurements of the negative ion fraction show that there is a continuous transition between an electron-ion plasma in the on period and an ion-ion plasma in the off period. This pulsed plasma instability may be advantageous for industrial applications.

ES2 28 Distribution function and instabilities in high power microwave produced plasmas BABAK SHOKRI, *Laser Research Institute* In microwave gas discharges, the plasma electrons experience rapid oscillations along the wave electric field. Since, in this case, electron energy is much higher than ionization energy of the gas atoms, fast electrons can escape from the region of the wave electric field and ionize the surrounding gas atoms, so that it becomes possible to produce even overdense plasmas. Being much weaker than the atomic fields the gas breakdown produced by high-power pulsed microwave fields is investigated in the non-relativistic case in the adiabatic approximation. The distribution function of the electrons produced by the interaction with intense linearly and circularly polarized microwave fields is obtained and it is shown that it is non-equilibrium and anisotropic. The discharge mechanism for the gas atoms is governed by electron-impact avalanche ionization. By analyzing the instability of the system and by finding its growth rate, it is shown that the instability which is governed by the anisotropic property of the distribution function is Wiebel instability. Furthermore, it is shown that for the circularly polarized field the growth rate of the Wiebel instability is $\sqrt{2}$ times of that for the linearly polarized field. In the both linear and circular polarization, instability propagates across the electric field radiation.

ES2 29 Modelling of collective effects in the multiphoton ionization of atomic deuterium FRANCESCO GIAMMANCO, *University of Pisa, Italy* BRIAN SHORTT,* *National University of Ireland, Maynooth* PETER VAN DER BURGT, *National University of Ireland, Maynooth* We present numerical calculations of collective effects in laser plasmas produced by resonant three-photon ionization of atomic deuterium. The calculations are compared with experimental measurements [1] performed by intersecting a pulsed 243 nm dye-laser beam with an atomic deuterium beam. The atomic process is 2+1 REMPI and is resonant with the metastable 2s state. Collective effects affect the yields of ions and Lyman-alpha photons emerging from the laser plasma. The collective model is based on a full fluid-dynamics description [2] of the coupled motion of the ions and electrons, and includes a Bloch equation model [3] for the production of ions and electrons during the laser pulse. Wavelength-dependent plasma effects are observed, that can only be explained quantitatively with a full two-fluid collective model including the cylindrical geometry of the interaction region. [1] B. Shortt et al, Phys. Rev. E 66, 046411 (2002). [2] F. Giammanco, Phys. Rev. A 40, 5171 (1989). [3] B. Shortt et al, Laser Physics 12, 1402 (2002).

*Permanent address: Jet Propulsion Laboratory, California

ES2 30 Interaction of charged-particle beams with neutral gas over six decades of gas pressure and five decades of beam intensity STRASBURG SEAN, *Naval Research Laboratory* MOSHER DAVE, *Naval Research Laboratory* SCHUMER JOSEPH, *Naval Research Laboratory* OTTINGER PAUL, *Naval Research Laboratory* SWANEKAMP STEVEN, *Naval Research Laboratory* The need for a physics model of charged-particle beam injection into initially-neutral gas arises when trying to understand the transport of intense beams for inertial confinement fusion (ICF), exposure of satellites to electromagnetic pulses (EMP) at various altitudes, and many other applications. The background gas pressure can range from roughly 1 milliTorr, at high altitudes or for plasma-processing industrial applications, to well above one atmosphere for electron-beam pumped excimer lasers. Beam current densities for radiographic applications can exceed 100 kA/cm^2, while photoelectric currents caused by EMP can be five orders of magnitude smaller. This wide variation in parameters requires that many different numerical and analytical models—each valid in a limited regime—be meshed together to yield an overall understanding of the complete beam-gas system behaviour. A wide variety of models have been used by the Naval Research Laboratory on these problems, and numerical, experimental, and theoretical results from these investigations are reported.

ES2 31 Hyper-Thermic Atomic Beam Source For Surface Studies TATIANA BABKINA, TIMO GANS, UWE CZARNETZKI, *Institut für Plasma- und Atomphysik, Ruhr-Universität Bochum, Germany* A hyper-thermic atomic hydrogen beam source has been set up and characterised. The source is based on neutralisation and reflection of ions at an electrode. Ions are generated in an inductively coupled RF discharge with magnetic confinement at pressures of a few Pascal. An adjustable voltage is applied to a small electrode inside the discharge volume. Ions are accelerated in the sheath potential in front of the electrode. At the electrode surface ions are neutralised and reflected. The reflected beam of neutrals is extracted by a small orifice to a differentially pumped chamber. The plasma was characterised by Langmuir probe measurements. The atomic hydrogen beam has been investigated by

optical emission spectroscopy and an energy resolved mass spectrometer. The generated hydrogen beam with adjustable energy in the range of 100 eV can be applied for detailed studies of exothermic chemical reactions at metal surfaces. The work is supported by the DFG in the frame of the SFB 616.

ES2 32 MODELLING OF ION NEUTRALIZATION FOR PLASMA ETCHING ALEKSANDRA STOJKOVIĆ, MARIJA RADJENOVIĆ-RADMILOVIĆ, ZORAN PETROVIĆ, *Institute of Physics, P.O.B. 68, 11080 Belgrade, Serbia and Montenegro* NATAŠA NEDELJKOVIĆ, LJ. NEDELJKOVIĆ, *Faculty of Physics, University of Belgrade 11000 Serbia and Montenegro* Using fast neutrals for plasma etching in addition to ions or as their replacement has been proposed more than 10 years ago. However, only recently it became obvious that fast neutral based plasma etching could be a good way to avoid charging damage that limits the resolution of plasma etching of high aspect ratio structures. We have used a gas phase Monte Carlo simulation of ion neutralization by charge transfer collisions, as well as different models of neutralization at grazing incidence collisions with walls in an attempt to optimize the fast neutral source proposed by Samukawa [1] which consists of a set of narrow tubes. Estimates of the efficiency of neutralization were made either by assuming a 100 percent efficiency for singular collisions or by calculating the efficiencies for different models of surface neutralization. In all cases efficiency of neutralization on surfaces is high and optimization can be achieved by adjusting geometry of the tubes. [1] S.Samukawa, K. Sakamoto and K. Ichiki, J. Vac. Sci. Technol., A20, 1-8 (2002).

ES2 33 Effect of Different Chamber Wall Materials on ICP Discharge Parameters YI-KANG PU, *Department of Engineering Physics, Tsinghua University* ZHEN-DONG YU, *Department of Engineering Physics, Tsinghua University* ZHI-GANG GUO, *Department of Engineering Physics, Tsinghua University* JIE MA, *Department of Engineering Physics, Tsinghua University* Experimental studies show that the characteristics of reactor walls have significant influences on plasma parameters in plasma materials processing. In this paper, influences of different chamber wall materials and sizes on inductively coupled plasma (ICP) parameters, such as plasma potential, electron temperature and number density, are presented. Nitrogen, argon and their mixtures are used as working gas. The experimental measurements show that: (1) nitrogen plasma parameters are more sensitive to the reactor wall materials than those of argon plasmas; (2) Both electron temperature and number density increase as the chamber diameter decreases.

ES2 34 Application of Atmospheric Corona Discharge for PES Fabric Modification* JAN PICHAL, JAN KOLLER, LUDEK AUBRECHT, *Department of Physics, CTU FEE Prague, Czech Repulic* Our research is focused on the application of atmospheric corona discharge for PES fabric modification. We studied the relation between the corona discharge input power and the fabrics hydrophobility and modification effect aging expressed in the feathering spot size time changes. The PES (Tesil 12) fabric specimens were modified by atmospheric corona discharge, generated between grounded large plane brass electrode and an electrode matrix. Hydrophobility was evaluated by means of the drop test. Modification effect strongly grows according to the discharge input power. The modification effectivity had sharply diminished in time. 4 days after modification there was measured no important difference in hydrophobicity of modified and unmodified specimens. The modification process seems to be more efficient in case of RF discharges, but having in mind the costs of modification process the comparison is more difficult. For detailed comparison of both methods further experiments are necessary.

*This project has been supported by grant Cost-MSMT OC 527.60, experimental work were accomplished in collaboration with Technical University of Liberec, Czech Republic

SESSION FM1: PLASMA APPLICATIONS
Monday morning, 27 September 2004
Belfast Room, Bunratty Conference Centre at 8:30
Yasuke Sakai, Hokkaido University, presiding

8:30
FM1 1 Microwave torch. Physics and applications SERGEI GRITSININ, VITALII KNYAZEV, IGOR KOSSYI, *Prokhorov Institute of General Physics of RAS* New construction of a coaxial microwave torch (CMT) has been developed, tested and investigated. CMT provides a means for plasma stream production virtually in all gases and gaseous mixture flow at atmospheric pressure. A broad spectrum of diagnostics has been applied including microwave and laser interferometry, optical active and absorptive spectroscopy, laser holographic interferometry, microwave radiation detection, high-speed photography, etc. The time evolution of the torch operating in the pulsed mode is considered. It has been revealed that the evolution is different in noble and molecular gases. The characteristic feature of torches in noble gases is a dense core with plasma density no less than 1016 cm-3. Plasma bunches with density of 1014-1015 cm-3 successively propagate downstream from this core, which are seen as glow bursts. In molecular gases, the core is absent and the torch is formed by propagating plasma bunches. By optical diagnostics application temperature of neutral component of microwave torch has been determined. With high efficiency energy of microwave radiation comes into gas heating. Gas temperature is maximal near the nozzle (4,5 - 5,0 kK) and falls down in axial direction (to 2,5 - 3,0 kK). Torch is thermally-non-equilibrium plasma formation capable of significant change of working and surrounding gaseous state. Peculiarities of discharge development and maintenance are under discussion as well as possibilities to use microwave torch as a spaceborne plasma source, combustion ignitor, mean for nanoparticles production, different plasmachemical applications etc. Contact information: Mailing address: Prof. I.A.Kossyi General Physics Institute, 119991, Vavilov Street 38 Moscow, Russia. E-mail: kossyi@fpl.gpi.ru

8:45
FM1 2 Generation and control of wide area, homogenous atmospheric pressure discharges for industrial coating applications. ALAN HYNES, CASTAGNA WALTER, KIERAN CARR, SEAN O'SHEA, TONY HERBERT, *Dow Corning Plasma Solutions, Midleton, Co Cork, Republic of Ireland* Dow Corning Plasma Solutions use diffuse atmospheric pressure plasma technology combined with a unique precursor delivery system for a new coatings approach: Atmospheric Pressure Plasma Liquid Deposition. Operating at atmospheric pressure and ambient temperature this process allows the use of a wide range of liquid precursors delivering high chemical functionality onto flexible substrates. Patented APPLD equipment enables plasma deposition onto wide area substrates up to 1.6m width in true reel-to-reel conditions at industrial line speeds up to 30m/min. Substrates can be either electrically insulating or conducting. Recent engineering developments addressing issues in electrode design, liquid delivery and gas retention and distribution, have significantly enhanced the stability and homogeneity of the plasma chemistry and coating performance. The process is controlled through monitoring and control of key plasma chemistry and process parameters. The process hardware and process control package will be described in detail with particular emphasis on plasma chemistry and process control tools.

9:00
FM1 3 VOC removal by a plasma-catalytic process CECILE AYRAULT, *LACCO* JOEL BARRAULT, *LACCO* JEAN-MICHEL TATIBOUET, *LACCO* STEPHANE PASQUIERS, *LPGP* PIERRE TARDIVEAU, *LPGP* The removal of air pollutants (VOC) is a main problem either in industrial or domestic activities. A non-thermal plasma can lead to the oxidation of VOC in air, but generally the removal is incomplete and the formation of by-products (partial oxidation products, CO, ozone) is observed. In addition to the plasma, the use of a catalyst located either in and/or after the plasma zone enhances the efficiency of the process and suppresses almost completely the by products formation. We have used a new DBD type plasma reactor where the catalytic active phase was supported on an alumina wash-coated honeycomb type monolith to treat a 2 heptanone containing air flow. A synergy effect between catalyst and plasma was observed when the catalyst (Pt/Al2O3) was located in the plasma zone. More than 90% of removal of 130 ppm of 2-heptanone in dry air was performed at room temperature with an energy density of 400J/L. But the ozone concentration was 63 ppm in the exiting air flow. By adding a MnO2 based catalyst located after the plasma zone, the residual ozone concentration was only 4 ppm showing the possible use of such system in industrial processes of air cleaning.

9:15
FM1 4 VOC removal by plasma-photocatalyst combination: Comparison between a low and an atmospheric pressure plasma ANTOINE ROUSSEAU, OLIVIER GUAITELLA, LINA GATILOVA, *LPTP, Ecole Polytechnique CNRS 91 128 Palaiseau France* FREDERIC THEVENET, CHANTAL GUILLARD, *LACE - CNRS Universit Claude Bernard LYON 1 69622 Villeurbanne cedex, France* MARIO HANNEMANN, JURGEN ROEPCKE, *INP-Greifswald, F.-L.-Jahn-Str. 19, 17489 Greifswald, Germany* The combination of a non thermal plasma with a photo-catalyst is promising for VOC and odour abatement at room temperature and at a very low energy cost. In classical photocatalysis, UV photons generate an electron hole pair on the surface of the photo-catalyst (TiO2), which generates primary radicals responsible of VOC oxidation. In plasma-photocatalysis combination, activation mechanisms of the photocatalytic surface are not clearly identified to the day. Our strategy is to compare a pulsed DBD at atmospheric pressure containing TiO2 pellets, with a pulsed low pressure DC discharge in contact with a porous TiO2 surface. These two discharge are characterized electrically and the efficiency of VOC removal is performed using infrared laser absorption spectroscopy and gas chromatography.

9:30
FM1 5 Gas-discharge improving ecological characteristics of the atmosphere GERMAN BATANOV, IGOR KOSSYI, VALERII SILAKOV, *Prokhorov Institute of General Physics of RAS* The possibility of improving ecological characteristics of the atmosphere with the help of freely localized microwave discharge is analyzed. Theoretical and experimental studies devoted to cleaning the troposphere of ozone-destroying pollutants and creating an artificial ozone layer in the stratosphere are reviewed. Experiments performed with convergent powerful microwave beam exciting discharge in condition close to the natural atmosphere one are discussed. Theoretical consideration of consequences of freely localized microwave discharge in atmosphere are analyzed and conclusions concerning to the possibility to improve ecological situation are made. Results of the studies in the

Institute of General Physics of the possibility of the plasmachemical utilization of the accumulated chlorofluorocarbons (CFCs), capable of depleting the ozone layer, are presented. Experiments open up new avenues for development of an efficient reactor dedicated to the ''harmful'' CFCs decomposition. The results of theoretical and experimental modeling are used to predict the plasmachemical consequences of creating artificial ionized regions in the upper atmosphere for the purpose of long-range radio and TV communications.

9:45

FM1 6 Electric discharge in the water: Physics of formation and radiative characteristics. ANDREI ANPILOV, EDUARD BARKHUDAROV, YURII KOZLOV, IGOR KOSSYI, VALERII SILAKOV, SAVELII TEMCHIN, *Prokhorov Institute of General Physics of RAS* Two types of electric discharge in the water have been investigated: discharge between two electrodes and multielectrode gliding surface discharge. Results are presented from experimental studies of the prebreakdown phase of an electric discharge between the point (anode) and plane (cathode) electrodes immersed in the water with different initial conductivity. When a high-voltage pulse is applied, the induced conductivity is detected in the discharge gap. Its value is one order of magnitude higher than the initial one. It is shown that the induced conductivity increases almost linearly with initial conductivity. The induced conductivity correlates with the UV emission from the cathode surface. A qualitative analysis of the experimental results is performed. Investigations of a spectrum of radiation of discharge in water have been carried out. On the base of broadening and shifting of atomic hydrogen and oxygen lines electron density in a prebreakdown as well as breakdown stages has been determined. Results are presented from investigations of multispark electric discharge in water excited along multielectrode metal-dielectric systems with gas supply into the interelectrode gaps. The intensity distribution of discharge radiation in the region covering the biologically active soft UV (190 l430 nm) has been determined and the absolute number of quanta in this wavelength interval has been measured. The potentiality of the gliding surface discharge in water for its disinfection is analysed.

SESSION FM2: ELECTRON-MOLECULE INTERACTIONS

Monday morning, 27 September 2004; Dublin Room, Bunratty Conference Centre at 8:30
Ann E. Orel, University of California, Davis, presiding

Invited Papers

8:30

FM2 1 Dissociative ionization of biomolecules.*
WINIFRED HUO, † *NASA Ames Research Center*

Dissociative ionization (DI) by electron impact plays a role in many different applications, including low-temperature plasma processing, the study of space and astrophysical plasmas, and the study of biological damages by high-energy radiation. In the present study, our goal is to understand the health hazard to humans from exposure to radiation during an extended space flight. DI by secondary electrons can damage the DNA, either directly by causing a DNA lesion, or indirectly by producing radicals and cations that attack the DNA. The theoretical model employed makes use of the fact that electronic motion is much faster than nuclear motion, allowing DI to be treated as a two-step process. The first step is electron-impact ionization resulting in a dissociative state of the molecular ion with the same geometry as the neutral molecule. In the second step the ion relaxes from the initial geometry and undergoes unimolecular dissociation. Thus the DI cross section is given by the product of the ionization cross section and the dissociation probability. For the ionization process we use the improved binary-encounter dipole (iBED) model. For unimolecular dissociation, we use the multiconfigurational self-consistent field (MCSCF) method to determine the minimum energy pathways to possible product channels. This model has been applied to study the DI of H_2O, NH_3, and CH_4, and the results are in good agreement with experiment. The DI from the low-lying channels of benzene has also been studied and the dissociation products are compared with photoionization measurements. The DI of the DNA bases guanine and cytosine are then discussed. Of the four DNA bases, guanine has the largest ionization cross section and cytosine has the smallest. The guanine radical cation is considered to be one of the precursors to the primary, direct-type lesions formed in DNA when it is irradiated. Comparison of DI products of guanine and cytosine will be made to understand the differences in their behavior upon irradiation.

*Research supported by NASA Ames Research Center IR&D funding.
†Collaborators: Christopher E. Dateo, Graham D. Fletcher, Dunyou Wang.

Contributed Papers

9:00

FM2 2 The Role of Resonances in Electron Scattering from Water MILICA JELISAVCIC, RADMILA PANAJOTOVIC, JAMES SULLIVAN, STEPHEN BUCKMAN, *Australian National University* The interaction of electrons with water molecules has significance in a wide range of naturally occurring phenomena and many practical applications. A particularly relevant area of study is the effect of ionizing radiation in the human body, whose water content is approximately 60 percent. It is well recognized that high-energy particles produce a large number of low-energy (1-20 eV) secondary electrons which undergo both elastic and inelastic scattering events. An important inelastic loss process involves the resonant capture of an electron to form a transient negative ion. In this work we present the measurements of excitation functions for elastic scattering and vibrational exci-

tation in the energy range from 5-10 eV and for scattering angles of 60, 90 and 120 degrees. In particular we wish to investigate the decay mechanisms of a temporary negative ion resonance at 7.5 eV, and the extent to which it mediates vibrational excitation.

9:15

FM2 3 Low-energy electron scattering by nitric oxide* T.N. RESCIGNO, ZHIYONG ZHANG, WIM VANROOSE, C.W. McCURDY, *LBNL* C.S. TREVISAN, A.E. OREL, *UC Davis* We present an ab initio study of elastic scattering and vibrational excitation of NO by low-energy (0-2.0 eV) electron impact. The cross sections in this energy range are dominated by shape resonance contributions associated with the $^3\Sigma^-$, $^1\Delta$ and $^1\Sigma^+$ states of NO^-. Resonance parameters for the three anion states were extracted from an analysis of fixed-nuclei variational (complex Kohn) calculations that employed elaborate trial wave functions. Independent estimates of the resonance parameters were obtained by analytically continuing the results of large-scale coupled-cluster calculations into the plane of complex momentum. We have employed both the local complex potential (Boomerang) and more elaborate non-local resonance models to calculate vibrational excitation cross sections, as well as the resonant portion of the vibrationally elastic cross sections. These results were combined with background contributions from the fixed-nuclei calculations to compute elastic and grand total cross sections. Our results will be compared to recent experiment.

*Work performed under aupcices of US DOE by Lawrence Berkeley National Laboratory and supported by DOE-OBES, Division of Chemical Sciences.

9:30

FM2 4 Relaxation behavior of ro-vibrationally excited H_2 in a plasma expansion RICHARD ENGELN, PETER VANKAN, DAAN SCHRAM, *Eindhoven University of Technology, The Netherlands* The evolution of the rotational and vibrational distributions of molecular hydrogen in a hydrogen plasma expansion, measured using LIF in the vacuum-UV range, will be presented. The evolution of the distributions along the expansion axis shows the relaxation of the molecular hydrogen from the high temperature in the up-stream region to the low ambient temperature in the down-stream region. During the relaxation, the vibrational distribution (recorded up to $v = 6$), is frozen in the expansion and can be described with a Boltzmann distribution at T ~ 2200 K. However, the rotational distributions, which have been recorded up to $J = 17$ in $v = 2$ and up to $J = 11$ in $v = 3$, can *not* be described with a single Boltzmann distribution. In the course of the expansion, the lower rotational levels ($J < 5$) adapt quickly to the ambient temperature (~ 500 K), while the distribution of the higher rotational levels ($J > 7$) is measured to be frozen in the expansion at a temperature between 2000 and 2500 K. A model based on Rotation-Translation energy transfer is used to describe the evolution of the rotational distribution of vibrational level $v=2$ in the plasma expansion. The behavior of the low rotational levels ($J < 5$) is described satisfactory. However, the densities of the higher rotational levels decay faster than predicted.

9:45

FM2 5 The Electronic-Vibrational Behaviour of O_2 in the Upper Atmosphere under Night-time Auroral Conditions D.B. JONES, D.C. CARTWRIGHT, L. CAMPBELL, P.J.O TEUBNER, M.J. BRUNGER, *School of Chemistry, Physics and Earth Sciences, Flinders University, GPO Box 2100, Adelaide, SA 5001, Australia.* M.J. BOTTEMA, *School of Informatics and Engineering, Flinders University, GPO Box 2100, Adelaide, SA 5001, Australia.* We report on the extension of our Statistical Equlibrium Code (SEC) to determine the electronic-vibrational behaviour of O_2 in the thermosphere, under night-time auroral conditions. This work was necessitated by the inadequacies in previous studies where the electron-impact cross section data bases employed have been superceeded, and/or direct excitation of states via electron impact has been neglected. Here we use the latest electron-impact cross section data bases to present the first electron-impact excitation rates for the 8 lowest lying electronic states of O_2. We then use these rates in conjunction with the most accurately available Franck-Condon factors, transition probabilities and quenching rates to determine the excited state populations. Note that predissociation, which is important for O_2, is also included in our model. We present radiative rates for various transitions and compare these results with those from other models and experimental rocket measurements.

SESSION GM: THE WILL ALLIS PRIZE LECTURE

Monday morning, 27 September 2004; Belfast Room, Bunratty Conference Centre at 10:30
Alan Garscadden, Wright Patterson Laboratory, presiding

10:30

GM 1 Colliding Electrons—Workhorses of Gaseous Electronics.*
BILL McCONKEY, *University of Windsor, Canada*

The need for electron scattering data to explain the various observed phenomena encountered in electric discharges through gases and indeed in plasmas of all types, has provided strong motivation to collision physicists over the years to carry out the appropriate measurements and calculations. The field has been continually stimulated by new discoveries in such diverse areas as planetary atmosphere processes, low and high temperature plasma physics, lasers and radiation chemistry. In addition, electron collisions undergird the efficient operation of a multitude of practical devices and industrial processes. This talk will seek to give a flavor of what has been happening in this field, particularly over the past half-century.

*Supported by NSERC, CIPI and CFI (Canada).

SESSION JM1: PLASMA APPLICATIONS FOR NANOTECHNOLOGY II

Monday afternoon, 27 September 2004
Belfast Room, Bunratty Conference Centre at 14:00
Greg Hebner, Sandia National Laboratory, presiding

14:00

JM1 1 Optical Emission Spectroscopy of a Microwave-excited Miniature Plasma Source for Very Small Propulsion YOSHINORI TAKAO, KOUICH ONO, KAZUO TAKAHASHI, YUICHI SETSUHARA, *Department of Aeronautics and Astronautics, Kyoto University, Kyoto, Japan* There has recently been an ongoing trend toward decreasing the mass, dimension, and overall complexity of spacecraft. Propulsion systems are no exception. This paper is concerned with the application of microplasmas to a very small thruster, presenting some results of experimental investigations of a microplasma source. The plasma source is made of a straight quartz tube 1.5 mm in inner diameter and 10 mm in length, where 4-GHz microwaves are injected to excite plasmas. The Ar gas flow rate is 140 sccm, the plenum pressure is 3 kPa, and the backpressure is 20 Pa. Optical emission spectroscopy has indicated that as the microwave input power increases, Ar I line intensities increase slightly, rise sharply at around 7 W, and then increase gradually again. As the power decreases, the intensities decrease and then drop steeply at around the same power. These results imply a mode change of the miniature plasma discharges at around 7 W in the experiment.

14:15

JM1 2 MICRO-DISCHARGE MICRO-THRUSTER JOHN SLOUGH, *University of Washington* J. J. EWING, *Ewing Technology Associates* This talk summarizes the experiments and analysis of the micro-discharge micro-thruster developed jointly by Ewing Technology Associates and the University of Washington. The key experimental result has been demonstrating that a discharge can be struck in a micro-discharge type of structure (aperture $<$ 300 microns) under very demanding flow conditions. In addition, the micro-discharge provides for power addition to the neutral gas in discharges that transition from high pressure ($\sim$10-100 mTorr) to vacuum on the supersonic flow side of the limiting aperture nozzle separating the discharge region from the vacuum region. The fact that a fairly stable discharge is maintained on the downstream side suggests that the fairly hot plasma ($\sim$2 eV) deposits power into the neutral gas (Argon) in a manner that produces a neutral flow of similar energy, much like an arcjet but at very low power (2-10 W). A crude measurement of the power deposition into the gas via an energy balance approach was obtained from thermocouple measurements, which also imply that the gas temperature may be as high as 1-2 eV. Coupling thrust measurements to measurements of discharge and plasma properties is an integral part of the path to future understanding. Ultimately a model needs to be developed to explain the gas and plasma dynamics involved in the device. High-temperature nozzle flows at low Reynolds numbers are typically studied numerically by the direct simulation Monte Carlo method, and results from initial calculations will be presented, as well as future plans.

14:30

JM1 3 Plasma Synthesis of Luminescent Silicon Quantum Dots ELIJAH THIMSEN, LORENZO MANGOLINI, UWE KORTSHAGEN, *Mechanical Engineering, University of Minnesota, Minneapolis* Semiconductor nanoparticles with photoluminescent properties are of interest for a wide range of applications from solid state lighting, to solid state lasers, to imaging biological systems. A wide range of compound semiconductor quantum dots has been produced with excellent photoluminescent properties such as, for instance, cadmium-selenide. However, many of these compound quantum dot materials are of environmental concerns due to their content of toxic heavy metals. Hence there is continued interest in silicon quantum dots as a luminescent material, since silicon is widely considered as environmentally benign. In this presentation we discuss a plasma process that is capable of producing crystalline, nonagglomerated silicon nanoparticles of less than 10 nm in size. The reactor is designed to be a flow through reactor which enables online analysis of the particle size distribution with a fast scanning nano-Differential Mobility Analyzer (DMA). The particles structural properties are studied with high resolution transmission electron microscopy. The luminescent properties of the particles are investigated by studying photoluminescence of the particles on illumination with UV radiation.

14:45

JM1 4 Modeling of dusty silane discharges: nanoparticle formation, transport and charging KATHLEEN DE BLEECKER, ANNEMIE BOGAERTS, RENAAT GIJBELS, *Plasmant - Dept. of Chemistry, University of Antwerp, Belgium* WIM GOEDHEER, *FOM Institute for Plasmaphysics, The Netherlands* A self-consistent 1D fluid model was developed to simulate the formation and behavior of sub-micrometer particles (ranging in size from 1 to 100 nm diameter) in a low-pressure capacitive rf silane discharge. The nanometer-sized particles are of special interest, as it has been shown that under certain conditions small nanoparticles can escape from the discharge and be incorporated into the growing film. The incorporation of nanocrystalline silicon particles in the deposition process of a-Si:H thin films, results in the production of polymorphous silicon (pm-Si:H), which proves to be a good material for the fabrication of high efficiency solar cells. In the model, the discharge is described by a combination of particle, momentum and energy density balances. The charging of the nanoparticles is calculated via the OML theory and the transport equation is extended to include the extra forces acting on the particles (ion and neutral drag, thermophoresis). In contrast to other modeling studies, the nucleation or growth kinetics of the nanoparticles is taken into account, as the particles are formed by successive reactions of anions with silane molecules. Several simulations for various particle radii were performed, which show that the resulting density profile of the nanoparticles greatly depends on the balance of the different forces acting on the particles.

15:00

JM1 5 Modeling of Sheath Ion-Molecule Reactions in Plasma Enhanced Chemical Vapor Deposition of Carbon Nanotubes D. B. HASH, T. R. GOVINDAN, M. MEYYAPPAN, *NASA Ames Research Center* In many plasma simulations, ion-molecule reactions are modeled using ion energy independent reaction rate coefficients that are taken from low temperature selected-ion flow tube experiments. Only exothermic or nearly thermoneutral reactions are considered. This is appropriate for plasma applications such as high-density plasma sources in which sheaths are collisionless and ion temperatures in the bulk plasma do not deviate

significantly from the gas temperature. However, for applications at high pressure and large sheath voltages, this assumption does not hold as the sheaths are collisional and ions gain significant energy in the sheaths from Joule heating. Ion temperatures and thus reaction rates vary significantly across the discharge, and endothermic reactions become important in the sheaths. One such application is plasma enhanced chemical vapor deposition of carbon nanotubes in which dc discharges are struck at pressures between 1-20 Torr with applied voltages in the range of 500-700 V. The present work investigates the importance of the inclusion of ion energy dependent ion-molecule reaction rates and the role of collision induced dissociation in generating radicals from the feedstock used in carbon nanotube growth.

15:15
JM1 6 Numerical Analysis for Nano-Particle Synthesis of Silicon-Based Intermetallic Compounds Using an Induction Thermal Plasma MASAYA SHIGETA, TAKAYUKI WATANABE, *Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo, 152-8550, Japan* An induction thermal plasma has been used in material processes such as nano-particle synthesis since it has high energy density, large plasma volume and chemical reactivity. Additionally the plasma itself is clean because it can be produced without electrodes. The formation of nano-particles of metals and ceramics with high purity can be easily achieved by the steep temperature gradients at the tail of the induction thermal plasma. In the present study, numerical analysis is conducted for the systems of silicide nano-particle synthesis using an induction thermal plasma to clarify the mechanism and particle size distribution. Silicide nano-particles are produced by evaporation and following recondensation of coarser metal and silicon particles. The homogeneous nucleation occurs at different positions accompanied with the differences of the saturation vapor pressures and the surface tensions of the materials. For example, nuclei of molybdenum are produced at the more upstream region where the plasma temperature is higher compared with other metals and silicon. There are, however, metals whose nucleation positions are more downstream than silicon. After homogeneous nucleation, the mixed vapors of metal and silicon condense on the nuclei. Silicon has wide liquid range between nucleation and melting temperature, which result in better preparation of silicide.

SESSION JM2: DISSOCIATIVE ATTACHMENT/DISSOCIATIVE RECOMBINATION
Monday afternoon, 27 September 2004; Dublin Room, Bunratty Conference Centre at 14:00
Thomas N. Rescigno, Lawrence Berkeley National Laboratory, presiding

Invited Papers

14:00
JM2 1 High resolution studies of dissociative electron attachment to molecules.
H. HOTOP, S. BARSOTTI, M. BRAUN, S. MARIENFELD, M.-W. RUF, *Fachbereich Physik, Technische Universitaet, D-67653 Kaiserslautern, Germany*
I. I. FABRIKANT, *Department of Physics and Astronomy, Univ. Nebraska, Lincoln, NE 68588, USA*

Experimental advances involving laser photoelectron sources have recently allowed detailed studies of low-energy electron attachment to several small molecules and molecular clusters at (sub)meV resolution [1]. For the first time, conclusive investigations of the limiting ($E\sim \rightarrow \sim 0$) threshold behaviour for the attachment cross section became possible with the laser photoelectron (LPA) method [1]. Absolute attachment cross sections over the energy range $E\sim = (0.5\sim - \sim 200)\sim$ meV are established by normalizing the LPA yields for negative ion formation to reliable attachment rate coefficients, determined at well-defined electron and gas temperature in swarm experiments. Towards higher energies, the attachment cross sections may exhibit sharp cusp-type structure at vibrational onsets, due to the interaction of the attachment process with other scattering channels, e.g. for SF_6 and CCl_4 [1]. For electron-molecule systems with sufficiently strong long-range interactions and suitable crossings of the diabatic anion potential with the neutral potential curve (e.g. CH_3Br or CH_3I), narrow and prominent vibrational Feshbach resonances occur in the cross section for dissociative attachment [1]. At the conference we highlight these topics by discussing specific molecules (including Cl_2, CF_3I, and CH_3I) for which the high resolution attachment data can be compared with theoretical calculations.For suitable cases (e.g. Cl_2, CH_3I), semiempirical input to the theory is fixed with reference to attachment cross sections and then offers a platform for theoretical predictions of elastic scattering and vibrational excitation cross sections [1]. This work has been supported by the Deutsche Forschungsgemeinschaft and by the Forschungszentrum OTLAP. [1] H. Hotop, M.-W. Ruf, M. Allan, I. I. Fabrikant, Adv. At. Mol. Opt. Phys. 49 (2003) 85-216.

Contributed Papers

14:30

JM2 2 Dissociative Recombination of Rare-Gas Diatomics ANN E. OREL, JEANNA ROYAL, *Department of Applied Science, University of California, Davis 95616, USA* VALERY NGASSAM, ANNICK SUZOR-WEINER, *Laboratoire De Photophysique Moleculaire, Universite Paris-Sud, France* Rare gas molecular ions play an important role in many gaseous discharges. We present results on the cross section for dissociative recombination for two such ions, He_2^+ and Ne_2^+. These ions have been observed to have very different rates of dissociative recombination, with He_2^+ having an extremely slow rate at low energies while Ne_2^+ has a very fast rate. For each system, the resonance curves and autoionization widths are abstracted from electron scattering calculations using the Complex Kohn variational method. These parameters are used in both a wave packet (He_2^+) and a Multichannel Quantum Defect (Ne_2^+) calculation for the dynamics. Our calculated cross sections are compared with recent experimental measurements. JR and AEO acknowledge support from NSF, PHY-02-44911, from The Center for Biophotonics, an NSF Science and Technology Center PHY 0120999 and US DOE Office of Basic Energy Science, Division of Chemical Science.

14:45

JM2 3 ERIC, A New Electron Attachment Spectrometer For Radicals THOMAS FIELD,* ANDREW SLATTERY, DARYL ADAMS, DAVID MORRISON, *Dept. Pure and Applied Physics, Queen's University Belfast, Belfast, BT7 1NN, Northern Ireland, U.K.* A new spectrometer, ERIC (electron radical interaction chamber), has been developed to study dissociative electron attachment to unstable molecules such as free radicals. It includes a trochoidal electron monochromator and a time-of-flight mass spectrometer. Radicals are generated with a microwave discharge at 2.45 GHz. Preliminary data are presented for SO, S_2O and S_2O_2 radicals formed when a mixture of helium and sulphur dioxide was passed through the microwave discharge. Several new resonacnes are observed with the discharge on, which are assigned to the radicals. Absolute cross sections for these processes have been estimated. Website: http://www.qub.ac.uk/mp/ampr/radical.html

*presenting author

15:00

JM2 4 ON EXPLANATION OF NEGATIVE ELECTRON MOBILITY MILOVAN ŠUVAKOV, ZORAN RISTIVOJEVIĆ, SAŠA DUJKO, ZORAN RASPOPOVIĆ, ZORAN PETROVIĆ, *Institute of Physics, P.O.B. 68, 11080 Belgrade, Serbia and Montenegro* Several examples of gas mixtures leading to negative absolute mobility (NAM) were reported in the literature, mixture of Fluorine and Argon in particular. In most cases it was the attachment heating of the EEDF combined with a special shape of the elastic cross section that led to the effect. The effect was shown to be stationary even though the requirement for its occurrence is the presence of strong attachment losses and therefore the decay of the plasma is fast. It was shown recently that the flux drift velocity is negative (in respect to the expected direction) while the bulk drift velocity is positive. Positive bulk drift velocity is necessary in order to satisfy the second law of thermodynamics. In the case of rf fields bulk drift velocity has a large phase delay. All this information led to an explanation of NAM where the mean velocity of electrons is indeed in the opposite direction to the expected leading to negative flux drift velocity. However, the positive bulk drift velocity is the result of spatial separation of electrons as a function of energy and strongly energy dependent attachment cross section that leads to a wave of attachment of slow electrons and shifts the center of balance of electrons in the positive direction.

15:15

JM2 5 Charge transfer and dissociative recombination processes in expanding thermal plasmas for a:SiOX-C,H film deposition M. A. BLAUW, M. CREATORE, M. C. M. VAN DE SANDEN, *Eindhoven University of Technology, The Netherlands* High rate deposition of a:SiOX-C,H for anti-scratch coatings on polycarbonate substrates is presently obtained by means of expanding thermal plasmas. This technology is of paramount importance to introduce polycarbonate as a lightweight glass replacement. Briefly, an argon plasma is ignited in a cascaded arc with variable cathode-anode distance at near-atmospheric pressure. It expands through a nozzle into the deposition chamber kept at a three orders of magnitude lower pressure. Deposition precursors are injected downstream. Fast charge transfer with Ar+ ions and dissociative recombination with low-temperature electrons generates radicals in the downstream region. The recombination of ions and the production of radicals were investigated by means of Langmuir probe measurements and Threshold Ionisation Mass Spectrometry, respectively. The downstream ion density of Ar-N2 and Ar-H2 mixtures was investigated to clarify the recombination processes in the downstream region. Eventually, similar processes are responsible for the dissociation of deposition precursors. Moreover, the influence of the cathode-anode distance on the downstream electron temperature, which is responsible for the dissociation paths of the deposition precursors, was investigated. Insight into the dissociation paths of hexamethyldisiloxane, which is used for the deposition of a:SiOX-C,H films, and correlations with material properties will be presented.

SESSION KM1: NEGATIVE IONS & INSTABILITIES
Monday afternoon, 27 September 2004
Belfast Room, Bunratty Conference Centre at 16:00
Michael Katsch, University Duisburg-Essen, presiding

16:00

KM1 1 Instabilities in electronegative ICP-type discharges N. PLIHON, C. S. CORR, P. CHABERT, J.-L. RAIMBAULT, *LPTP, Ecole Polytechnique, France* A. J. LICHTENBERG, *EECS, UC Berkeley, USA* Electronegative ICPs are widely used for plasma processing. The stability of such discharges is a key problem to control the process and its reproducibility. We have studied the stability of an Ar/SF6 inductively coupled discharge originally designed for helicon operation. For most of the usual operating conditions, the discharge is unstable with strong modulation of the plasma parameters. Two different instabilities have been identified: source oscillations (E-H relaxation oscillations) [1] and downstream instabilities due to the opposite flows of negative and positive ions [2]. For the latter, spatial measurements show a narrow region (in the downstream region) of abrupt change in the time-averaged plasma parameters. This region is unsteady and separates a weak electronegative plasma (upstream) and a

high electronegative plasma (downstream). The dynamics of the fluctuations are currently investigated using time resolved probe measurements. [1] Lieberman *et al.* 1999 App. Phys. Lett **75** 3617
[2] Tuszewski *et al.* 2003 Phys. Plasmas **10** 539

16:15

KM1 2 Negative Ions in a Dual-Frequency Capacitive Plasma in $Ar/C_4F_8/O_2$ JEAN-PAUL BOOTH, GARRETT CURLEY, NICOLAS BULCOURT, SEBASTIEN DINE, *Laboratoire de Physique et Technologie des Plasmas, Ecole Polytechnique, Palaiseau, France (CNRS UMR 7648)* Dual-frequency capacitive plasmas in $Ar/C_4F_8/O_2$ gas mixtures are widely used for etching dielectric materials in integrated circuit manufacture. C_4F_8 is reported to be a highly electronegative gas [1] and therefore one would expect that negative ions could play an important role in this type of plasma. The presence of negative ions will modify the positive ion velocity at the sheath edge and therefore the positive ion flux arriving at a surface. We have attempted to directly measure the negative fluorine ion F^- density using broadband UV absorption spectroscopy, setting an upper limit on their density of $5x10^{11}cm^{-3}$. These measurements were complimented by measurements of the positive ion flux and the electron density. In conjunction with analytical models, these methods provide another avenue to determine the negative ion fraction. We acknowledge financial support from the Lam Foundation. [1] Kono et al, Jpn. J. Appl. Phys. (39) 2000, 1365-1368

16:30

KM1 3 Instabilities in Inductively Coupled Oxygen Plasma VANESSA RABALLAND, GILLES CARTRY, DAVID EON, CHRISTOPHE CARDINAUD, *IMN-LPCM, 2 rue de la Houssinire, BP 32229, 44322 Nantes cedex 03, France* In inductively coupled plasma, instabilities are observed when operating with electronegative gases, because the transition between capacitive and inductive modes does not occur at fixed power but on a range of power. We observed instabilities in oxygen for pressure between 5 and 20mTorr. Time resolved Langmuir probe has been used to record plasma parameters (ne, Te, Vp, eedf) during instability. For pure O2, O2-Ar (10variations are observed. Typically, electronic density varies by almost two orders of magnitude during the instability period. This confirms the oscillation between the E-mode with low densities, and the H-mode with higher densities. The electronic temperature presents also important variations. Electron energy distribution functions have been obtained. We studied the influence of pressure and source power on plasma parameters. Complementary measurements with planar probe are presently carried out to measure the exact time resolved positive ion flux. Negative ion fractions could then be determined.

16:45

KM1 4 Time Resolved Diagnostics During Low-Pressure Inductively Coupled Fluorocarbon Plasmas Instabilities GILLES CARTRY, VANESSA RABALLAND, DAVID EON, FREDDY GABORIAU, CHRISTOPHE CARDINAUD, *IMN-LPCM, 2 rue de la Houssinire, 44322 NANTES, BP 32229, France* Recently, many groups have observed instabilities in inductively coupled plasmas using electronegative gases such as O2, Cl2 or SF6. Until now, few work have been done concerning fluorocarbon plasmas (CHF3, C2F6, CF4). We observed that they can be strongly unstable and we suspect that it may affect plasma etching. For that reason, we started to characterize these instabilities, using a capacitive planar probe. This probe has the advantage to directly measure the ion flux, which is one of the most important parameter for dielectric etching in fluorocarbon plasmas, and to accurately operate even under polymerising environment. We showed that the capacitive planar probe can be efficiently used for time resolved measurements. Preliminary results indicate that the ion flux can be modulated by a factor 2 during the C2F6 instability period (to be compared with the factor 100 we measured for electron density modulation under oxygen plasma instabilities). We now use the measured ion flux to understand instability influence on plasma etching.

17:00

KM1 5 Stable and unstable regimes of a helicon discharge C.S. CORR, N. PLIHON, P. CHABERT, *LPTP, Ecole Polytechnique, France* Helicon plasma sources have generated much interest due to their ability to produce high etch rates and high selectivity. In this work we investigate a low-pressure Ar/SF6 helicon discharge. When gradually increasing the SF6 fraction, the plasma transport processes are drastically changed and the discharge becomes unstable. Due to the presence of an axial dc magnetic field (needed for helicon wave excitation) the radial profiles are such that the discharge is separated into two regions: an electron-ion plasma core surrounded by an ''ion-ion'' plasma. Instabilities similar to those observed in an ICP discharge with a diffusion region are present [1]. However, the instability window in the pressure-power space is greatly reduced by the magnetic field. Both instabilities and transport properties are investigated by time-averaged and time-resolved measurements of the radial and axial distributions of the charged particles, plasma potential and electron temperature. Theoretical work is currently underway to gain insight into the experimental observations. [1] Tuszewski M. 2003 Phys. Plasmas 10 539

17:15

KM1 6 Why it is Better to run an RF Plasma Generator/ Matching Network Unmatched, or How to make a More Stable Matching Network/RF Plasma JOHN H. KELLER, *K2 Keller Consulting, LLLC* Most of us have been led to believe that RF plasma generators and matching networks should be run in a matched condition with near zero reflected power. In many cases this can lead to unstable operation, plasma oscillation and variable etch conditions. It will be shown that operating with more reflected power, but such that when the plasma density is reduced the system approaches a matched condition, is much more stable and reduces plasma oscillations. A number of ways to achieving this will be discussed. In addition this method increases the net forward power when the plasma starts and allows the system to operate at lower pressure. This is because of the increased stability even at low efficiencies.

SESSION KM2: MATERIAL PROCESSING IN LOW PRESSURE PLASMAS I
Monday afternoon, 27 September 2004
Dublin Room, Bunratty Conference Centre at 16:00
Jong W. Shon, Lam Research Corporation, presiding

16:00
KM2 1 Mass Spectroscopy during Inhibitor Film Desorption from a cryogenic etching process REMI DUSSART, *GREMI* LAWRENCE OVERZET, *PAL/University of Texas at Dallas* XAVIER MELLHAOUI, *GREMI* THOMAS CHAILLOU, *GREMI* ANTOINE PROUET, *GREMI* THOMAS TILLOCHER, *GREMI* PHILIPPE LEFAUCHEUX, *GREMI* PIERRE RANSON, *GREMI* GREMI/ORLEANS TEAM, PAL/UNIVERSITY OF TEXAS AT DALLAS COLLABORATION Cryogenic etching of deep silicon trenches can be used for a wide variety of MEMS and electronic device applications. The process involves taking a wafer to roughly -100 C; and as a result, an ordinarily isotropic SF6-O2 etch process can be made to etch extremely anisotropically. The etch process is thought to proceed according to an ion enhanced inhibitor mechanism, with the inhibitor film coating the sidewalls only because of the extremely low temperatures. The etch process is also remarkably clean because the inhibitor film desorbs as the wafer temperature rises, leaving behind a very clean surface. We have made (and are making) measurements of the evolution of this inhibitor film using mass spectroscopy and ellipsometry with the goal of determining both the identity of the inhibitor film molecule(s) and the temperature(s) at which it desorbs. To accomplish this, we performed etches under well defined conditions then closed off the reactor chamber and measured the mass spectra as the wafer temperature was raised. We saw signals from many masses rising faster than the pressure during this process, with the most dramatic rise occurring around -80 C for mass 85 amu (SiF3). The data are still being collected, and so a final conclusion is not yet possible, but silicon-fluorides themselves may be integral to the inhibitor film.

16:15
KM2 2 Methodology for Predicting Trench (Gap-) Fill Profiles in High Density Plasma CVD RON KINDER, *Novellus Systems* GEORGE PAPASOULIOTIS, *Novellus Systems* PRAMOD SUBRAMONIUM, *Novellus Systems* High-density plasma CVD (HDP-CVD) reactors are used to provide void-free gap fill of high-quality dielectric films in high aspect ratio device structures. However, the ability to accurately model an HDP-CVD tool remains a difficult challenge due to the complex coupling of power deposition and plasma transport in a CVD chamber. Furthermore, the ability to predict gap-fill profiles not only depends on the ability to accurately model bulk chamber characteristics, but also on the accuracy of the reaction mechanism used to model the chemistry of deposition and sputtering in the feature. To investigate issues related to power deposition and electron transport, we have used the Hybrid Plasma Equipment Model (HPEM) to simulate the chamber conditions. The magnitude and angular energy distributions of the incident fluxes to the wafer from the HPEM are then used as input conditions for the Monte Carlo Feature Profile Model (MCFPM) to simulate trench filling. The coupling between bulk HPEM and MCFPM is through the sticking coefficients on the wafer surface for bulk depositing species. Results of trench profiles for process gases (SiH4/O2/He) at low pressures (< 15 mTorr), operating at a few kWs of input power, and varying bias are discussed. The results agree with experimentally observed trends and indicate that the formation of voids strongly depends on the ratio of sputter to deposition rate.

16:30
KM2 3 Topography Profile Simulation on High Aspect Ratio Oxide Contact Hole Etching: Evolution of Bowed Profiles YOUNG-KYU CHO, *Samsung Electronics Co. LTD* SUNG-IL CHO COLLABORATION, CHEOL-KYU LEE COLLABORATION, YE-RO LEE COLLABORATION, TAI-KYUNG KIM COLLABORATION, KYEONG-KOO CHI COLLABORATION, CHANG-JIN KANG COLLABORATION, HAN-KU CHO COLLABORATION, JOO-TAE MOON COLLABORATION As design rules of ULSI shrink beyond 100nm generation, plasma etch technology for high aspect ratio (HAR) oxide contact holes has confronted to several critical issues such as insufficient oxide selectivity to photoresist, etch-stops, contact hole bottom distortion, bowed profiles etc. Among the above issues, the profile-bowing, especially, is the most critical challenge because the bowed profiles of HAR Contact holes spaced closely with a small pitch may touch to the neighboring contact holes at the position around the bowing of the profiles. The hole-to-hole touch can be even worse because we have to clean the wafer with F-based wet chemicals prior to filling the plug materials into the contact holes. In this study, the reduction of profile bowing is carried out by understanding of the oxide contact hole etch mechanism. The formation of bowed profile was analyzed in a mechanisms point of view using Topography simulation which employs the newly developed oxide contact hole etching models. The radical flux in the new model was separated into two radical fluxes, the CxFy Radical flux and the Fluorine/Oxygen radical flux. The evolution of the bowed profile is caused by the insufficient sidewall polymer protection around the position of the bowing corresponding to Radical Depletion Region (RDR) of the new model. One of the possible RDR mechanism is based on the distribution difference between radicals flux in the contact holes, such as Fluorine, Oxygen, Carbon, CxFy etc, along the depth of the hole. The cathode temperature has been turned out to be a critical parameter for bowing reduction. In the experiment, as the wafer temperature increases, the profile bowing was decreased drastically due to the reduction of sticking coefficient of radicals without significant change of other process performance, which is also predictable by the Topography simulation with the RDR model.

16:45
KM2 4 XPS and Real Time Ellipsometric Investigation of Plasma Nitridation of Silicon and its Chemistry for GaN Growth T. ISHIJIMA, T. OKADA, Y. HONDA, H. SUGAI, *Nagoya University, Japan* A mask layer of SiO_2 film has been used as a mask layer in the fabrication of Gallium Nitride (GaN) field emitter arrays by selective Metalorganic Vapor Phase Epitaxy. However, oxygen contamination, dislocation and the bending of crystalline axis due to the stress between SiO_2 and GaN occur during the growing process of GaN. In order to avoid these drawbacks, plasma nitridation of silicon (111) substrate was investigated for alternative of SiO_2 mask layer or for application to a buffer layer between GaN and Si. The purpose of this work is to understand the behavior of nitrogen atoms and ions in rare-gas based high density plasma. Plasma nitridation was performed in Surface Wave Plasma reactors with in-situ ellipsometer. The thickness of Si-nitridation layer and its atomic composition were measured by X-ray Photoelectron Spectroscopy (XPS) for various

parameters such as discharge power, pressure, gas mixture ratio (Ar, He, N_2) and substrate temperature. Optical Emission Spectroscopy (OES) was used to obtain an insight into the plasma chemistry. Preliminary OES measurements suggest that $N(^2P)$ intensity increase with the discharge power, however N_2^+ intensity is saturated at 700 W for the mixing ratio $Ar/N_2=1$ at 100 mTorr.

17:00

KM2 5 Plasma etching of SiO_2 and Si_3N_4 with NF_3/C_2H_4–A new approach to reduce global warming gas production P. MACHIMA, N. HERSHKOWITZ, *Center for Plasma-Aided Manufacturing, University of Wisconsin - Madison* Plasma etching of SiO_2 in the fabrication of semiconductor devices is normally achieved by using a fluorocarbon gas to produce: fluorine for chemical etching; a very thin steady-state intermediary film deposited on the surface being etched; and energetic ions. Unfortunately the byproducts of this process are strongly global warming gases. Here we report the first results of experiments designed to provide fluorine for etching and carbon for thin film formation from separate parent gases. Varying wafer bias frequency and the source input power provides control of ion energy distribution functions. High-density low-pressure inductive plasma was used to study SiO_2 and Si_3N_4 etching with NF_3/C_2H_4-based feed gas chemistry. Thus far etch rates of SiO_2 over a wide range of conditions are roughly 0.6 times those of Si_3N_4 etch rates. Attempts to establish likely etching mechanisms from ex-situ X-ray photoelectron spectroscopy data will be discussed. Work Supported by US EPA grant no. RD-83145901-0

17:15

KM2 6 Precision CD control for sub-90nm nitride hard mask etching using integrated optical CD measurements J. W. SHON, *Lam Research Corporation* Y. J. JUNG, K. J. MIN, *Samsung Electronics Corp.* LAM RESEARCH DIELECTRIC ETCH COLLABORATION, SAMSUNG R & D COLLABORATION Latest trend in small feature size semiconductor processing is the use of advanced process control based on on-wafer metrology data. Feature size is small enough that the fine tuning of the baseline process is now required for every wafer, which is based on the real measurements of that particular wafer. Advanced process control based on wafer by wafer metrology data will be the differentiator for high-end semiconductor equipment market. For sub-90nm DRAM manufacturing, precision CD control based on integrated optical CD measurements is strongly required for nitride hard mask etching. In this paper, we will review principles of how optical CD and thickness measurements are performed and compared to SEM and CDSEM data. Then, we will show the CD control capability of the current sub-90nm nitride hard mask etching based on integrated optical CD measurements.

SESSION LT1: BIOLOGICAL AND EMERGING APPLICATIONS OF PLASMAS
Tuesday morning, 28 September 2004; Belfast Room, Bunratty Conference Centre at 8:30
Nick Braithwaite, The Open University, presiding

Invited Papers

8:30
LT1 1 Electron Interactions with Biological Molecules and their Clusters.
KIT BOWEN,* *Dept. of Chemistry, Johns Hopkins University, Baltimore, MD 21218, USA*

The interactions of low energy electrons with biological molecules and assemblies of such molecules are known to play important roles in several life processes, and they are probably important in many more. Using negative ion photoelectron spectroscopy, we have prepared and studied the anions of biological molecules and clusters composed of nucleic acid bases, solvated nucleic acid bases, halouracils, a nucleic acid base pair, zwitterions of amino acids, zwitterions of hydrated amino acids, and several dimer anions, each of which is composed of a nucleic acid base and a proton donor. These systems will be discussed in terms of dipole binding of excess electrons, competition between dipole binding and valence anion formation, solvent stabilization of otherwise unstable anions, and barrier-less proton transfer, as appropriate.

*Calculations by M. Gutowski have contributed to the interpretation of some of these species.

9:00
LT1 2 Resonances and Bond-breaking in Bio-molecules.
PAUL D. BURROW, *Department of Physics and Astronomy, University of Nebraska-Lincoln, Lincoln, NE 68588-0111*

Stimulated in part by observations of DNA strand-breaking by slow electrons, collision processes with small molecules of biological interest are generating considerable activity. The DNA bases, the RNA base uracil and the halo-uracils have received the most attention, with sharp structures evident in the total scattering cross sections and in the dissociative attachment decay channels. Because these molecules have large dipole moments, their negative ion spectroscopy is quite rich and displays structure arising from vibrational Feshbach resonances as well as shape resonances from occupation of valence orbitals. The use of these gas phase results to interpret DNA strand-breaking is challenging, but a possible scenario will be described. Future advances in this field require a constructive mix of quantum chemical structure calculations, scattering theory and some innovative means to put bio-molecules into the gas phase without decomposition.

Contributed Papers

9:30
LT1 3 ECR Plasma Sterilisation, Argon and Nitrogen Treated Plasma SELCUK HELHEL, *T.C. Süleyman Demirel Üniversitesi* LUTFI OKSUZ, *T.C. Süleyman Demirel Üniversitesi* OSMAN CEREZCI, *T.C. Süleyman Demirel Üniversitesi* ABBAS Y. RAD, *T.C. Süleyman Demirel Üniversitesi* ECR type plasma system was built to produce plasma in axial direction. Plasma was initiated in a specially designed Nickel Chrome cylindrical vacuum tube which is being driven through dielectric window by 2.45GHz commercial magnetron source. Tube is also surrounded by a coil driving 150ADC to generate approximately 875Gauss magnetic field at the center. Langmuir probe and ICCD for optical spectrometry were used to characterize internal parameters like electron density, electron temperature and different characteristics of the plasma. Bacillus Subtilis var nigar, bacillus Stearothermophilus, bacillus pumilus E601, Escherichia coli and staphylococcus aureus type bacteria were selected as a reference. Each is resistant for different actions while the Bacilus cereus is the most resistant bacteria for microwave interaction. This study presents the effect of system on used bacteria. Those are gram positive and gram negative bacteria that refers to structure of cell wall. The sterilization efficacy of Argon type ECR plasma was found to be over 99, 5 Staphylococcus aureus, Staphylococcus epidermidis, Bacillus subtilis (vegetative cell), Bacillus cereus (vegetative cell), Bacillus pumilus and Escherichia coli. System response type is less than 2 minutes.

9:45
LT1 4 Effect of Plasma Pretreatment on the Adhesion of Biocompatible Films on 316L Stainless Steel Deposited by Plasma Enhanced Chemical Vapour Deposition of HMDSO RAM PRASAD, *National Centre for Plasma Science and Technology, Dublin City University* STEPHEN DANIELS, *National Centre for Plasma Science and Technology, Dublin City University* DAVID CAMERON, *National Centre for Plasma Science and Technology, Dublin City University* BRIAN McNAMARA, *National Centre for Sensor Research, Dublin City University* The adhesion of biocompatible, silica-like thin films prepared by plasma enhanced chemical vapor deposition (PECVD) of HMDSO and Oxygen mixtures can be improved with the plasma pretreatment of medical grade 316L stainless steel. In this study the PECVD process is characterized in order to achieve optimal adhesion while preserving an acceptable level of biocompatibility. The individual effects of plasma pretreatment process parameters such as Oxygen/Argon

gas ratios, applied rf power, process pressure, and pretreatment time are investigated. Surface characterization techniques, including Fourier Transform Infra Red (FTIR) spectroscopy and X-Ray diffraction (XRD), are used to explain the underlying mechanisms affecting the adhesion.

SESSION LT2: PLASMA SURFACE INTERACTIONS
Tuesday morning, 28 September 2004
Dublin Room, Bunratty Conference Centre at 8:30
Richard Engeln, Technical University Eindhoven, presiding

8:30
LT2 1 Surface recombination of O and H atoms in the discharge conditions DMITRIY LOPAEV, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* ALEXEY SMIRNOV, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* The investigation surface recombination of atoms on a chemically inert surface directly in the discharge is one of the experiments that allows to insight into the detail mechanisms of complicated surface kinetics in plasma conditions. To provide accordance between micro- and macro-parameters, i.e. to develop a correct model of surface processes and thereby to determine micro-parameters themselves, it is necessary carry out enormous number of measurements. We have developed a modulating actinometry method allowing us to measure surface loss probabilities of atoms and radicals as functions of various macro-parameters (surface temperature, gas composition and pressure, atom density etc.) in thousands data points for reasonable time. In this work the O and H atom recombination on a fused silica surface in the discharge conditions is studied. The analysis of the experimental data has allowed us as to reveal detail mechanism of atom recombination on a surface and to clarify role of Eley-Rideal and Langmuir-Hinshelwood recombination as to determine values of some important micro-parameters such as chem- and phys- adsorption energies, activation energies and rate constant of some surface reactions with O and H atoms. The relation of obtained results with nature of active surface sites is also discussed.

8:45
LT2 2 Multiscale Modeling of the Treatment of Polymer Films Using Atmospheric Pressure Pulsed Coronas* ANANTH BHOJ, *Dept. Chem. and Biomolecular Engr., University of Illinois at Urbana-Champaign* MARK J. KUSHNER, *Dept. Elect. and Comp. Engr., University of Illinois at Urbana-Champaign* Atmospheric pressure plasmas are used to treat polymer surfaces to impart desired properties such as adhesion and wettability. Plasma produced radicals functionalize the polymer surface creating favorable chemical groups and modifying the surface energy. Commercial reactors use pulsed corona-like plasmas in a dielectric-barrier configuration with gap spacings of a few mm whereas the polymer layer being modified is 10s nm thick. Multiscale modeling techniques have been developed to investigate functionalization of polymer surfaces in such systems. A 2-d plasma hydrodynamics model using unstructured meshes has been integrated with a plasma chemistry surface site-balance model which is implemented along the polymer surfaces exposed to reactant fluxes from the plasma. The model has been applied to the treatment of polypropylene using humid air and nitrogen plasmas while resolving individual strands of the polymer ($< 1\ \mu$m); and deposition of biocompatible films. Results for evolution of gas phase species and densities of surface functional groups, and their variation with pressure, humidity and energy deposition will be presented.

*Work supported by National Science Foundation

9:00
LT2 3 Plasma Surface Interactions Common to Advanced Fusion Wall Materials and EUV Lithography - Lithium and Tin D.N. RUZIC, D.A. ALMAN, B.E. JURCZYK, R. STUBBERS, M.D. COVENTRY, M.J. NEUMANN, W. OLCZAK, H. QIU, *University of Illinois, Urbana, IL 61801* Advanced plasma facing components (PFCs) are needed to protect walls in future high power fusion devices. In the semiconductor industry, extreme ultraviolet (EUV) sources are needed for next generation lithography. Lithium and tin are candidate materials in both areas, with liquid Li and Sn plasma material interactions being critical. The Plasma Material Interaction Group at the University of Illinois is leveraging liquid metal experimental and computational facilities to benefit both fields. The Ion surface InterAction eXperiment (IIAX) has measured liquid Li and Sn sputtering, showing an enhancement in erosion with temperature for light ion bombardment. Surface Cleaning of Optics by Plasma Exposure (SCOPE) measures erosion and damage of EUV mirror samples, and tests cleaning recipes with a helicon plasma. The Flowing LIquid surface Retention Experiment (FLIRE) measures the He and H retention in flowing liquid metals, with retention coefficients varying between 0.001 at 500 eV to 0.01 at 4000 eV.

9:15
LT2 4 Investigation of DBD for Fabrics Depending on Experimental Parameters SUNDUZ KORKMAZ, *T.C. Süleyman Demirel Üniversitesi* LUTFI OKSUZ, *T.C. Süleyman Demirel Üniversitesi* FATMA GOKTEPE, *T.C. Süleyman Demirel Üniversitesi* SELCUK HELHEL, *T.C. Süleyman Demirel Üniversitesi* EVREN KATI, *T.C. Süleyman Demirel Üniversitesi* The presence of scale on a wool and cotton fiber surface introduces a number of problems such as felting and a surface barrier to dyestuffs in the wool and cotton industry. In the past, chemical methods were the major treatment for eliminating those problems. However, the effluents generated from wool and cotton dyeing and finishing processes are seriously contaminated with different kinds of chemicals, e.g. chlora-organic compounds from the anti-felt process. With the increasing of ecological and economical restrictions imposed on the textile industry, the industries were required to find environmentally favorable alternatives in wool and cotton treatment processes. Dielectric barrier discharge (DBD) is one of the treatment methods. The results of the surface treatment, using an atmospheric pressure dielectric barrier discharge (DBD), of wool and cotton in order to establish the most suitable conditions for textile treatments, are presented. Surface treatments will be performed with different applied voltages, different gap sizes, different thicknesses of dielectric at atmospheric pressure of air conditions. Scanning Electron Microscope (SEM) will be used to detect the physical surface changes on the samples. Surface luster, wet ability, dye ability of specimens will be presented. Breaking extension for cotton is increased by about 21% in length from 14.4mm by DBD and about 27% in length from 14.4 to 18.254 by ECR. ECR modified samples are more strength than DBD applied. Hydrofility for cotton is also increased.

9:30
LT2 5 Modification of polyethylene terephthalate track membrane properties by ammonia plasma LYUBOV KRAVETS, SERGUEI DMITRIEV, *Joint Institute for Nuclear Research, Dubna, Russia* GEORGE DINESCU, *National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania* ANDRADA LAZEA, ERIC RAICIU, *National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania USA* The properties of polyethylene terephthalate track membranes (PET TM) exposed to ammonia are investigated. The influence of the conditions of plasma treatment on the basic characteristics of the membranes, namely pore size and shape, wettability, water permeability, is studied. PET TM of the thickness of 10 μm with the effective pore diameter of 0.215 μm (pore density $2 \cdot 10^8$ cm^{-2}) were under study. The plasma treatment was performed on a plasma-chemical installation realizing a RF-discharge on the frequency 13.56 MHz. The process was conducted in a dynamic mode. Before delivering vapours of the plasma forming gas, the chamber was beforehand vacuumed down to residual pressure of 10^{-2} Torr. One side of the membranes was subjected to plasma. The discharge parameters (gas pressure in the vacuum chamber, discharge power) and the duration of plasma action were varied. It has been figured out that when treating the membranes in plasma of the explored gas there are two competing processes: etching of a polymeric matrix and deposition of a polymeric layer on their surface. It has been shown that at a short time of plasma action and low values of the discharge parameters, an etching process is mainly observed. Decrease in the thickness of the membranes and increase in the effective pore diameter testifies it. A result of the gas-discharge etching is also a hydrophilization of the TM surface stipulated by formation of polar function groups in the points of breaking chemical bonds. Here the value of the water contact angle of surface decreases down to 45-50 degrees in some cases. It has been shown that at a longer action of the plasma and increase of the discharge parameters, as accumulation in the chamber of etch products takes place, a process of deposition of a polymeric film becomes dominating, and it is proved by increasing the width of the membranes and changing their color. The value of the water contact angle of surface in this case is grown and, depending upon the discharge parameters and the duration of the plasma action, will be 80-110 degrees. It has been noted that the modification of the TM properties results in changing their hydrodynamic characteristics. It has been found that the water permeability (both the initial value and change of the flow in time) of the membranes treated in plasma substantially depends upon their surface properties.

9:45
LT2 6 Etching of titanium nitride electrode for DRAM capacitors of high capacitance SUNG-IL CHO, JONG-KYU KIM, KYEONG-KOO CHI, CHANG-JIN KANG, HAN-KU CHO, JOO-TAE MOON, *Samsung Electronics Co. LTD* As design rules of DRAM shrink, metal electrodes for capacitors to achieve high capacitance are required. Among the proposed metal electrodes, TiN has attracted much interest due to the chemical stability and good electrical properties. However, the absence of the node formation method for TiN electrode restricts the introduction of MIM capacitor. In this work, we fabricated the MIM capacitor with TiN electrode with a structure of cylindrical stack. Especially, the node separation process of TiN electrode is deeply studied using CF4/O2 and Cl2/Ar chemistries in an ICP chamber. In a Cl2/Ar chemistry, TiN is etched at room temperature because the Cl radicals easily react with TiN forming volatile products such as TiClx and NClx. However, the etched profile has a sharp point at the top of the electrode node caused by the spacer-shaped profile along the sidewall of the hole. A capacitor having such a sharp point could have characteristics of high leakage degrading the data retention time. On the other hand, in a CF4/O2 chemistry, TiN can be etched at specific condition because the etch product, TiFx, is nonvolatile at room temperature. The profile etched with the CF4/O2 chemistry shows an isotropic etched shape without any sharp point at the top of electrode nodes. The rounded top of the electrode shows good electrical properties showing low leakage current. However, certain byproducts may remain on the SiO2 surface with the CF4/O2 process. From the analysis of gas phase reaction by OES, we found that the etching of SiO2 is accelerated during the byproduct formation. It is found that the power is the most effective parameter to determine the amount of the byproducts. We also found the robust process window without any byproducts under a certain threshold power.

SESSION MT1: PLASMA BOUNDARIES
Tuesday morning, 28 September 2004
Belfast Room, Bunratty Conference Centre at 10:30
Ralf-Peter Brinkmann, Ruhr University Bochum, presiding

10:30
MT1 1 Magnetized Collisionless Plasma-Wall Problem* NATALIA STERNBERG, *Clark University* A model for the collisionless plasma-wall problem under the action of an applied magnetic field is developed. The plasma and the sheath are then modeled separately to obtain the position of the quasi-neutral plasma boundary and the position of the edge of the electron-free sheath. It is shown that the plasma boundary can be specified as the point where the component of the ion velocity normal to the wall reaches the ion sound speed (Bohm criterion), and the sheath edge can be specified as the point corresponding to Godyak's criterion for the electric field. Studying the behavior near the plasma boundary and the sheath edge, the plasma and the sheath solutions are patched together to approximate the solution of the plasma-wall problem.

*This work was done in collaboration with J. Poggie, Air Force Research Laboratory, Wright-Paterson AFB, OH, USA

10:45
MT1 2 Change of phases in the problem of ionization layer at the edge of a fully ionized plasma* N. A. ALMEIDA, *Departamento de Fisica, Universidade da Madeira, 9000 Funchal, Portugal* M. S. BENILOV, *Departamento de Fisica, Universidade da Madeira, 9000 Funchal, Portugal* R. N. FRANKLIN, *The Open University, Oxford OX1 5HR, UK* G. V. NAIDIS, *Institute for High Temperatures RAS, Moscow 127412, RF* The ionization layer separating a fully ionized low-temperature thermal plasma from the space-charge sheath adjacent to a solid surface (an electrode or a wall) is treated by means of the (multi)fluid model. The problem has different mathematical structure in different ranges of control parameters. A solution for some parameters has been found and it has been shown that known boundary conditions are insufficient to single out a unique solution for other parameters. An approximate approach which spans the whole range of control

parameters is suggested. While being incomplete theoretically, this approach is sufficient for practical purposes and gives results that are in agreement with the experiment. On the other hand, the question of how the mathematical problem should be closed remains open and challenging.

*The work was supported by the projects 32411/99 of the program POCTI of FCT and FEDER and NumeLiTe of the 5th Framework programme ENERGIE of the EC

11:00

MT1 3 Structures of sheath electric fields in electronegative Ar/SF_6 plasmas measured by laser-induced fluorescence-dip spectroscopy K. SASAKI, K. TAKIZAWA, A. KONO, *Nagoya University, Japan* The structure of sheath electric field in electronegative plasma is still an open question in discharge physics. In the present work, we measured the distributions of electric fields in the sheath region of electronegative Ar/SF_6 plasmas by laser-induced fluorescence-dip spectroscopy. The negative ion density was dependent on the partial percentage of SF_6, the rf power, and the total gas pressure. We measured the ratio of the negative ion density to the electron density ($\alpha = n_-/n_e$) by probe-assisted laser photodetachment using a XeCl excimer laser. In the discharge condition corresponding to $\alpha = 29$, we observed multistage structure in the electric field distribution in the sheath region. The electric field had steep decrease with the distance z from the electrode (from 400 V/cm at $z = 0.4$ mm to 150 V/cm at $z = 0.7$ mm). After the rapid decrease, the electric field was roughly constant at $0.7 \leqslant z \leqslant 2.3$ mm. Another steep decrease to 10 V/cm was observed at $2.3 \leqslant z \leqslant 2.7$ mm. The second rapid decrease was followed by a roughly constant electric field. This multistage structure may be attributed to the reflections of negative ions and electrons at distances of 2.5 mm and 0.5 mm from the electrode, respectively. The experimental result was compared with the distribution of electric field evaluated by a fluid model.

11:15

MT1 4 A modeling of functional separation in a 2f-CCP etcher —Effect of a bias frequency on the ion velocity distribution incident on a wafer TAKASHI YAGISAWA, *Keio University* TOSHIAKI MAKABE, *Keio University* Two frequency capacitively coupled plasma (2f-CCP) source is expected as a powerful tool for SiO_2 etching in the next generation. In our previous work, an independent control of a high-density plasma generation by VHF (100 MHz) and a high energy ion injection to a wafer by LF (1 MHz) has been presented [1]. Under these circumstances, typical ion velocity distribution (IVD) with nonlinear time-dependence at LF bias is shown [2]. In the present study, the influence of a bias frequency on the time-varying IVD of ions incident on a wafer is discussed in a 2f-CCP in $CF_4(5\%)/Ar$. With increasing a bias frequency up to RF (10 MHz), IVD is shifted to a time-averaged profile because massive ions cannot synchronize with the sheath field, modulated strongly in both time and space. In addition, the finite time delay of incident ion energy with respect to the instantaneous sheath field becomes larger. It is found that the bias amplitude must be decreased in order to achieve a functional separation, resulting in the reduction of impact ion energy incident on a wafer. [1] K. Maeshige et al, J. Appl. Phys., 91, 9494 (2002), T. Kitajima et a1, Appl. Phys. Lett. 77, 489 (2000) [2] T. Yagisawa and T. Makabe, IEEE Trans. Plasma Sci., 31, 521 (2003)

11:30

MT1 5 A Wholly Kinetic, Quasineutral Plasma Model* RICHARD FERNSLER, *Plasma Physics Division, Naval Research Laboratory* Quasineutral models obtain the electrostatic field in the plasma interior without using Poissons equation. These models are useful, if not essential, in dense plasmas that vary slowly in space and time relative to the plasma Debye length, plasma frequency, and plasma conductivity. Quasineutral field equations are usually derived, even for kinetic treatments, by setting the charge density to zero in the fluid equations. For example, a common approximation is the Boltzmann relationship proposed by Langmuir. In this talk, a fully kinetic quasineutral model is proposed, based directly on Gausss law. The resulting quasineutral field equation provides new insight on the limitations and basis of quasineutrality, and it leads directly to the Bohm condition but without the singularities plaguing earlier analyses. The same approach can be used for fluid models, and the kinetic version can be used to improve those models by eliminating certain singularities.

*Work supported by the Office of Naval Research

11:45

MT1 6 Multi-frequency Sheath Dynamics STEVEN SHANNON, *Applied Materials* ALEX PATERSON, *Applied Materials* THEODOROS PANAGOPOULOS, *Applied Materials* DANIEL HOFFMAN, *Applied Materials* JOHN HOLLAND, *Applied Materials* DENNIS GRIMARD, *The University of Michigan* Dual frequency capacitive discharges have become the new standard in dielectric etch processing. Typically, frequencies are selected such that bulk plasma dissociation and plasma sheath dynamics can be independently controlled. Recently, dual frequency development has focused on the interaction of the two frequencies in the sheath surrounding the plasma. This presentation focuses on the dynamics of a discharge, with particular focus on the sheath above a powered electrode, for complimentary frequencies ranging from the typical high frequency / low frequency combinations seen in process systems to more novel frequency combinations where the interaction of the two RF waveforms results in a system where the frequency decoupling assumption typically used is no longer valid.

12:00

MT1 7 Electron heating by vibrationally excited molecules in the afterglow of a pulsed, inductively coupled Hydrogen plasma MARIANA OSIAC, BRIAN G. HEIL, TIMO GANS, UWE CZARNETZKI, *Institut für Plasma- und Atomphysik, Ruhr-Universität Bochum, Germany* THOMAS SCHWARZ-SELINGER, *Max-Planck-Institute for Plasma Physics, Garching, Germany* DEBORAH O'CONNELL, MILES TURNER, *Plasma Research Laboratory, Dublin City University, Dublin, Ireland* Vibrationally excited molecules are able to heat electrons and act as a reservoir of energy in the afterglow of pulsed discharges. In a Hydrogen afterglow, time resolved ion energy distribution functions were measured at the grounded electrode of a pulsed, inductively coupled GEC Cell. H_3^+ ions had a constant energy of the order of eV for several hundreds of micro seconds depending upon discharge conditions. The corresponding sheath potential is caused by the heating of electrons in the afterglow. A PIC simulation confirms electron heating via superelastic collisions with vibrationally excited molecules. The vibrational temperature of H_2 was measured using OES. An analysis of the electron particle balance,

which assumes that the inelastic scattering off of vibrational states is dominant at lower energies, predicts a two temperature structure for the EEDF. Langmuir probe measurements in the after glow confirm this structure. The work is supported by the DFG in the frame of the SFB 591.

12:15

MT1 8 Experimental and theoretical investigations of electron sheaths L. OKSUZ,* *University of Wisconsin-Madison, USA* N. HERSHKOWITZ, *University of Wisconsin-Madison, USA* Electro-negative potential plasmas are obtained by electron injection into a multi-dipole plasma from a hot thoriated tungsten filament biased at different voltages. Langmuir probes and emissive probes are used to investigate the plasma characteristics. The electron injection into the plasma changed the plasma potential, electron temperature, and plasma density. Electron sheaths are obtained by biasing a boundary plate 12 cm diameter positively with respect to the plasma potential. Presheath like potential profiles and potential dips are found outside of the electron sheath and their characteristics are measured. The experimental and theoretical presheath and sheath properties of plasma with plasma potentials more negative than the conducting boundary potential plasmas will be provided. Work Supported by US DOE grant no. DE-FG02-97ER 54437.

*Present Address: Dublin City University, Ireland

SESSION MT2: CAPACITIVELY COUPLED DISCHARGES

Tuesday morning, 28 September 2004
Dublin Room, Bunratty Conference Centre at 10:30
Philip Steen, Dublin Room City University, presiding

10:30

MT2 1 Potentials and fields in a 300-mm dual-frequency reactor PAUL A. MILLER, EDWARD V. BARNAT, GREGORY A. HEBNER, *Sandia National Laboratories* ALEX PATERSON, JOHN HOLLAND, THORSTON LILL, *Applied Materials* Dual-frequency reactors employ source rf power supplies to generate plasma and bias supplies to extract ions. There is debate over choices for the source and bias frequencies. Higher frequencies facilitate plasma generation but their shorter wavelengths may cause spatial variations in plasma properties. Electrical nonlinearity of plasma sheaths causes harmonic generation and mixing of source and bias frequencies. These processes, and the resulting spectrum of frequencies, are as much dependent on electrical characteristics of matching networks and on chamber geometry as on plasma sheath properties. We investigated such electrical effects in a 300-mm Applied-Materials plasma reactor. Data were taken for 13.56-MHz bias frequency (chuck) and for source frequencies from 30 to 160 MHz (upper electrode). An rf-magnetic-field probe (B-dot loop) was used to measure the radial variation of fields inside the plasma. We will describe the results of this work. This work was supported by Applied Materials and by Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energys National Nuclear Security Administration under contract DE-AC04-94AL85000.

10:45

MT2 2 Influence of frequency on the characteristics of VHF capacitively coupled plasmas in a 300 mm chamber G. A. HEBNER, E. V. BARNAT, P. A. MILLER, *Sandia National Laboratories* A. PATERSON, J. HOLLAND, T. LILL, *Applied Materials* We have investigated the characteristics of VHF capacitively coupled plasmas produced in a modified Applied Materials chamber. The chamber had a 14-inch diameter upper electrode (source) that was driven at 10 to 160 MHz and a 300 mm diameter electrostatic chuck with a ceramic process kit that was driven at 13.56 MHz (bias). Diagnostics employed include a microwave interferometer to measure the line-integrated electron density, a hairpin microwave resonator to measure the spatially resolved electron density, absorption spectroscopy to determine the argon metastable temperature and density, laser induced fluorescence (LIF) to determine the spatial distribution of the excited species, and spatially resolved optical emission. We found that for constant source rf power, the electron density increased with rf frequency. The argon 1s5 metastable temperature was slightly above room temperature (300 400K), significantly cooler than our previous measurements in inductively coupled plasmas. The metastable density was not a strong function of source frequency or rf power. The metastable spatial distribution was always peaked in the center of the chamber and had a weak dependence on frequency. Scaling of the plasma parameters with frequency, power and pressure, and implications to energy deposition models will be discussed. This work was supported by Applied Materials and Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energys National Nuclear Security Administration under contract DE-AC04-94AL85000.

11:00

MT2 3 Measurements and Modeling of Plasma Parameters in Frequency Mixed Capacitive Plasmas ALEX PATERSON, *Applied Materials* THEODOROS PANAGOPOULOS, *Applied Materials* VALENTIN TODOROW, *Applied Materials* JOHN HOLLAND, *Applied Materials* THORSTEN LILL, *Applied Materials* The use of the combination of two RF frequencies for RIE and MERIE plasma reactors provides significant benefits over conventional single frequency reactors. Unlike ICP systems wherein the plasma characteristics is largely independent of excitation frequency, the capacitively coupled plasma characteristics are very strongly influenced by the RF waveform. In this regard, the role of different frequency combinations for a dual frequency capacitively coupled plasma source is examined. Langmuir probe measurements of plasma densities and electron energies for both single and dual frequency plasmas show that both the spatial distribution and electron energy distribution function (EEDF) are distinctly different. Similarly, the delivery of the rf frequencies to the chamber, either being applied together through the bias cathode or independently through a bias / source arrangement will produce different plasma results. Capacitive plasmas produced in Argon by radio frequencies ranging form 2MHz to 100MHz have been investigated using electrical and optical diagnostics and the observed plasma parameter trends will be shown. Additionally, the effect the mixing of two RF frequencies on the sheath voltage has been both experimentally measured and calculated using a simple analytical sheath model. Implications of the effect of frequency mixing on the plasma processing of wafers will also presented.

11:15
MT2 4 Tracking the sheath border position for single and dual frequency capacitively coupled plasmas sustained in hydrogen AUREL SALABAS, RALF PETER BRINKMANN, *Ruhr-University Bochum, Theoretical Electrical Engineering, D-44780 Bochum, Germany* Radio-frequency (rf) discharges operating in capacitively and inductively configurations are often the adopted industrial solutions for deposition and etching purposes in microelectronics. In the recent years, multi-frequency sources are used to achieve the *functional separation* of biasing and sustaining voltages in capacitively coupled plasmas (CCP). In this work, a recently developed fluid model [1] has been exploited for a comparative analysis of single and dual frequency capacitively coupled discharges. Within the frame of fluid formulation, an appropriate and practical definition is introduced to track the space-time dynamics of the sheaths in 1f- and 2f-CCP. The simulation results indicate that the velocity of the sheath expansion for a H_2 discharge operating at 13.56 MHz, p=0.5 Torr and V_{rf}=200 V is about $2.5 \cdot 10^7$ cms^{-1}. For 2f-CCP the calculations show that the modulations of the plasma potential by the high frequency voltage are transferred to the sheath border position. The magnitude of this modulation is stronger at the time moments when the sheath thickness is small. Such a behavior is justified by the presence of considerable electronic currents flowing toward the electrodes at that time moments. [1] A. Salabaş et al. *J. Appl. Phys.* 95/9 (2004), 4605.

11:30
MT2 5 Anomalous Heating in Capacitively Coupled Plasmas T. MUSSENBROCK, J. OPRETZKA, R. P. BRINKMANN, *Theoretische Elektrotechnik, Ruhr-Universität Bochum, D-44780 Bochum, Germany* In order to achieve a better ion energy control, there is a trend in plasma processing units to operate an capacitively coupled plasma in the low pressure regime. In this regime electron collisions are relatively rare and ohmic heating is no longer an effective mechanism of energy deposition to the plasma. But there is another mechanism of electron heating which sustains the plasma, i.e. the collisionless or anomalous heating. For this phenomenon no reliable interpretation has been given yet. The object of this contribution is to give a new line of sight to the anomalous heating mechanism in capacitively coupled plasmas. Based on a non-linear lumped circuit model the self-excited electron resonance is observed [1]. This damped (so called) plasma series resonance arises from the non-linear interaction of the current transport processes in the plasma boundary sheath and the plasma bulk. It is shown that the damping of this certain resonance is a measure for an anomalous heating mechanism in capacitively coupled plasmas, i.e. for decreasing pressure an increasing anomalous heating can be observed. [1] T Mussenbrock, Thesis, Ruhr-Universität, 2004

11:45
MT2 6 A Sheath Resolved Numerical Model for High Density Plasma with RF Bias NING ZHOU, *ESI US R&D, Inc* The high-density plasma ($\sim$ 1E+18 /m^3), such as that generated by inductive coupling, is characterized by the thin sheath whose width is sub-millimeter and more than 3-order smaller as compared with the overall dimension of the plasma. Traditionally the sheath is modeled analytically, or semi-analytically as the boundary condition for plasma, thus to avoid the numerical difficulties associated with the high disparity of grid size required to resolve the sheath. However, the accuracy issues incurred by the simplified sheath modeling prompted the recent study for the coupled plasma and sheath model (D. Bose et al., IEEE Trans Plasma Sci, vol.30, (2002) 653-659). In actual application of ICP in semiconductor industry, the plasma is usually RF biased under wafer. This RF bias, which was not considered in Bose et al. (2002), presents an even greater numerical challenge for coupled plasma/sheath modeling. This study is an attempt to tackle this challenge. The proposed numerical model is implemented in the commercial plasma simulation code CFD-ACE+. The drift-diffusion is assumed for electron while ion momentum is solved to account for the collisionless sheath. Numerical results will include 1-D simulation study of a RF biased high-density plasma, and a 2-D demonstration of Ar plasma in a typical ICP reactor with RF bias.

12:00
MT2 7 Sub millimeter absorption spectroscopy of oxygen containing fluorocarbon etching plasmas ERIC BENCK, KAREN SIEGRIST, *National Institute of Standards and Technology* The role of oxygen in fluorocarbon etching plasmas is investigated using sub millimeter wavelength absorption spectroscopy. The plasmas were created in a specially modified capacitively coupled Gaseous Electronics Conference (GEC) Reference Reactor with a commercial electrostatic chuck. Photoresist and SiO_2 blanket coated wafers were etched in $C_4F_8/O_2/Ar$, $C_5F_8/O_2/Ar$, and $C_4F_6/O_2/Ar$ discharges. The absolute density of various radicals (CF, CF_2, CHF_3, COF_2, CO, etc.) were measured as a function of the percentage of oxygen in the feed gas mixture using a sub millimeter source based on a 48x frequency multiplication chain. These results are also compared with $C_xF_y/O_2/Xe$ mixtures.

SESSION NT1: LASER DIAGNOSTICS
Tuesday afternoon, 28 September 2004; Belfast Room, Bunratty Conference Centre at 14:00
Paul Miller, Sandia National Laboratory, presiding

Invited Papers

14:00
NT1 1 Probing low temperature plasmas with diode lasers.
GUS HANCOCK, *Oxford University, Physical and Theoretical Chemistry Laboratory*

Laser diodes operating in the visible and near infrared region can be used to measure concentrations and energies of the active species present in low temperature plasmas. Here we describe recent experiments in inductively coupled RF plasmas which illustrate a variety of techniques: direct absorption, wavelength and frequency modulation, cavity en-

hancement methods, and the use of frequency doubling and mixing to extend the wavelength range into the UV and mid infrared. Examples given will concentrate on plasmas of Ar, Ne and nitrogen, with measurements on excited atomic and molecular states. Translational energies, and where appropriate rotational and vibrational energies are measured, and the absolute concentrations of the species compared with those predicted from modelling calculations which use measured electron energy distributions.

Contributed Papers

14:30

NT1 2 Visualized measurements of densities and velocities of Fe and Cu atoms in magnetron sputtering plasmas JUNSI GAO, NAYAN NAFARIZAL, *Department of Electrical Engineering and Computer Science, Nagoya University, Japan* KANJI SHIBAGAKI, *Suzuka National College of Technology, Japan* KOICHI SASAKI, HIROTAKA TOYODA, SATOSHI IWATA, TAKESHI KATO, SHIGERU TSUNASHIMA, HIDEO SUGAI, *Department of Electrical Engineering and Computer Science, Nagoya University, Japan* The distributions of densities and flight velocities of sputtered Fe and Cu atoms in magnetron sputtering plasmas were studied and compared by using laser-induced fluorescence (LIF) imaging spectroscopy. The dependences of the distributions of the sputtered atom densities on the input power and the gas pressure were investigated systematically. The expanding velocities of sputtered atoms, perpendicular and parallel to the target surface, were both measured and visualized according to Doppler shift effect, in which the velocities of sputtered atoms were determined by scanning the wavelength of an OPO laser having a power below the saturation level. In a low gas pressure of 3 mTorr, the velocity of Fe atoms was as high as 3.6 km/s in the region adjacent to the target surface. In addition, the comparison of the density distributions of Fe and Cu atoms shows that the high-density area of Cu is farer from target surface than that of Fe at a high gas pressure (60 mTorr) and a low gas pressure (3 mTorr). In the next step, we will investigate the influence of the density and the velocity of metal atoms on the interface of multilayer for high-density storage devices.

14:45

NT1 3 Surface dependant electric field structure and rf discharge excitation in argon E. V. BARNAT, *Sandia Nationla Laboratories* G. A. HEBNER, *Sandia Nationla Laboratories* We employed laser-induced fluorescence-dip (LIF-dip) spectroscopy to measure both spatial and temporal distributions of the electric field above various configurations of a planar, rf powered electrode. The electrode configurations included a metal-dielectric interface, a stepped interface and a dissimilar metal interface. The spatial maps of the electric fields became two-dimensional around the interface of the irregularities present on the surface of the electrode. Furthermore, spatial maps of 1s4 argon atoms and optical emission demonstrated that these irregular surfaces introduced a two-dimensional structure to the excitation of the discharge. We illustrate the dependence of the field and excitation structure on the discharge conditions and discuss mechanisms that may result in the observed profiles. This work was supported by the Division of Material Sciences, BES, Office of Science, U. S. Department of Energy and Sandia National Laboratories, a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energys National Nuclear Security Administration under contract DE-AC04-94AL85000.

15:00

NT1 4 A high sensitivity broad-band mode-locked cavity-enhanced absorption technique with a femtosecond laser E. ESLAMI, *University Joseph Fourier & CNRS* T. GHERMAN, *University Joseph Fourier & CNRS* D. ROMANINI, *University Joseph Fourier & CNRS* N. SADEGHI, *University Joseph Fourier & CNRS* A new high sensitivity absorption technique is developed which combines the multipass advantage of the cavity-enhanced absorption technique with the simultaneous acquisition over a broad spectral range of the classic broad-band absorption spectroscopy. Absorption spectra in the 400 nm range are acquired after the frequency doubling of a commercial tunable mode-locked Ti:Sa femtosecond laser in a BBO crystal. The technique is applied for the measurement of the density of metastable Ar*($^3P_2$) atom in a low pressure argon glow discharge, through its weakly absorbing 394.75 and 394.898 nm lines, and of N_2^+ ions in the Short-Lived-Afterglow of a flowing 440 Pa -wave nitrogen plasma, from absorption on the 1^- band of nitrogen around 391 nm. Rotational temperatures in the ground state of N_2^+ ions are 1300 K and 800 K in the discharge zone and in the maximum of the SLA, respectively. The absolute density of N_2^+ ions is much lower than the electron density measured by -wave interferometry and indicates that N_4^+ ions must be the dominant ions of the SLA.

15:15

NT1 5 Stark shifts and width of a hydrogen atom in Debye plasmas ANTHONY C.H. YU, *Institute of Atomic and Molecular Sciences, Academia Sinica, Taiwan* Y. K. HO, *Institute of Atomic and Molecular Sciences, Academia Sinica, Taiwan* Plasmas have been investigated since 1927 by Appleton and Altar, a large amount of data and reports have already been systematically and well documented in the literature. However, the effects of an atomic energy levels and resonances in the dense plasma environment under the external electric field of an isolated atom/ion are incomplete. It is clear that applying those atomic data for isolated atoms/ions to dense plasma environment may have some inaccurate effects. The effect would be physically interesting and intricate, even for the isolated ''simple'' hydrogen atom. Hence, it is vital to study the change of the atomic energy levels and resonances under an electric field for an atom imbedded in dense plasma environments. In this work we have employed the complex coordinate rotation method (CRM) which has been proved to be very successful to study atomic collisions and atoms in external electric fields [1,2,3]. The Debye screening potential has been utilized to simulate the plasma effects. The best optimize value is calculated and thus, there is a new data for the shortest screening length. A computational scheme has been developed and used to investigate the influence of the plasma environments for atomic auto-ionization by using CRM. The modified atomic auto-ionization under the electric field effects on the ground state of hydrogen in plasmas environments are reported here. Our field-free results are also compared with available data [4,5]. Reference [1] Y. K. Ho, Phys. Rep., 99, 1 (1983). [2] Y. K. Ho, Phys. Rev. A, 52, 375 (1995). [3] T.K. Fang and Y. K. Ho, Phys. Rev. A, 60, 2145,(1999). [4] L.B. Zhao and Y.K. Ho, Phys. of Plasmas, 11, 1695,(2004) [5] C. Stubbins, Phys. Rev. A, 48, 220 (1993)

SESSION NT2: COLD COLLISIONS
Tuesday afternoon, 28 September 2004; Dublin Room, Bunratty Conference Centre at 14:00
Don Madison, University of Missouri, Rolla, presiding

Invited Papers

14:00
NT2 1 Making Molecules at MicroKelvin.
WILLIAM STWALLEY, *University of Connecticut*

The cooling and trapping of atoms and atomic ions is a rapidly advancing field of fundamental science (e.g. Bose-Einstein condensation). We are attempting to extend the field to neutral molecules, e.g. for study of collisions in the highly quantum mechanical regime at extremely low energies. The UConn group has employed single- and multicolor photoassociation to produce translationally ultracold alkali dimers from ultracold alkali atoms confined in a magneto-optical trap. Photoassociation of ultracold atoms (as opposed to thermal atoms) includes sharp resonances with wavelength as long-range rovibrational levels (turning points of hundreds of Bohr) are accessed from colliding atomic pairs with 10 MHz of relative kinetic energy and in only a few partial waves. Potential energy curves derived from these spectra test calculations of interatomic potentials. The molecules formed are translationally ultracold and rotationally cold. The UConn group has used one- and two-color resonance enhanced multiphoton ionization to directly detect translationally ultracold molecules in the $X\ ^1\Sigma^+_{(g)}$ ground state and a $^3\Sigma^+_{(u)}$ excited state of $^{39}K_2$, $^{85}Rb_2$ and $^{39}K^{85}Rb$. These singlet and triplet molecules are formed in two different ways: (1) in intermediate to high vibrational levels following spontaneous emission from very high levels of the $A^1\Sigma^+_{(u)}$ state, formed in turn by one-color photoassociation of ultracold atoms; and (2) in low to intermediate vibrational levels (e.g. v = 0) via two-color photoassociation.

Contributed Papers

14:30
NT2 2 Collisions and Interactions in Ultracold Rydberg Plasmas RAYMOND FLANNERY, *Georgia Institute of Technology* DANIEL VRINCEANU, *Harvard University* A new branch of atomic physics with many applications—the interactions, dynamics and collisions in ultracold ($T \ll 1K$) systems—has naturally evolved from recent advances in the cooling and trapping of neutral gases. Cold Rydberg plasmas, wherein electrons and ions coexist with atoms $Ry(n\ell)$ in highly excited Rydberg states n,ℓ have been recently produced by laser ionization of atoms initially prepared at sub-millikelvin temperatures. Three-body recombination permits Rydberg production over a broad range of angular momentum states $\ell = n - 1, n - 2, \ldots, 2, 1, 0$. The plasma is maintained by electron-ionization, de-excitation and recombination. The variation of the ionization cros section with ℓ is therefore of key interest. In this paper, the full dependence of the cross sections on the initial angular momentum ℓ of Rydberg atoms is revealed, with interesting physical characteristics which are explained. Rates for three-body capture into state n,ℓ are then deduced from detailed balance. Analytic expressions for the ionization cross section are also derived within the classical impulse approximation and compared with the classical trajectory results.

14:45
NT2 3 Autoionizing Rydberg States of Argon and Xenon J. WRIGHT, M. VAN LIER-WALQUI, J. LAMBERT, H. FLORES-RUEDA, J. DISCIACCA, T. MORGAN, *Dept. of Phys., Wesleyan Univ., Middletown, CT* B. GRAHAM, *Dept. of Phys., Queen's Univ., Belfast, N. Ireland* Recently, Rydberg states have been shown to be present in the plasma of an Argon glow discharge [1]. Properties of Rydberg states in electric fields contribute to the overall behavior of the ion-electron plasma, converting, for example, free electrons into Rydberg electrons and vice versa. We are investigating the role of Rydbergs in low-temperature plasmas. An experimental study is in progress to ascertain the properties of autoionizing Rydberg states of Argon and Xenon atoms in electric fields. The study involves the use of laser-fast-beam Stark spectroscopy. The initial state is metastable, formed by 5 keV charge transfer collisions of singly charged ions with atomic potassium vapor. Final states are Rydberg autoionizing states that lie between the lowest fine structure thresholds. Photoabsorption spectra will be presented along with Fourier transformed recurrence spectra that provides a semiclassical analysis of the dynamics of these states. Supported by NSF and IRCEP. [1] R. Mason et al, Phys. Rev. 68, 16408 (2003)

SESSION PT1: POSTER SESSION III
Tuesday afternoon, 28 September 2004
Clonmoney, Fitzpatrick Bunratty Hotel at 16:00

PT1 1 INDUCTIVELY COUPLED PLASMAS

PT1 2 Effect of Oxygen Injection on Argon Induction Plasmas by Chemically Non-equilibrium Modeling NOBUHIKO ATSUCHI, MASAYA SHIGETA, TAKAYUKI WATANABE, *Reseach Laboratory for Nuclear Reactors, Tokyo Institute of Technology* Thermal plasmas have simply been used as a high temperature source. This indicates that thermal plasmas may have more capabilities in material processing, especially production of high-quality and high-performance materials, if thermal plasmas are

utilized effectively as chemically reactive gases. Therefore, characteristics of thermal plasmas with chemically reactive gas should be investigated. The purpose of this work is to investigate the effective injection location of oxygen into argon induction plasmas. A non-equilibrium modeling of argon-oxygen induction thermal plasmas was performed without chemical equilibrium assumptions. The thermofluid and concentration fields were obtained by solving of two-dimensional modeling. Chemical reaction kinetics rates of the dissociation and recombination as well as the ionization were taken into account in this modeling. The transport properties were estimated using Chapman-Enskog method with higher order of Sonine polynomial expansion with collision integrals at each of the calculation step. As a result, the high-temperature region and high-concentration region of dissociated oxygen spread toward the wall in the chemically non-equilibrium model. Deviation from the LTE assumption at the coil region is not negligible in argon-oxygen induction plasmas under atmospheric pressure.

PT1 3 Global Models for Real Time Feedback Control Applications D. MONAHAN, *Dublin City University, Ireland* B. KEVILLE, *National University of Ireland Maynooth, Ireland* M. M. TURNER, *Dublin City University, Ireland* Real time feedback control using physically based models is a possible future avenue of development for a variety of plasma processes where tight control of the process parameters is desirable. An acceptable model for this purpose must be not be computationally intensive and must be numerically robust. The most elaborate type of model that seems appropriate in this context is a volume-averaged or global model. While global modeling is a well-known procedure, the criteria for evaluating such models for control applications are somewhat different from those usually employed. In particular, in a process control context there is reduced emphasis on predicting equilibrium values of plasma parameters, and increased emphasis on predicting dynamic behaviour in response to changes in gas flow, power, or other actuators. In this paper we will present a critical evaluation of global model behavior in comparison with results from a kinetic plasma simulation using the particle-in-cell simulation method.

PT1 4 Ionization Balance and Radiation Transport in Low Pressure Discharges D. MONAHAN, *Dublin City University, Ireland* M. M. TURNER, *Dublin City University, Ireland* Multi-step ionization may be an important process in discharges. Usually, some of the intermediate excited states that are involved in multi-step ionization are radiatively coupled to the ground state, and this may be the most important quenching process for these states apart from further excitation leading to ionization. Radiative transitions to the ground state are often to some degree trapped, so that an emitted photon is likely to be reabsorbed elsewhere in the discharge, and many such absorption-emission cycles may occur before the photon is lost. This both extends the effective lifetime of the excited state and changes its spatial distribution. Discharge models commonly treat radiation trapping using escape factors (multipliers on the radiative lifetime in vacuum), which address the extension of the radiative lifetime but not the change in the spatial distribution. If the spatial distribution is changed appreciably by radiative transport, and multi-step ionization is important, there will be implications for the overall discharge ionization balance. In this paper, we will use particle-in-cell calculations of plasma characteristics combined with a Monte Carlo radiation transport model to address these issues and consider the extent to which a self-consistent radiation transport model is desirable.

PT1 5 Spectroscopic Study of "Plasmoids" in an Inductively Coupled Discharge A. J. G. McCARTER, *Dublin City University, Ireland* M. M. TURNER, *Dublin City University, Ireland* A. R. ELLINGBOE, *Dublin City University, Ireland* A plasma phenomenon frequently observed is that of plasmoids, although little published work exists. Plasmoids may generally be described as an instability in which there is a region of more intense glow than the surrounding plasma [1]. In our cylindrical inductively coupled plasma we observe plasmoids as regions of intensified glow surrounding a re-entrant helical antenna. The number of plasmoids (mode number) observed may range from two up ten plasmoid "lobes" depending on operating parameters—input power, gas pressure and gas composition. Plasmoids also rotate about the antenna with a frequency ranging up to tens of Hz. The rotation frequency is also dependent on input power, gas pressure and gas composition and is also affected by an external dc magnetic field. We present a characterisation of plasmoid behaviour using optical emission diagnostics and internal electrical diagnostics. [1] Brian Chapman, Glow Discharge Processes—Sputtering and Plasma Etching (Wiley, 1980)

PT1 6 Trapping of fast electrons and stepwise excitation in an rf ICP afterglow plasma* C. A. DEJOSEPH, JR., *Air Force Research Laboratory, Wright-Patterson AFB, OH* V. I. DEMIDOV, *UES, Inc., Dayton, OH* In the afterglow of a low pressure rf-driven plasma, metastable atoms can react to create fast electrons through pooling reactions, if ionization is produced, and collisions of the second kind with slow electrons. Depending on the production rate of these fast electrons and the loss rate of ions, there can be a dramatic increase in the near-wall potential drop, leading to partial trapping of the fast group. This partial trapping leads to a temporary increase in the fast electron density. This effect has been experimentally investigated in a pulsed (100% modulated) rf ICP discharge in argon. The transition between regimes of free-flight and partial trapping has been observed over a pressure range of 3 to 20 mTorr. During this transition, the wall potential increases from a few tenths of a volt to several (7-8) volts. Experimentally we observe a significant increase in the intensity of spectral lines corresponding to transitions between the argon $3p^5 4p$ and $3p^5 4s$ levels, which is consistent with stepwise excitation.

*This work supported by the Air Force Office of Scientific Research.

PT1 7 The influence of Ar metastables on plasma maintenance in Inductively Coupled Plasma TOSHIKAZU SATO, *Keio University* TOSHIAKI MAKABE, *Keio University* Inductively Coupled Plasmas (ICPs) have been widely used in ULSI fabrication such as metal etching and deposition. ICPs, however, are not employed in SiO_2 etching because of the excessive dissociation of fluorocarbon gas. Also ICP has a mode transition between the E- and H-modes with hysteresis as a function of rf current source [1]. In order to realize ICP oxide etcher, external plasma conditions and the structure must be set properly. In the present work we numerically investigate the influence of metastables on the plasma maintenance as a function of the power in pure Ar. The stepwise ionization and the electron quenching of Ar metastables are competitive processes for the plasma maintenance. At high power condition, the electron quenching due to high density of electron is dominant as compared with the stepwise ionization, while at very low power the ICP is sustained by way of the stepwise ionization of the metastables. Also the spatial distribution intrinsic to pres-

sure gives a strong influence on the sustaining mechanism. We will discuss the transition of the plasma maintenance processes and the plasma structure. [1] Y. Miyoshi Zoran Lj Petrović and T. Makabe J. Phys. D: Appl. Phys. 35, 454 (2002)

PT1 8 Electron energy distribution function measurement in a magnetized ICP Source B. JEON, *Dublin City University, Ireland* A. R. ELLINGBOE, *Dublin City University, Ireland* Electron Energy Distribution Functions (EEDFs) are measured using a single langmuir probe in conjunction with the ac superposition method in the source region and in the diffusion region of a magnetized Inductively Coupled Plasma (ICP) source. We can define source region and diffusion region by measuring EEDFs. The source region can be defined as the region where ionization is significant, so that plasma is generated in the source region and diffuses into the diffusion region. When we increase the magnetic field, the source region expands, and we can consequently control the volume of the source region by changing the magnetic field. We can also control the plasma parameters in the diffusion region by changing the magnetic field. Local power dissipation is measured by using a B-dot probe, and electron flow from source region to diffusion region is measured by using a directional planer probe. This also gives us information about the boundary of source region and diffusion region.

PT1 9 Immersed Antenna Inductively Coupled Plasmas for Mitigation of EUV Light Source Debris B. E. JURCZYK, D. N. RUZIC, D. A. ALMAN, M. A. JAWORSKI, *University of Illinois at Urbana-Champaign* In order to continue the reduction of semiconductor feature sizes, EUV light sources are currently being researched. Gaseous discharge sources produce a large amount of sputtered electrode material and high energy fuel ions as debris. In order to prevent damage to sensitive optics, mitigation of this debris is necessary. The Plasma-Material Interaction group at the University of Illinois is investigating the use of immersed antenna inductively coupled plasmas in order to ionize neutral particles for mitigation by electrostatic or magnetic fields. Experimental results from a half wavelength helical resonator antenna are presented in this paper. A large amount of capacitive coupling has been observed between the antenna and plasma resulting in increased antenna sputtering. During low power (15 W) and low density (10^9 cm^{-3}) experiments, mitigation of 60% of the discharge produced debris has been inferred from experimental observations. Greater than 99% mitigation is necessary for the use of advanced fuels such as tin. The effects of a magnetic field on Ne, Te, Vp, Vf, and the antenna floating potential have also been measured. A new high power full wavelength, faraday shielded immersed antenna has been designed and installed in the chamber. Initial results of Ne, Te, Vp, and Vf are presented here.

PT1 10 The effect of the novel internal-type linear inductive antenna for large area magnetized inductive plasma source S.H. LEE, OLGA SHULIKA, *Pohang University of Science and Technology* K.N. KIM,* G.Y. YEOM,* *Sungkyunkwan University* J.K. LEE, *Pohang University of Science and Technology* As the technology of plasma processing progresses, there is a continuing demand for higher plasma density, uniformity over large areas and greater control over plasma parameters to optimize the processes of etching, deposition and surface treatment. Traditionally, the external planar ICP sources with low pressure high density plasma have limited scale-up capabilities due to its high impedance accompanied by the large antenna size. Also due to the cost and thickness of their dielectric material in order to generate uniform plasma. In this study the novel internal-type linear inductive antenna system (1,020mm×830mm×437mm) with permanent magnet arrays are investigated to improve both the plasma density and the uniformity of LAPS (Large Area Plasma Source) for FPD processing. Generally plasma discharges are enhanced because the inductance of the novel antenna (termed as the double comb antenna) is lower than that of the serpentine-type antenna and also the magnetic confinement of electron increases the power absorption efficiency. The uniformity is improved by reducing the standing wave effect. The total length of antenna is comparable to the driving rf wavelength to cause the plasma nonuniformity. To describe the discharge phenomenon we have developed a magnetized two-dimensional fluid simulation. This work was supported by National Research Laboratory (NRL) Program of the Korea Ministry of Science and Technology. [References] 1. J.K.Lee, Lin Meng, Y.K.Shin, H,J,Lee and T.H.Chung, Modeling and Simulation of a Large-Area Plasma Source, Jpn. J. Appl. Phys. Vol.36(1997) pp. 5714-5723 2. S.E.Park, B.U.Cho, Y.J.Lee*, and G.Y.Yeom*, and J.K.Lee, The Characteristics of Large Area Processing Plasmas, IEEE Trans. Plasma Sci., Vol.31,No.4(2003) pp. 628-637

PT1 11 GaN Etch Rates Compared with Atomic Chlorine Density and Ion Flux in an Argon/Chlorine Inductively Coupled Plasma C.M.O. MAHONY, S.A. RIZVI, P.D. MAGUIRE, *Nanotechnology Research Institute, N.I. Bio-Engineering Centre, University of Ulster, BT37 0QB, Northern Ireland* F. GARCIA, W.G. GRAHAM, *Dept of Physics, Queens University Belfast, BT7 1NN, Northern Ireland* We present GaN etch rates (maximum 700nm/min), atomic chlorine densities (via Laser Induced Fluorescence at 200W RF power), positive ion densities (Langmuir probe) and positive ion wall flux (capacitive planar probe) using an Inductively Coupled Plasma as a function of chlorine in argon gas fraction from 0% to 100% at maximum RF power and pressure of 400 W and 20 mTorr respectively. In general, with chlorine addition, etch rates rise initially then tend to saturate at fractions above 50% Cl_2. Wall flux and n^+ approximate the inverse of this behaviour. The atomic chlorine density at 200W RF power rises monotonically with a pronounced inflection near 50% Cl_2. The positive ion wall flux - atomic chlorine density product strongly correlates with etch rate suggesting physical etching dominates below 50% Cl_2 and chemical processes above. This is reflected in changes of the Ga/N surface stoichiometry, determined by XPS analysis.

PT1 12 MAGNETICALLY ENHANCED PLASMAS

PT1 13 Electron drift and the loss balance of charged particles in planar unbalanced dc magnetron discharge SANG-HUN SEO, JUNG-WHAN IN, HONG-YOUNG CHANG, *Korea Advanced Institute of Science and Technology* The electron drift phenomenon is investigated in the downstream region of an unbalanced dc magnetron argon discharge. The spatially resolved measurements of the electron velocity distribution function (EVDF) using a planar probe reveal the existence of a strong on-axis electron drift parallel to magnetic field in spite of a very

small axial variation less than 1 V in the plasma potential. The average drift velocities calculated from the asymmetry of the measured EVDFs show that there exists the significant electron drift from cathode to substrate with a maximum speed of about 1e106 m/s which is comparable to the bulk electron temperature. The magnetic mirror force which is driven by the axial gradient of magnetic field (i.e. the parallel B force) is suggested as a possible source for the parallel electron drift. Carrying out a scaling of current densities with the measured data, it is found that the parallel B force can produce the electron current enough to balance the discharge current, implying that the electron transport in the downstream region is determined not by the classical diffusion model in which electron motion toward the anode is diffusion and mobility dominated but by the modified diffusion model in which electron motion is drift dominated.

PT1 14 Fast dynamics of ionized species in high power pulsed magnetron discharges PETR VAŠINA, MARCEL MEŠKO, MICHEL TOUZEAU, JEAN BRETAGNE, MIHAI GANCIU, *LPGP, Université Paris-Sud, France* A high power density ($\sim$ 1kW/cm^2) preionized pulsed magnetron [1] plasma was investigated. Applied voltage of $\sim$ 1 kV caused fast magnetron current increase and, after few μs, dense plasma was formed characterized by a pressure independent current of 40 A for Cu target of 3 cm in diameter. For pressure range 0.7 - 10 Pa we observed a sharp Ar and Ar^+ lines increase which droped after about 4 μs in favour of Cu^+ and Cu^{++} which remained nearly constant during the rest of pulse. Important amount of sputtered atoms caused T_e drop and pushed the buffer gas out of the magnetized region. For times $>$ 5 μs the plasma composition was dominated by metal ions. We observed a faster dynamics when Ar was replaced by He. We evidenced the possibility to quickly reach gas-metal plasma transition (more than 5 times that was already reported). By changing discharge parameters we can work in different modes (gas, metal/gas, metal). Short pulses avoid the arc formation [1] and using high repetition keeps sufficient deposition rate. [1] M Ganciu, J P Dauchot, M Hecq, S. Konstantinidis, J Bretagne, L de Poucques, M Touzeau, European Patent Appl, N°4447072.2/22.03.2004.

PT1 15 Biased Grid and Substrate Effects in Magnetized ICP SANGHYUN JUN, *Korea Advanced Institute of Science and Technology* HONG YOUNG CHANG, *Korea Advanced Institute of Science and Technology* Highly energized electrons or ions can be made through the biased grid. The energetic electrons or ions may give energies to other ions in the plasma bulk of diffusion region. Also, a biased substrate can affect the plasma parameters related to ion heating. The velocity distribution functions of the heated ions can be measured by diode LIF(Laser Induced Fluorescence) technique at 668.6nm for argon ion metastable LIF in magnetized ICP. We can take ion temperature, density and drift velocity from the velocity distribution functions. We investigate the argon ion characteristics, comparing with plasma parameters by a electrical probe, to see the possible ion heating through the collisions with energetic electrons and ions.

PT1 16 Self-consistent modeling of 1-D magnetically-enhanced, low-pressure, low-temperature inductively-coupled discharges. Influence of the electron-cyclotron and cavity resonances on the electrodynamics of magnetized plasmas OLEG POLOMAROV, CONSTANTINE THEODOSIOU, *Department of Physics and Astronomy, University of Toledo, Toledo, Ohio, 43606-3390* IGOR KAGANOVICH, *Plasma Physics Laboratory, Princeton University, Princeton, NJ 08543* DEMETRE ECONOMOU, *Plasma Processing Laboratory, Department of Chemical Engineering, University of Houston, Houston, TX 77204-4004* The influence of a weak constant external magnetic field on the properties of low-pressure, low-temperature inductively-coupled plasmas is shown through a self-consistent, one-dimensional, fast modeling of planar magnetically enhanced inductively-coupled discharges, driven by a radio frequency electromagnetic field. Introducing of an external magnetic field leads to considerable increase of plasma resistivity, due to possible electron-cyclotron and cavity resonances. The related changing of the discharge parameters, such as electron temperature and plasma density is considered. The effects of self-consistency and the importance of explicit accounting of the non-uniformity of a plasma profile, due to the significant influence of an ambipolar electrostatic potential on the power deposition through the collisionless heating, are demonstrated.

PT1 17 Plasma Dynamics in a Unipolar Pulsed Magnetron Sputtering Discharge J. T. GUDMUNDSSON, *Science Institute, University of Iceland* J. ALAMI, *Department of Physics, Linkping University, Sweden* K. B. GYLFASON, *Science Institute, University of Iceland* J. BOHLMARK, *Department of Physics, Linkping University, Sweden* U. HELMERSSON, *Department of Physics, Linkping University, Sweden* We report on the spatial and temporal behavior of the plasma parameters, the electron energy distribution function (EEDF), the electron density and the average electron energy using a Langmuir probe. The temporal behavior of the electron density shows that a dense localized plasma (electron density $n_e \approx 10^{18}$ m^{-3}) is created by applying a high energy unipolar pulse to a planar magnetron sputtering source. The high density plasma is created by applying a high energy pulse (3 – 12 J) with pulse length of 50 – 100 μs and repetition frequency 50 Hz to a planar magnetron discharge. This dense localized plasma travels away from the magnetron target. We have confirmed that this dense plasma is an ion-acoustic soliton. The large amplitude of the solitons (maximum density perturbation $10 < \delta n/n_0 < 100$) and the absence of an initial background plasma are distinctive features of this method of soliton generation. The velocity, width, and amplitude characteristics of the solitons are found to be in agreement with the basic properties of the expanding soliton solution of the Korteweg-de Vries equation in a spherical geometry. We discuss the characteristics of the soliton and the plasma dynamics at various operating pressure.

PT1 18 Evaluation of a Plasma Pre-Sheath Model for Pulsed DC Magnetron Discharges TAMARA MOISEEV, *Dublin City University, School of Electronic Engineering, NCPST, Glasnevin, Dublin 9, Ireland* The behaviour of the plasma pre-sheath in pulsed DC discharges is difficult to predict theoretically and the complex time and space dependent phenomena make experimental measurements difficult. The existence and intensity of the pre-sheath electric field can influence the time-scale of the sputtering and self-sputtering processes, important for pulsed DC magnetron operation. In this paper the influence of the pre-sheath in an opposed target magnetron pulsed DC discharge is investigated through Monte Carlo calculations of the energy and travel time to target of Ar+ gas ions. Computation results are compared to mea-

sured ion energy spectra and respectively, to time-resolved Optical Emission Spectroscopy measurements. A computer code that simulates 3D ion trajectories in 3D electric and magnetic fields has been developed and used to simulate Ar+ ion trajectories in a 50kHz, 2016ns pulsed DC discharge at 2A constant current run and 0.4Pa Ar gas pressure. The electric and magnetic field and a time-dependent Child-Langmuir sheath are calculated at each time step of the simulation. The most probable Ar+ ions starting energy was determined from the measured ion energy spectra. Three pre-sheath models having a constant electric field of 1V/m, 10V/m and respectively 100V/m have been considered. Computation results are discussed in connection to the OES and measured ion energy spectra and indicate the middle value as best match to the experimental data.

PT1 19 Importance of Dielectric Quarter Wave Window Design for Coupling Efficiency SELCUK HELHEL, *T.C. Süleyman Demirel Üniversitesi* LUTFI OKSUZ, *T.C. Süleyman Demirel Üniversitesi* ECR plasma system was built to produce plasma in an axial direction. Plasma is initiated in a Nickel Chrome vacuum tube by 2.45GHz commercial magnetron. The window that microwave is being driven through was made up of different thickness of dielectric material and different type of materials. Silica and pyrax were chosen for this aim. Mathematically and experimentally shown that quarter wave window design effects the coupling quality. Whereas reflected power is considerably less, different thickness chose increases reflectivity. This design is also important for concentration of microwave into the system. Spatial and temporal measurements are provided for argon, nitrogen and hydrogen plasma of each window type for comparison.

PT1 20 ELECTRON-MOLECULE INTERACTIONS

PT1 21 Near-Threshold Total Dissociation Electron Impact Cross Sections for C_2F_6, C_3F_8, and CHF_3* DAVID FLAHERTY, MICHAEL KASPER, DAVID GRAVES, HAROLD WINTERS, *University of California at Berkeley USA* Absolute total dissociation electron impact cross sections, σ_{TD}, are reported near threshold (8-30eV) for C_2F_6, C_3F_8, and CHF_3 using the technique described by Winters and Inokuti [1]. Total neutral dissociation cross sections, σ_{ND}, are obtained by subtraction using total ionization cross sections, e.g. [2]. σ_{ND} for C_2F_6 and $C_3F_8$are compared with values inferred from swarm data and to reported partial dissociation cross sections for production of CF_3 and C_2F_5 over the range of electron energies measured [3,4]. Work supported in part by the NSF/SRC ERC for Environmentally Benign Semiconductor Manufacturing. [1] H. Winters and M. Inokuti, Phys. Rev. A 25, 1420 (1982). [2] L. Christophorou and J. Olthoff, J. Phys. Chem. Ref. Data 28, 131, (1999) [3] S. Motlagh and J. Moore, J. Chem. Phys., Vol. 109 (2),. 432, (1998) [4] Hayashi and Niwa, Gaseous Dielectrics V, Pergamon, New York, p. 27, (1987).

*Work supported in part by the NSF/SRC ERC for Environmentally Benign Semiconductor Manufacturing.

PT1 22 Electron Impact Fragmentation of CH4 Molecules* RYOJI SUZUKI, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* KAZUHIRO OGURI, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* CASTEN MAKOCHEKANWA, *Graduate School of Sciences, Kyushu University, Fukuoka 812-8581, Japan, and Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* MASASHI KITAJIMA, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* HIROSHI TANAKA, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* Absolute electron-molecule impact dissociation cross sections are of interest in many fields of physics and chemistry, plasma etching of microelectronic devices and other industrial applications. However, experimental data on these cross sections is scarce mainly because of the difficulties involved in measuring neutral fragments [1]. Electron impact dissociation of CH4 molecules into the CH3 radicals have been investigated over the energy range 15.0 to 37.0 eV. The experimental procedure involves a dual-electron-beam in a two-stage collision system in conjunction with a quadrupole mass spectrometer (QMS). This is similar to the threshold-ionization mass spectrometry method [2]. Significant differences, in magnitude up to four times at 100 eV, exist between the only available absolute measurements by Sugai et al. [2] and Moore et al. [3]. Our data shows very close agreement with the Moore et al. data, which which show reasonable consistency with the available CH4 total dissociation data by Winters [3]. [1] L. S. Polak and D. I. Slovetsky, Int. J. Rad. Phys. Chem. 8, 257 (1976). [2] H. Sugai, H. Toyoda and T. Nakano, Jpn. J. Appl. Phys. 30, 2912 (1991). [3] H. F. Winters, J. Chem. Phys. 63, 3462 (1975).

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PT1 23 Electron Impact Vibrational Excitation of H2O Molecules* HIDETOSHI KATO, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* RINA KAJITA, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* TAKAHIRO TANAKA, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* CASTEN MAKOCHEKANWA, *Graduate School of Sciences, Kyushu University, Fukuoka 812-8581, Japan, and Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* MINEO KIMURA, *Graduate School of Sciences, Kyushu University, Fukuoka 812-8581, Japan* HYUCK CHO, *Physics Department, Chungnam National University, Daejeon 305-764, South Korea* MASASHI KITAJIMA, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* HIROSHI TANAKA, *Physics Department, Sophia University, Chiyoda-ku, Tokyo 102-8554, Japan* Electron impact interaction studies with water have invited a lot experimental and theoretical attention for more than half century because it falls into the unique group of polar molecules whose dipole moments are above the critical dipole moments, thus enabling studies of dipole-related threshold peaks [1]. However, because of the experimental difficulties encountered in separating the three fundamental modes of vibration, for instance, there remained controversies about the existence of resonance effects in the vibrational excitation. In this report, the H2O vibrational exciation into modes (100) and (001) investigated at energy losses of 0.43, 0.46, 0.49 and 0.51 eV, where peaks for these two modes closely overlap, while sweeping the impact energies from 1.6 to 10

eV, at angles 60 and 90, using a cross-beam method [2]. The continuum multiple scattering (CMS) [4] calculations have also been performed for the theoretical analysis of the experimental results. We have observed distinct resonance enhancement only in the symmetric stretching (100) mode, but not in the antisymmetric (001) and bending (010) modes. The theoretical interpretation is provided. [1] K. Rohr and F. Linder, J. Phys. B 9, 2521 (1976). [2] H. Tanaka, L. Boesten, D. Matsunaga and T. Kudo, J. Phys. B 21, 1255 (1988). [3] M. Kimura and H. Sato, Comments At. Mol. Phys. 26, 333 (1991).

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PT1 24 Low Energy Electron Scattering from N_2 I. OZKAY, J. G. CHILDERS, MURTADHA A. KHAKOO, *California State University, Fullerton, CA 92834, USA* P. JOHNSON, I. KANIK, *Jet Propulsion Laboratory, Pasadena, CA 91109, USA* We present new measurements of the differential cross sections for the electron impact excitation of the *A*, *W*, *B*, *B'*, *a'*, *a*, *w* and *C* electronic states of N_2 at 10 eV, 12.5 eV, 15 eV, 17.5 eV, 20 eV and 30 eV incident energies. The data are compared to existing measurements at these energies. This work is funded by the National Science Foundation under grant # NSF-RUI-PHY-0096808 and by the NASA Planetary Atmospheres program.

PT1 25 A new apparatus for study of fragmentation processes in clusters ELAINE DUFFY, *National University of Ireland, Maynooth* PETER VAN DER BURGT, *National University of Ireland, Maynooth* A new experiment has been set up for study of electron and photon impact fragmentation of clusters. Van der Waals clusters are generated in a supersonic expansion. The clusters are probed with energy-resolved electron impact and with photo-excitation and ionisation, and fragmentation into ions and long-lived neutral metastable species will be investigated. A reflectron time-of-flight mass spectrometer is used for mass-selective detection of ionized fragments. Time-of-flight detectors are used to measure kinetic energy distributions of neutral metastable fragments. Detection of neutral metastable fragments has been applied with great success in electron and photon impact dissociation of many different molecules, but has only recently been applied in fragmentation studies of rare-gas clusters. The intial focus will be on pure rare-gas clusters and metal-embedded rare-gas clusters (MRn clusters with M = Hg, Na, K, and R = Ar, Kr, Xe). An overview will be given of the apparatus, the data acquisition, and plans for the future.

PT1 26 DISTRIBUTIONS AND TRANSPORT COEFFICIENTS

PT1 27 Particle and energy balance in low-density plasma discharges SCOTT ROBERTSON, *Department of Physics, University of Colorado, Boulder, CO 80309-0390* ZOLTAN STERNOVSKY, *Department of Physics, University of Colorado, Boulder, CO 80309-0390* For nearly-collisionless, unmagnetized plasma discharges, it is shown that electron particle and energy balance can be found from a model that includes 1) the energy distribution of the newborn electrons [Opal et al., J. Chem. Phys. 55, 4100, 1971], 2) the rate of heating of confined electrons by collisions with more energetic electrons, and 3) the rate at which electrons are lost over the confining potential barrier. The model is applied to a simple low-density, hot-filament discharge. The more energetic electrons responsible for heating are identified as secondary electrons from the chamber walls released upon impact of primaries from the filament [Sternovsky and Robertson, to appear in Phys. Plasmas]. The plasma density, electron temperature, and confining potential are shown to have approximately the values given by the model.

PT1 28 Electron Drift Velocity Determination in Argon, Nitrogen and Hydrogen in Strong Electric Fields VALERIY LISOVSKIY, *LPTP, Ecole Polytechnique, Palaiseau 91128, France* JEAN-PAUL BOOTH, *LPTP* SOPHIE MARTINS, *Unaxis Displays Division France SA, 5, Rue Leon Blum, Palaiseau 91120, France* KARINE LANDRY, *Unaxis Displays Division* DAVID DOUAI, *Unaxis Displays Division* VALERICK CASSAGNE, *Unaxis Displays Division* This paper reports measurements of the ignition curves of rf capacitive discharges in low pressure argon, nitrogen and hydrogen. The rf discharge was ignited in the pressure range p = 0.01-30 Torr with the rf frequencies f = 13.56 MHz and f = 27.12 MHz. The distance between the parallel-plate electrodes (143 mm in diameter) was varied in the range L = 2.5-27 mm. We determined the electron drift velocity from the location of the turning points in the ignition curves in the range of E/p = 42-832 V/(cm Torr). For comparison, we also calculated the electron transport parameters, over the range E/p = 1-1000 V/(cm Torr), using published cross-sections and the numerical code Bolsig. The electron drift velocities obtained by these two methods are in good agreement, and are similar to those of other authors.

PT1 29 IONIZATION

PT1 30 Fragmentation of Hexamethyldisiloxane in Electron Impact Ionization and Argon Charge Transfer C. Q. JIAO, *ISSI, Dayton, OH, USA* C. A. DEJOSEPH, JR., A. GARSCADDEN, *Air Force Research Laboratory, Wright-Patterson AFB, OH, USA* Dissociative ionization of Hexamethyldisiloxane (HMDSO) by electron impact and Ar^+ charge transfer have been examined using Fourier transfer mass spectrometry. In both cases, the dominant fragment ions are $Si_2OC_5H_{15}^+$(m/z147), $Si_2OC_4H_{11}^+$(m/z131) and $SiC_3H_9^+$ (m/z73). Partial ionization cross-sections for the major channels have been measured and results will be compared with previous measurements. A collision-induced dissociation (CID) technique is used to probe the pathways of the ion fragmentation, which provides information on the production of neutral products from the electron impact ionization. In brief, the five most abundant fragment ions from electron impact and Ar^+ charge transfer are found to be generated by these paths: the parent ion $Si_2OC_6H_{18}^+$(m/z162) undergoes unimolecular dissociation to form $Si_2OC_5H_{15}^+$(m/z147), which in turn dissociates

forming mainly two ions, $Si_2OC_4H_{11}^+$(m/z131) and $SiC_3H_9^+$(m/z73). The latter two ions undergo further fragmentation to yield $SiC_2H_7^+$(m/z59) and $SiCH_5^+$(45), respectively. * This work is supported by Air Force Office of Scientific Research.

PT1 31 Single ionization of two-electron systems by electron BIDHAN C. SAHA, *Department of Physics, Floroda A&M University, Tallahassee, FL 32307* ARUN K. BASAK, *Department of Physics, University of Rajshahi, Rajshahi, Bangladesh* M. ALFAZ UDDIN, *Department of Physics, University of Rajshahi, Rajshahi, Bangladesh* The electron impact single ionization cross sections on few two-electron ionic systems, ranging from Li to U, are calculated using the siBED model[1,2]. It is found that the simple siBED model with the same parameters is good for neutral He target but becomes inadequate for ionic targets. We report to important modifications of the siBED model. The first one QIBED that includes ionic corrections [2] and the other one includes both the relativistic corrections[3] and the ionic corrections, and denoted it as RQIBED. The predictions of these methods are in excellent agreement with the available theoretical as well as experimental findings. [1] W. M. Huo, Phys. rev. A 64, 042719 (2001). [2] M. A. Uddin, M. A. K. Fazlul Haque, A. K. Basak and B. C. Saha, Phys. Rev. A (in press), 2004. [3] M. A. Uddin, A. K. Basak and B. C. Saha, Int. J. Quan. Chem., (in press) 2004.

PT1 32 WITHDRAWN

PT1 33 Triple differential cross sections for excitation-ionization of helium by electron impact ZHANGJIN CHEN, D. H. MADISON, *Laboratory for Atomic and Molecular Research, University of Missouri-Rolla, Rolla, MO 65401, USA* The triple differential cross sections (TDCS) for electron impact ionization of helium with simultaneous excitation have been calculated in the second-order distorted wave Born approximation. Whereas previous second-order calculations have used the plane wave Born approximation and have used approximations to simplify the evaluation of the second-order term, we perform a full distorted wave calculation and make no approximations in the evaluation of the second-order amplitude (i.e. we sum over all contributing intermediate states). The present TDCS will be compared with experimental measurements and other theoretical results.

PT1 34 Electron Impact Ionization of Helium ERIC SCHOW, KEN HAZLETT, CRISTINA MEDINA, GIL VITUG, J. G. CHILDERS, MURTADHA A. KHAKOO, *California State University, Fullerton, CA 92834, USA* Doubly-differential cross sections for the electron impact ionization of helium have been measured at low incident energies. The measurements were taken using the moveable nozzle technique recently developed in our laboratory.[1] Data taken at 26 eV, 28 eV, 30 eV, 32 eV, 34 eV, 36 eV, and 40 eV incident energies are presented. Good agreement is observed with the theoretical convergent close-coupling (CCC) calculations of Bray *et al.*[2] This work is funded by the National Science Foundation under grant # NSF-RUI-PHY-0096808.

[1]M. Hughes, K. E. James, Jr., J. G. Childers, and M. A. Khakoo, *Meas. Sci. Technol.* **14**, 841 (2003)

[2]Igor Bray, Dmitry V. Fursa, and Andris T. Stelbovics *J. Phys. B* **36**, 2211 (2003)

PT1 35 Spin Asymmetry Parameters for Electron-Impact Ionization of Xenon ANDREW PRIDEAUX, *University of Missouri-Rolla* DON MADISON, *University of Missouri-Rolla* Electron Impact ionization of atoms provides a fundamental test of the current understanding of atomic structure as well our understanding of the three body problem. Spin asymmetry parameters represent a very sensitive test of theoretical models and very recently experimental measurements of both fully differential and doubly differential spin asymmetry parameters have been reported for electron-impact ionization of xenon. The Distorted Wave Born Approximation (DWBA) has been one of the most successful theoretical approaches for studying atomic ionization particularly for heavier atoms. One of the important shortcomings of the DWBA lies in the neglect of the final state electron-electron interaction [often called post collision interaction (PCI)] in the final state wavefunction. Consequently, we have generalized the DWBA to include PCI to all orders of perturbation theory and we have labeled the new approach 3DW. The effects of PCI will be studied by comparing DWBA and 3DW results with experiment for the spin asymmetry measurements for xenon.

PT1 36 Accuracy of continuum distorted waves for He and H^- S. JONES, *University of Tennessee* JOSEPH H. MACEK, *University of Tennessee and Oak Ridge National Laboratory* D. H. MADISON, *University of Missouri-Rolla* The accuracy of continuum distorted waves for ground and excited states of He and H^- is investigated by considering a number of different physical processes including double ionization by photoabsorption, Compton scattering, and electron impact. In the high-energy limit of these processes, the accuracy of the initial ground state can be ascertained without reference to the final double-continuum state. In this limit, we find that a Hylleraas description is superior to the Pluvinage one. For intermediate energies, final-state correlation becomes important, so we employ a 3C description of the final state (the 3C wave function is the double-continuum analog of the Pluvinage wave function). In this case, however, better agreement with experiment is obtained with the Pluvinage initial state. A possible explanation for this seemingly paradoxical result is suggested.

PT1 37 PHOTOIONIZATION

PT1 38 K-shell Photoionization of C^{2+} ions: Experiment and Theory S. W. J. SCULLY, E. D. EMMONS, R. A. PHANEUF, *University of Nevada, Reno, USA* A. AGUILAR, D. LEITNER, A. S. SCHLACHTER, *Lawrence Berkeley National Laboratory, USA* A. M. COVINGTON, *Lake Tahoe, Community College, USA* M. LUBELL, *City College, New York, USA* R. PUTTNER, *Freie Universitat Berlin* A. MUELLER, *Justus-Leibig-Universitat Giessen* B. M. McLAUGHLIN, *Queen's University of Belfast and ITAMP* RENO COLLABORATION, LBL COLLABORATION, LAKE TAHOE COLLABORATION, CITY COLLEGE COLLABORATION, BERLIN/GIESSEN COLLABORATION, QUB/ITAMP COLLABORATION. We report the first experimental absolute cross-section measurements for K-shell photoionization of Be-like C^{2+} ions, in the photon energy range 292 eV - 325 eV. Measurements have been made using the photo-ion merged-beam endstation located at the Advanced Light Source, Lawrence Ber-

keley, National Laboratory. Absolute measurements compared with theoretical results from the R-matrix method indicate that the primary C^{2+} ion beam consisted of 67% ground-state ($1s^2 2s^2 {}^1S$) and 33% metastable ($1s^2 2s 2p {}^3P^o$) ions. Suitable agreement with theory is seen for absolute photoionization cross sections, resonance energies and autoionization lifetime linewidths of the K-shell vacancy Auger states. Detailed results will be presented at the meeting.

PT1 39 POST-DEADLINE ABSTRACTS

PT1 40 Ion Energy Distributions: The Role of Ionization, Resonant and Non-Resonant Charge Exchange Collisions NATALIA BABAEVA, JAE KOO LEE, *Department of Electronic and Electrical Engineering, Pohang University of Science and Technology, Pohang, Korea* JONG WON SHON, ERIC HUDSON, *Lam Research Corporation, Fremont, CA, USA* Typical form of ion energy distribution (IED) at the electrodes often exhibits numerous peaks that are primarily due to charge exchange (CX) collisions. In the present paper capacitively coupled RF discharges operating in oxygen/argon mixtures are investigated using Particle-in-Cell/Monte Carlo (PIC/MCC) method. The role of ionization, resonant and non-resonant CX collisions in the formation of ion energy distribution at the electrodes is studied. By turning off/on the corresponding collisional processes it is shown that ionization can play an essential role in formation of the IED structure. The discharge operating in O2/Ar (95mixture is maintained in a chamber between two electrodes separated by a gap of 2 cm. The bottom electrode is capacitively coupled to RF power supply while the upper electrode is grounded [1]. Operating parameters are: pressure is 26mTorr, applied voltage is 900 V, RF frequency is 27 MHz. The total reaction scheme includes four species (electrons, O2+, Ar+ and O- ions) with 35 reactions between them. IED at the grounded electrode (RHS) for O2+ ions is considered. When all the processes are included IED shows typical CX collision-dominated profile with numerous humps in the tail region. When resonant and non-resonant CX collisions are turned off IED is almost collision-less. However, the small peaks still exist. Finally, ionization is turned off at the sheath near the grounded electrode which results in disappearance of the humps. Ionization can not be turned off in all the region as no discharge will develop in this case. Simulations show that the humps still exist in the LHS sheath where there is ionization. Thus, the conclusion can be made that ionization also contributes to the fine structure of ion energy distribution. [1] J. K. Lee, N. Babaeva, H. C. Kim, O. Manuilenko, and J. W. Shon, IEEE Trans. Plasma Sci. 32, 47 (2004).

PT1 41 Fault Detection and Classification JOHN SCANLAN, *Straatum, Dublin, Ireland* Plasma processes are used widely in the manufacture of semiconductor devices. Recent trends in this industry have focussed on methods for automated process control. For limiting processes such as plasma etch, an emerging focus is on real time Fault Detection and Classification (FDC). Simply put, the aim is to provide a system that not only detects faults but also identifies the root cause. For example, semiconductor production fabs regularly encounter faults that result in unscheduled tool downtime and reduced yield. Among these are real-time process and tool faults, post maintenance recovery problems and tool mismatching at start-up and process transfer. The objective of any FDC scheme should be to reduce this product loss and tool downtime by identifying the core problem as rapidly as possible, and replace the usual trial-and-error approach to fault identification. There are a couple of key requirements in any control system. Firstly, an estimation of the process state, and secondly, a scheme for providing real-time control. This paper focuses on methods for addressing both problems on plasma etch tools. A non-intrusive high-resolution RF sensor is used to provide in situ process-state and tool-state data. Examples will be presented on how such a sensor can give a repeatable fingerprint of any plasma process. The challenge then becomes the manipulation of this data into usable information. The process control scheme presented is knowledge-based, in that it is trained and does not rely on statistical methods with underlying assumptions of Gaussian data spread. A fingerprint of known fault states is the knowledge set and real-time control is provided by comparison of the sensor fingerprint to the fault fingerprints.

PT1 42 A Study of RF and Transport Effects in Magnetized Capacitive Discharges* P. M. RYAN, M. D. CARTER, *Oak Ridge National Laboratory* D. J. HOFFMAN, D. BUCHBERGER, *Applied Materials* Static magnetic fields have been used to expand the operational envelope, increase power efficiency, and control processing parameters in capacitively-coupled radio frequency plasma discharges. A simple physical model has been developed to investigate the roles of the plasma dielectric tensor and plasma transport in determining the ion flux spatial profile along a wafer surface over a range of plasma density, neutral pressure and magnetic field strength and orientation. The model has been incorporated into the MORRFIC code[1] and calculations have been made for a capacitively-coupled 300-mm etch tool operating at 162 MHz. Preliminary efforts using a Lieberman sheath model show effects that can occur when the sheath voltages are made to be consistent with the driven RF fields in the collisional unmagnetized limit. A two-dimensional transport model to account for magnetized cross-field diffusion is under development. Results isolate magnetic field effects that are caused by modification of the plasma dielectric from transport effects that are caused by the reduced electron mobility perpendicular to the magnetic field. [1] M. D. Carter, this conference

*This work was supported by Applied Materials

PT1 43 The Modular Oak Ridge RF Integration Code (MORRFIC)* MARK CARTER, *Oak Ridge National Laboratory* Magnetic fields can enhance the operation of capacitive discharges. However, magnetized plasma is a complicated medium with tensor RF dielectric properties and anisotropic transport. In this work, we describe the implementation of an integrated model of these discharges using MORRFIC. Many components of the model have been derived from studies of magnetized fusion and helicon plasmas. The geometry supported in the code allows perfectly electrical conducting boundary conditions with azimuthally symmetric dielectrics and three dimensional antenna structures. The model solves Maxwell's equations for a cold magnetized plasma as well as other simpler lossy dielectric materials. A sheath model based on Lieberman's work is incorporated at the plasma boundaries, and the computational resolution allows the RF fields

to be resolved inside the sheath region while modeling the overall reactor. The sheaths are fed by a rudimentary transport model to illustrate effects that can occur in the model when sheath voltages are made to be consistent with the driven RF fields.

*Research sponsored in part by ORNL, managed by UT-Battelle, LLC, forthe U.S. DoE under contract DE-AC05-00OR22725.

PT1 44 Accurate and fast simulation approach of a radiating thermal plasma RENS ZIJLMANS, RICHARD ENGELN, DAAN SCHRAM, *Eindhoven University of Technology, The Netherlands* To optimize the geometry of a radiating thermal plasma for use as a light source, a simple and still accurate simulation is necessary. A new method has been developed to simulate near to equilibrium plasmas in partial equilibrium, applied for argon in a cascaded arc. Nevertheless this simulation takes non-equilibrium explicitly into account. Extensions for a xenon plasma and for plasmas further from equilibrium are being developed. The simulation method is based on the formulation of the various plasma transport properties in terms of electron density, pressure and two non-equilibrium parameters. The latter two describe the deviation from thermal equilibrium and ionization equilibrium of the ground state. The electron density is a suitable parameter, because the radiative properties depend mainly on the square of the electron density. Simple fits through the curves of transport property against the electron density can be made, which vary only slightly with non-equilibrium assumptions as compared to an LTE plasma. By solving the balance equations using these fits, the plasma behavior can quickly be determined. Comparisons with experimental data and the scaling behavior of a cascaded arc will be presented.

PT1 45 Optical Diagnostics Of a Carbon Nanotube Growth Plasma BRETT CRUDEN, *NASA Ames UARC NASA Ames Research Center* We report a characterization of a RF-driven methane/hydrogen plasma used for carbon nanotube growth by two optical diagnostics. Ultraviolet absorption spectroscopy is used for quantitative measurement of CH3 radical density. Optical emission spectroscopy with an argon actinometer is used to characterize other components in the plasma. The H2 rotational emission spectrum is used to extract neutral temperatures. A model is constructed to analyze and predict intensities of atomic Ar lines and the atomic H Balmer series lines. From the relative intensities of these lines, it is possible to back-calculate electron temperature, electron number density and atomic to molecular hydrogen ratios. The results are compared to straightforward application of actinometry and the limitations of the model will be discussed.

PT1 46 Effect of an ac-superposed cathode on dust charging and nonlinear behavior in the dust vertical oscillation SEONGCHONG PARK, CHANGRAE SEON, WONHO CHOE, *Department of Physics, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong, Yuseong-gu, Daejeon 305-701, Korea* Experimental and theoretical studies were conducted to investigate the controllability of dust charge and dynamics by focusing on the effect of plasma density modulation on particle trap structure and nonlinear behavior of dust oscillation in a dc discharge with externally-injected particles. It was shown that the ac-superposed cathode was found to not only change the particle trap structure but also make the nonlinearity of the particle oscillation weak, which suggests the controllability of the dynamical properties of the particles. Neither hysteresis nor subharmonic peak occurred as the ac-modulation voltage increased, and it is attributed to the fact that the ac modulation made sheath structure less nonlinear. In addition, as the ac-frequency decreased from 10 kHz to 400 Hz at the same ac-voltage (15 V), the subharmonic peak became weakened sensitively with its frequency, which means that the dust charge is the main parameter of determining occurrence of the subharmonic peak. We consequently expect that it is possible to control the dust particle dynamics as well as trap structure by cathode ac-modulation.

PT1 47 A wave function to describe realistically the motion of an electron in a gas environment in between collisions THOMAS O'MALLEY, *Retired* The Schrodinger equation is an extension of classical mechanics which can describe any possible motion of an electron. For the electron bound inan H atom, its eigenstate solution resembles a time exposure. It's appearance is what would result if the wave is a description of all its possible motions, given its quantum symmetries. For an electron and a single atom, the eigenstate solution predicts the collision cross section correctly from inside the potential. But outside,the wave is inadequate, expanding aimlessly outward. In a gas environment, we know that a free electron goes directly from collision to collision, and that Boltzmann theory predicts its mobility accurately by simply using quantum cross sections - plus, at elevated densities, the generalization of Fermi's (1934) scalar potential energy field. For a free electron in a gas, the space-time paths of Feynman's point-to-point wave packets are a natural continuation of the eigenfunction's outgoing rays. The obvious targets of the wave packets are the cross sections of all the electron's possible collision partners. The time-dependent equation for a free electron then, like the eigenvalue equation inside a potential, is able to describe all its possible space-time motions in a gas environment. [An actual collision at one cross section changes the electron's momentum state there, eliminating all other possibilities (A probability collapse)].

PT1 48 Accelerator Physics GENNADY STUPAKOV,* *NLC Design Group, Stanford USA* We present a study of orbit jitter and emittance growth in a long linac caused by misalignment of quadrupoles. First, assuming a FODO lattice, we derive analytical formulae for the RMS deviation of the orbit and the emittance growth caused by random uncorrelated misalignments of all quadrupoles. We then consider an alignment algorithm based on minimization of BPM readings with a given BPM resolution and finite mover steps In this paper we study the emittance dilution of a beam caused by quadrupole misalignments in a long linac. To suppress the beam break-up instability an energy spread is usually introduced in the beam. For the Next Linear Collider (NLC) [1], the rms energy spread within the bunch will be of order of 1of the beam by displaced quadrupoles results in the dilution of the phase space and the growth of the projected emittance. The effect of lattice misalignments has been previously studied in many papers. A qualitative analysis and main scalings were obtained in Ref. [2], and detailed studies with intensive computer simulations are described in Refs. [3, 4, 5]. The purpose of this paper is to develop a simple model based on a FODO lattice approximation for the linac which allows an analytic calculation of the emittance dilution. The model can be also generalized, to include a slow variation of the lattice parameters, as well as variation of both beam energy and the energy spread [6]. Throughout this paper we as-

sume that the number of quadrupoles in the linac is large, N 1, and neglect terms of the relative order of N−1 in the calculations. For future linear colliders with the center of mass energy in the range of 1 TeV, typically N 103, and N−1 is indeed a small number

*QUADRUPOLE MISALIGNMENTS AND STEERING IN LONG LINACS

PT1 49 Swarm derived electron cross section set for the perfluorocyclobutane molecule MASAHIRO YAMAJI,* *Keio University* YOSHIHARU NAKAMURA,† *Keio University* The cross section set of perfluorocyclobutane (c-C_4F_8) is determined by the electron swarm method. The modification is applied to the vibrational excitation cross section and the elastic momentum transfer cross section. Our previously measured electron swarm parameters (drift velocities, longitudinal diffusion coefficients and effective ionization coefficients) in 0.468the determination of the vibrational excitation cross section. The measured drift velocity and longitudinal diffusion coefficient in pure c-C_4F_8 are used to determine the correct elastic momentum transfer cross section. The calculated electron transport coefficients were derived from the Monte Carlo simulation method.

*doctor
†professor

PT1 50 Comparison of a range of microchannel plate image intensifiers ANDREW HANVEY, *Andor Technology Ltd* In this paper, comparisons of gain, irising, equivalent background illumination (EBI), halo and relative quantum efficiency (QE) of four microchannnel plate image intensifiers (MCPII) has been carried out. A Generation (Gen) III filmed, a Gen III filmless, a Gen II with metal grid underlay and a Gen II without underlay but with new technology XR5 are compared. For relative comparison the MCPII's have been built into identical type Intensified Charge Coupled Device (ICCD) cameras manufactured by Andor Technology. Measurement techniques and conclusions are discussed within this paper.

PT1 51 Experimental Investigation on the difference between the plasma potential and the floating potential of the cylindrical probe in an inductively coupled plasmas WONKI LEE, SEJIN OH, S.H. JANG, I.J. CHOI, CHINWOOK CHINWOOK, *Devision of Electrical and Computer Engineering, HanYang Univ, Seoul, Republic of Korea* The difference between plasma potential (Vp) and floating potential (Vf) is of interest because it directly relate to ion energy inciding to a floating wall or silicon wafer. F. F. Chen et. al. [F.F. Chen and D. Arnush, Phys. Plasmas, 8, 5051(2001)] show that the potential difference between them in cylindrical probe is a function of plasma density. However, F. F. Chen et. al. assumed that the electron energy distribution function-(EEDF) is Maxwellian and the EEDF is constant against RF powers. To investigate the effect of the EEDF on the potential difference in inductively coupled plasma, the electron energy distribution functions (EEDF) are measured at low pressure (2 and 10mTorr). The EEDFs are bi-Maxwellian EEDFs with two temperatures below the ionization energy of the electrons. It is found that the difference (Vp - Vf) is not constant but a strong function of plasma density as Chens theoretical results and the theoretical potential difference lies within those calculated by high electron temperature and low electron temperature. The results of our experiment agree qualitatively with F. F. Chen's theory

PT1 52 Studies of Profile Topology in Capacitive Parallel Plate Discharges DOUGLAS KEIL, *Lam Research Corporation* ERIC A. HUDSON, *Lam Research Corporation* ALEXEI MARAKHTANOV, S.M. REZA SADJADI, *Lam Reserch Corporation* The spatial distribution of plasma density and electron temperature in a planar capacitive discharge is dependent on the diffusion regime in which the device is operated. Particle and power balances largely determine this diffusion regime. Recently, S. Cho and M.A. Lieberman (Plasma Sources Sci. Technol. 12, (2003) 244-254) have highlighted the roles of both local and global particle and power balance in determining the basic shape of density and temperature radial profiles. This paper presents a characterization of profile topology for a parallel plate capacitively coupled Rf discharge. The plasma density distributions for a range of plasma conditions have been measured using a double Langmuir probe. Plasma density profiles with a cosine dependence are typically observed in the axial direction. These and other data are compared to both high pressure diffusion models and to the models of S. Cho and M.A. Lieberman. Implications for uniform plasma processing are discussed.

PT1 53 Investigation of an Oxygen/Argon Plasma Excited by a Planar Inductively-coupled Radiofrequency Plasma* ALBRECHT BROCKHAUS, GEORGE FELIX LEU, JÜRGEN ENGEMANN, *Forschungszentrum für Mikrostrukturtechnik - fmt, University of Wuppertal, Germany* A low-pressure plasma in Oxygen/Argon mixtures has been investigated by means of various probe diagnostics, actinometry, and the laser photodetachment technique in combination with a probe. The plasma is generated with a planar inductively-coupled plasma source consisting of a four-arm spiral coil. The study is intended to improve the understanding of (i) the chemical composition in the bulk plasma as well as (ii) the particle transport between plasma and wall. Even in the bulk plasma the electronegativity is generally small i.e., in the range below 30%. Nevertheless the negative ion density in front of a target wall could be measured with sufficient spatial resolution to determine the density gradient in the pre-sheath. The diagnostic findings are interpreted in the framework of a zero-dimensional fluid model.

*Financial support from the Deutsche Forschungsgemeinschaft DFG within the SFB 591 is gratefully acknowledged.

PT1 54 Ion kinetics and symmetric charge-transfer collisions in DC discharges of N_2 RAO MANGINA, JIM OLTHOFF, *National Institute of Standards and Technology* Translational ion kinetic-energy distributions of N^+, N_2^+, N_3^+, and N_4^+ have been measured in diffuse, low-current Townsend-type discharges at high electric field-to-gas density ratios (E/N) in the range of 1 $x10^{-18}$ to $30x10^{17}$ Vm^2. The discharges were generated in N_2 under uniform-field conditions and ion energies were measured using a quadrupole mass spectrometer in conjunction with an elec-

trostatic energy analyzer. The mean ion energies determined from the measured energy distributions are compared with the mean energies predicted from the solutions of the Boltzmann transport equations based on the assumption that symmetric resonance charge transfer is the predominant ion-neutral interaction. The results for N_2^+ are consistent with predictions made using a energy independent cross section for which an effective ion temperature can be defined, and symmetric charge-exchange cross sections are calculated. However, N^+ exhibit deviation from Maxwellian distribution with increasing E/N, indicative of multiple ion-molecule reactions affecting the ion transport. The maximum energy of N^+ exceeds those of N_2^+ at the same E/N, and, at the higher values of E/N, extend to the maximum kinetic energies possible for the applied gap voltage.

PT1 55 On a Dual Inductively Coupled Plasma for Direct and Remote Plasma in a Reactor S.H. UHKM, K.H. LEE, S.H. CHANG, *Dept. of Physics. KAIST, Daejon, Republic of Korea* CHINWOOK CHUNG, *Division of Electrical and Computer Engneering, HanYang Univ. Seoul, Republic of Korea* A dual inductively coupled plasma (ICP) system in which a remote ICP (upper ICP) with small volume is attached to a main ICP (lower ICP) is developed. Two ICP antennas are connected in parallel and a variable capacitor (C_{var}) is installed in series at the end of the main ICP antenna. By adjusting the capacitance of the variable capacitor, the plasma densities and the electron temperatures in the remote region and the main region are controlled. The electron energy distribution functions(EEDFs) and plasma potential from the EEDFs are measured along z axis. It is found that there is a potential dip in the midway of two ICP antennas and the potential dip is formed to keep two plasmas quasi neutral. In two regions, the EEDFs in high energy range are almost same (nonlocal) but they are different in low energy range because low energy electrons can not overcome the potential dip. The dual ICP is applied to Si etching. According to Si etch results, it was observed that Si etch rate increased by 20% as the plasma density in the remote region increased, even though the plasma density in the main region decreased. This might be understood by considering the role of the remote ICP as a radical generator.

SESSION PT2: POSTER SESSION IV
Tuesday afternoon, 28 September 2004
Cork, Bunratty Conference Centre at 16:00

PT2 1 DIELECTRIC BARRIER DISCHARGES, DISPLAYS

PT2 2 Analysis of Discharge Propeties in Atmospheric Pressure and Low Frequency O_2 Barrier Discharges AKINORI ODA, TAKASHI KIMURA, *Graduate School of Engineering, Nagoya Institute of Technology, Japan* Previously, atmospheric pressure and low frequency O_2 barrier discharges have been used as an conventional-type ozonizer. However the discharge properties have not been clealy known yet. We analysed the properties using a one-dimensional fluid model conposed of the continuity equations for 4 charged species and 5 neutrals and the Poisson equation. The discharges were produced between the dielectrics with 0.05 cm thickness and dielectric constant of 4 in the discharge gap of 0.13 cm–0.2 cm, by applying the sinusoidal voltage with amplitude of 5 kV–9 kV and frequency of 1 kHz to the metallic electrodes with area of 38.5 cm^2. From the calculated voltage-current characteristics, we found that the discharges in the present calculation conditions were consisted of multiple pulsed discharges during a half cycle of applied voltage. In the phase of maximal discharge current, electron avalanche directed towards anode were found and its peak density was the order of magnitude of 10^8 cm^{-3}. Also, the density of negative and postive ions was 10^8 cm^{-3} and 10^{10} cm^{-3} respectively. Judging from the above results, the discharges may be distinguished as Townsend-like discharges. This work was partially supported by Grant-in-Aid from Japan Society for the Promotion of Science.

PT2 3 Plasma emission in PDP-like discharge TAO JIANG, *Eindhoven University of Technology* MARK BOWDEN, *Eindhoven University of Technology* ERIK WAGENAARS, *Eindhoven University of Technology* GERRIT KROESEN, *Eindhoven University of Technology* Microdischarges such as the one in a plasma display panel (PDP) are becoming more common in various technologies. In order to predict processes in these discharges, their fundamental properties must be modeled, diagnosed and understood. The aim of this research is to study the way in which breakdown occurs in this microdischarge. To do this, the space and time variations of plasma emission in a PDPC like cell were measured with a fast gated ICCD camera (image-intensified charge-coupled device) and 5x magnification optics. The size of discharge cell is similar to a real PDP cell with coplanar electrodes and the electrode gap was 0.1mm, although there is no address electrode in our case. The temporal resolution was about 10ns and the spatial resolution was about 10m. The images of this microdischarge show a typical AC PDP discharge. In this paper, we will present these ICCD camera images and discuss the evolution of the microdischarge and compare these results with results from a simulation of the plasma.

PT2 4 THERMAL PLASMAS

PT2 5 Acceleration Phenomena of Rarefied Arc Jet at the Magnetic Nozzle TOSHIAKI KANUMA, MASAHIKO HATCHO, TAKESHI SAKAMOTO, MITSUO MATSUZAKI, HARUAKI MATSUURA, HIROSHI AKATSUKA, *Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology* We measured basic plasma parameters of a supersonic helium arc jet accelerated through a magnetic nozzle from a uniform magnetic channel. The arc jet is generated by a normal arc discharge under atmospheric pressure, and ejected into a rarefied gas wind tunnel with a uniform longitudinal magnetic field of 0.16 T. The strength of the magnetic field decreases to 0.01 T at 20 cm down from the end of the coils. The longitudinal velocity of the plasma

jet was measured by Mach probes. At the maximum gradient of the magnetic field, the peak of the Mach number 3.1 of the flow velocity was observed. We found lowering of the plasma potential at the exit of the nozzle, and the ions were accelerated at this area. After the maximum of Mach number, electron temperature increased from 0.1 eV to 0.5 eV, whereas the electron density decreased gradually. Experimental results show that the acceleration is caused by the change in the plasma potential rather than fluid dynamic effect.

PT2 6 LIGHTING PLASMAS

PT2 7 X-ray absorption measurements to determine gas temperature of HID lamps XIAOYAN ZHU, J. J. A. M. VAN DER MULLEN, *Applied Physics Department, Eindhoven University of Technology, P.O.Box 513, 5600 MB Eindhoven, The Netherlands* MARCO HAVERLAG, *Central Development Lighting, Philips Lighting, P.O.Box 80020, 5600 JM Eindhoven, The Netherlands* To measure the gas temperature of high intensity discharge (HID) lamps, an X-ray absorption (XRA) experimental set-up has been designed and constructed. From the XRA experiment, the relative density profile of the mercury content will be obtained. From the ideal gas law, the absolute temperature profile is obtained in combination with the wall temperature measurement. The challenges are: 1. The beam hardening effect as created by the large absorption of the burner material. 2. The fact that the Hg density has a hollow profile makes Abel inversion difficult. 3. The shift, expansion and rotation of the lamp due to heating. The experimental results will be given and discussed for various kinds of the HID lamps. It was found that the radial temperature profile varied significantly as a function of axial position for some metal halide lamps due to segregation effect.

PT2 8 Electrodeless HID lamp excited by microwaves in a dielectric waveguide* JIN JOONG KIM, JUNG YOUNG KIM, *Sejong University* KYOUNG SHIN KIM, SUNG HO HONG, *Taewon Lighting Laboratory* It is difficult to scale down high-power electrodeless high-intensity discharge (ELS_HID) lamps such as electrodeless sulfur lamp for applications in general lighting or projection displays. We report on the demonstration of a stable ELS-HID lamp using sulfur or indium bromide excited by 100~ 300 W microwaves at 2.45 GHz in TM01 mode in a dielectric waveguide. The emission spectra are similar to those obtained in high-power operations. The color rendering index exceeds 92 for the mixture of S2 and InBr, covering the whole range of the visible wavelength and the brightness is better than 2.7E7 cd/m2. This paper will also show the simulation of the microwave mode structure in the waveguide and present other photometric paramters of the 100-W class ELS-HID lamps.

*Work supported by a contract from Korean Ministry of Commerce, Industry, and Energy

PT2 9 Investigation of high flux radical and intense ultraviolet generation in fast-pulsed dielectric barrier discharges JOSE LOPEZ, ABE BELKIND, KURT BECKER, *Stevens Institute of Technology* PETER BLETZINGER, JAMES M. WILLIAMSON, *Innovative Scientific Solutions Inc.* BISWA N. GANGULY, *Air Force Research Laboratory, WPAFB* Dielectric Barrier Discharges (DBDs) produce highly non-equilibrium plasmas that allow for the effective generation of ions, excited species, and radicals from energetic electron-driven processes. DBDs have further proven to be efficient sources of intensive UV and VUV excimer radiation. In an effort to improve the production of the excited species, radicals, and UV radiation, which is strongly influenced by the reduced electric field, it is more effective to use a pulsed high voltage of very short duration, particularly if the aim is to keep the gas temperature low. Operating with short pulses and high reduced electric fields will transfer most of the electron energy into excitation, ionization, and molecular dissociation, while only a minor part into the vibrational and rotational excitation of gas molecules. In an effort to better understand this phenomenon, electrical measurements in conjunction with plasma emission spectroscopy of a pulsed DBD were carried out using a fast intensified CCD (ICCD) camera and a calibrated photodiode. These investigations allowed for the determination of the temporal and spatial developments of important plasma species such as radicals (OH, NO, and various oxygen radicals) and absolute intensity measurements of UV radiation. Work supported by the Air Force Office of Scientific Research through a STTR Phase I award.

PT2 10 Pollution-free efficient source of visible light of high brightness on runaway electrons SERGEY BELOSTOTSKY,* DMITRIY LOPAEV, EVGENIY MURATOV, ALEXANDER RAKHIMOV, VLADIMIR SAENKO, *Skobeltsyn Nuclear Physics Institute of Lomonosov Moscow State University, 119992, Moscow, Russia* Nowadays photoluminescent lamps, which contain mercury vapor, are considered to be the most efficient and the brightest sources of visible light. Due to harmful influence of mercury on human health the problem of mercury-free sources of light is very important. A new pollution-free wide-angle efficient source of visible light of high brightness by using the open discharge in inert gases has been developed. Direct excitation of phosphor screen by runaway electron beam is its principal feature. About 80% of energy deposited into the discharge is carried by runaway electron beam. The optimization of construction features of the light source has been carried out. As a result, the efficiency of more than 30 lm/W and brightness of more than 20000 cd/m^2 have been obtained. Furthermore, as experimentally shown, the intensity of a back light flux from the phosphor surface in the direction of the electron beam is 2-3 times higher than the light flux intensity behind the phosphor screen. The evaluation calculations have confirmed these results. Thus, the application of special phosphor arrangement allows one to increase a total light yield and provide the source efficiency, comparable with the mercury-containing photoluminescent lamps. Constructive simplicity and respective low cost of the light source advantageously distinguishe it from other cathodoluminescent lamps.

*Student of Faculty of Physics, Lomonosov Moscow State University

PT2 11 3-D Simulation of Sustain Discharge with Auxiliary Pulse in an AC-PDP YOSHIKUNI HIRANO, KEIJI ISHII, YASUSHI MOTOYAMA, YUKIO MURAKAMI, *NHK Science and Technical Research Laboratories* KUNIHIDE TACHIBANA, *Department of Electronic Science and Engineering, Kyoto University*

In order to improve the discharge characteristics of a surface discharge type alternating current plasma display panel (AC-PDP) with addressing and sustaining electrodes, voltage control of the addressing electrode of the cell by applying auxiliary pulses has been widely investigated. As the detailed mechanisms are not well understood, we used 3-D multi-fluid computer simulation to examine the mechanism for improving the efficiency of generating excited particles for emission of vacuum ultraviolet (VUV) rays. As a result, it was pointed out that the discharge volume was increased due to the influence of the high address voltage, and the electrons which spread in the cell space have sufficient energy to excite Xe atoms. When the voltage of the auxiliary pulse was high, the generation efficiency of Xe* was improved about 40% compared with the case when the voltage was low, because the quantity of Xe* generated increased sharply even though the power consumption increased. This result is the same as that already reported[1], and so accurately reflects the actual phenomenon.

[1]Y. Shintani et al., J. Phys. D, Appl. Phys. 36, 2928(2003).

PT2 12 DIAGNOSTICS II

PT2 13 Measurements of Line Strengths and Calculations of their Temperature Dependence of n2 IR Transitions of the Methyl Radical J. ROEPCKE, G. D. STANCU, *INP-Greifswald, Greifswald, Germany* P. B. DAVIES, *University of Cambridge, Cambridge, U.K.* The determination of methyl radical concentrations in terrestrial and astronomical sources using infrared spectroscopy relies on the availability of accurate line strengths and transition dipole moments. The ν_2 fundamental of CH_3 near 606 cm^{-1} is particularly useful for this purpose but up to the moment only one transition line strength, Q(8,8), was presented [1]. This value is measured at room temperature with an uncertainty of at least 32%. We have measured the line strength of 9 Q-branch lines of the 2^1_0 band of CH_3 from Q(1,1) to Q(12,12) using diode laser absorption spectroscopy. Calculations of the temperature dependence of the line strengths were done. The choice of line to optimise the sensitivity for detecting the methyl radical by infrared absorption spectroscopy is an important consideration in practical applications. Therefore, line strength of the strongest lines and their temperature variation will be given for different temperature range: for the astronomical use, cryogenic temperatures, for typical kinetic flow tube and laboratory plasma, 300 – 1000 K, and for diamond deposition plasma, above 2000 K. [1] J. Wormhoudt, K.E. McCurdy, Chem. Phys. Letters, **156** 1 (1989) 47

PT2 14 Relative Chlorine Atom Density Measurements in Chlorine-containing Plasmas FERNANDO GARCIA, *Queen's University Belfast, Belfast BT7 1NN, Northern Ireland* PHILIP STEEN, *School of Physical Sciences, Dublin City University, Ireland* WILLIAM GRAHAM, *Queen's University Belfast, Belfast BT7 1NN, Northern Ireland* Laser Induced Fluorescence (LIF) measurements have been performed in an inductively coupled RF-driven reactor containing Argon and Chlorine mixtures in order to study the relative Chlorine atomic density. A 233.3nm UV beam focused at the centre of the discharge pumps the ground state by two-photon absorption through a spin-forbidden transition. From the three radiative decay channels at 725.6, 754.7 and 774.4nm, the 725nm one was monitored. Power and pressure dependences were studied for a series of Ar:Cl mixtures together with the mixing ratio dependence, over a pressure range of 10 to 60 mT and up to powers of 100W. The measured fluorescence increases with power and then remains constant above 40W and before reaching the inductive mode at about 100W. A growth in Chlorine atom density was observed with increasing pressure and with increasing Chlorine mixing ratio. Time-dependant measurements are underway in an instability at the inductive-capacitive interface.

PT2 15 Chemical dynamics of $Ar/N_2/H_2$ and Ar/NH_3 plasma expansions RICHARD ENGELN, JEAN-PIERRE VAN HELDEN, PETER VAN DEN OEVER, DAAN SCHRAM, ERWIN KESSELS, RICHARD VAN DE SANDEN, *Eindhoven University of Technology* In unravelling the dynamics leading to the production of NH_3 in plasmas produced from mixtures of N_2 and H_2, the density of NH_3 as well as the density of radicals like NH and NH_2 has been measured under varies plasma conditions by means of cavity ring down spectroscopy. In one of the experiments the pressure dependence of the ammonia production in a pure N_2/H_2 plasma expansion has been determined. It was concluded that ammonia is produced mainly at the reactor walls[1]. In experiments in which NH_3 is injected in an Ar plasma expansion, the density of NH_2 and NH as function of the ammonia flow has been measured. First results indicate that the density of NH_2 and NH as function of the injected NH_3 flow can be explained by forward gas phase chemistry. When an N_2/H_2 plasma is generated and expanded, the NH density as function of the ratio of the hydrogen flow to the total flow shows an almost constant behavior up to a ratio of 0.4 and decays rapidly at higher H_2 flows. The behavior could be due to the change in dissociation efficiency of the arc for the different mixtures. A one-dimensional plug-down model is being developed to describe the behavior of the different species in the plasma. [1] P. Vankan *et al.*, Appl. Phys. Lett. **81** (2002) 418

PT2 16 Measurement of Ion velocity by Mach probes in flowing unmagnetized plasmas E. KO, X. WANG, N. HERSHKOWITZ, *Dept. of Engineering Physics, University of Wisconsin* G. SEVERN, *Dept. of Physics, University of San Diego* Measurements of plasma flow in unmagnetized plasmas were performed using two Mach probes; one is a planar Mach probe and the other is spherical. The planar Mach probe consists of two single sided Langmuir probes with an insulator between the probe tips. The spherical Mach probe consists of an Aluminum ball that has two Tantalum probe tips, insulated from the ball and mounted at $\theta = 0^o$(down-stream) and 180^o(up-stream) with respect to the flow direction. The experiments were performed along a presheath in a multi-dipole DC plasma for ion beam velocity $v_f < 1.0c_s$, where c_s is sound velocity, and in a double plasma system for $v_f > 1.0c_s$ with Argon pressure ranging from 0.1mTorr to 1mTorr and plasma density range of 10^7 - 10^{10} cm^{-3}. The measured supersonic ion drift velocities were compared to the velocity determined by a gridded Ion energy analyzer and single sided probes. Results are compared to Hutchinson's numerical simulations[1,2] of Mach probes in unmagnetized plasma. *Work Supported by US DOE grant no. DE-FG02-97ER 54437. [1]I. H. Hutchinson, Plasma Phys. Control. Fusion 44, 1953 (2002) [2]I. H. Hutchinson, Plasma Phys. Control. Fusion 45, 1477 (2003)

PT2 17 Phase resolved optical emission spectroscopy on an industrial confined dual frequency capacitively coupled radio frequency discharge P. D. SWIFT, *Dublin City University, Ireland* M. M. TURNER, *Dublin City University, Ireland* T. GANS, *Ruhr-Universität Bochum, Germany* R. FAULKNER, *Dublin City University, Ireland* Phase-resolved optical emission spectroscopy (PROES) has been used to investigate an industrial etch reactor (Exelan, Lam Research Inc.). The reactor is a confined dual frequency capacitively coupled radio frequency (DF-CCRF) discharge. The discharge is operated with one electrode grounded and the second electrode driven simultaneously with two rf voltages (2 MHz and 27 MHz). PROES yields detailed insight into the electron dynamics within both rf cycles. A high speed ICCD camera (LaVision GmbH) allows us to use every rf cycle for phase resolved measurements with spatial resolution along the discharge axis. The high sampling rate of the ICCD camera allows us to measure even faint emission lines with temporal resolution. Spectral resolution is achieved using a 2m-spectrometer. First experimental results on the sheath dynamics in the Exelan reactor are discussed and compared to a particle-in-cell (PIC) simulation for a neon discharge.

PT2 18 Plasma diagnostics through analysis of Ar I line profiles in the 4s–4p transition VLADIMIR MILOSAVLJEVIĆ, *Faculty of Physics, University of Belgrade, P.O. Box 368, Belgrade, Serbia; & School of Physical Sciences, Dublin City University, Glasnevin, Dublin 9, Ireland* STEVAN DJENIZE, *Faculty of Physics, University of Belgrade, P.O. Box 368, Belgrade, Serbia* On the basis of the measured three (751.465, 763.511 and 772.376 nm) neutral argon (Ar I) line shapes (in the 4s–4p transition) the basic plasma parameters i.e. electron temperature (T) and electron density (N) have been obtained using the line deconvolution procedure, in a plasmas created in a linear, low–pressure, pulsed arc. The working gases were 72% Ar + 28% He and 97% Ar + 3% H_2. The mentioned plasma parameters have been measured using independent experimental diagnostics techniques as well. The separate electron and ion contributions to the total Stark width and shift, have also been obtained for these argon spectral lines. The Stark parameters, the width (W) and the shift (d), of these Ar I spectral lines have been studied. The line shapes are measured in three different plasmas at about electron temperature of 16 000 K and electron density of 7.0×10^{22} m^{-3}. The separate electron and ion contributions to the total Stark width, as well as to the total Stark shift, have also been obtained. On the basis of the observed asymmetry of the Stark broadened line profile we have deduced the ion broadening parameters which describe the influence of the ion static (A) and the ion–dynamical effect (D) on the line width and shift (E). Stronger influence of the ion contribution on lines shape has been evidenced than is the one predicted by current theory.

PT2 19 Relationship between rotational temperature and energy density in atmospheric pressure hollow-needle to plate electrical discharge STANISLAV PEKREK, *Czech Technical University in Prague, Technick 2, 166 27 Prague 6, Czech Republic* MILAN SIMEK, *Insttute of Plasma Physics, Academy of Sciences of the Czech Republic, Za Slovankou 3, 182 24, Czech Republic* We studied the excitation of the N2(C3Pu) state in a DC hollow needle to plate electrical discharge in synthetic air for the needle biased negatively. Vibrational distributions and rotational temperatures were obtained by means of emission spectrometry as a function of a mean energy density dissipated in the discharge. Observed behavior of the N2(C3Pu,v) excitation is consistent with predominant processes effective at inspected conditions. Vibrational excitation of the N2(C3Pu) decreases with increasing energy density and the shape of vibrational distributions reflects the electron impact excitation and energy pooling mechanism by N2(A3S u+) metastables. Rotational temperatures Trot(C3Pu) evolve in the range of 1000-1800 K and linearly increase with the mean energy density. This work was supported by the Grant Agency of the Academy of Sciences of the Czech Republic under contract GAAV 1043403.

PT2 20 Line-of-Sight Mass Spectrometric and Optical Emission Studies of an Oxygen Inductively-Coupled Plasma VINCENT M. DONNELLY, PETER F. KURUNCZI, *University of Houston* Mass spectrometry and optical emission spectroscopy were used to measure the production of atomic O in a high-density, inductively coupled oxygen plasma. The mass spectrometer was line of sight with the center of the plasma. Plasma species pass through a 2mm diameter orifice in the wall of the reactor and through two differentially pumped chambers. The resulting molecular beam was chopped, resulting in a beam to background signal intensity ratio of 30:1. With the plasma off, a strong beam signal was observed at mass 32 and a weak signal at mass 16 due the small amount of dissociative ionization of O_2 in the mass spectrometer ionizer. With the plasma on the signal at mass 16 increases dramatically due to the formation of O atoms in the plasma. From the known cross sections we computed O atom densities at 500W of 6.5% of the total density at 2 mTorr and 2.5% at 8mTorr. Optical emission from traces of rare-gases was used to measure T_e (e.g. 5.6 eV at 4.8 mTorr and 400 W). O-atoms absolute densities were also measured by actinometry (O 844 nm –to-Ar 750 nm emission ratio). E.g. in the center of the plasma at 4.8 mTorr and 200 W, the O density was 2.5% that of O_2, compared to 1.9% measured with the mass spectrometer at comparable conditions.

PT2 21 Silicon halides absolute densities measured in HBr/Cl2/O2 plasmas by UV broad band absorption spectroscopy MARTIN KOGELSCHATZ, NADER SADEGHI,* *Laboratoire de Spectromtrie Physique, 38402 St Martin d'Hres, France* GILLES CUNGE, *Laboratoire des Technologies de la Microlectronique, 17 rue des Martyrs, 38054 Grenoble, France* Broad band UV absorption spectroscopy is used to detect silicon etching by-products during silicon gate etching in high density HBr/Cl2/O2 plasmas and their mixture with fluorocarbon gases. The vibrationally resolved spectra of SiClx, SiFx and SiO etch products (x = 0-2), allow to derive the absolute concentrations of these radicals. These concentrations are typically about 10[1]0 cm-3 for Si, 10[1]1 cm-3 for SiCl and SiF, and 10[1]2 for SiCl2 and SiF2. The silicon atoms density is obtained as the sum of the ground and metastable state populations, and is extracted by taking into account the instrumental width of the monochromator. The absorption spectrum of SiBr is presented, together with a new absorption band of SiCl around 220 nm. Finally, the addition of CF4 to the plasma allows to identify the absorption spectrum of the SiClF radical, which is unknown in literature. The results are helpful to validate numerical models.

*Presenting author

PT2 22 Development of density measurement method of negative ion in plasmas using laser Thomson scattering YUKIHIKO YAMAGATA, HIROATSU SAIHO, KIICHIRO UCHINO, *Interdisciplinary Graduate School of Engineering Sciences, Kyushu Univ., Japan* KATSUNORI MURAOKA, *Faculty of Engineering, Chubu Univ., Japan* Measurements of negative ion density in plasmas have been an important subject for many years. We have proposed a new method to measure the negative ion density in plasmas using laser Thomson scattering (LTS), and successfully measured O^- ion density in an radio frequency inductively coupled plasma [1]. In order to ensure the reliability of this technique and to estimate the accuracy, we have measured O^- ion density in the same experimental conditions using the second (SHG) and third harmonics (THG) of a Nd:YAG laser as different laser sources. The LTS spectra measured at pure argon plasma (500 W, 20 mTorr) fitted in a straight line well in both SHG and THG cases. As for the plasma at 500 W in 20 mTorr with Ar/O_2=95%/5%, a clear *bump* in LTS spectra, which is caused by photo-detached electrons, was observed below 0.9 eV for the SHG case and 2 eV for the case, as predicted by a difference between the electron affinity of O^- ion and the laser photon energy. The electron temperatures, the electron densities and the O^- ion densities, which were obtained from the spectral shape and intensity of both LTS spectra, were in agreement each other within an experimental error. [1] M. Noguchi, K. Ariga, T. Hirao, P. Suanpoot, Y. Yamagata, K. Uchino, K. Muraoka, Plasma Sources Sci. Technol., **11** (2002) 57.

PT2 23 Measurements of EEDF by Using High-Efficiency Laser Thomson Scattering Spectroscopy in the Vicinity of the Dielectric Window of a Surface Wave Plasma Source M. ARAMAKI, *Nagoya University* J. KOBAYASHI, A. KONO, E. STAMATE, H. SUGAI The surface wave plasma (SWP) is a promising plasma source for large-area processes with low electron temperature. It is important to clarify the electron heating mechanisms and the spatial structure of EEDF in SWP. We have improved the detection efficiency of the multichannel Thomson scattering measurement system in order to investigate the variation of the high energy tail of EEDF near the dielectric window.@The observation efficiency per unit time was improved about 60 times as compared with our previous system (Rev. Sic. Instrum. **77** (2000) 495). The positions of slot antennas were rearranged to improve the radiation efficiency of a microwave (2.45 GHz). The electron density was increased to over 10^{12} cm^{-3} at Ar 10 mTorr, microwave power 600 W, and 5 mm from the dielectric. It was 10 times higher than that of our previous result. We will report the detailed spatial variation of EEDF of this high efficiency SWP near the dielectric window. This work has been performed under the 21st Century COE Program by the MEXT Japan.

PT2 24 Development of the Motional Stark Effect with Laser-Induced Fluorescence (MSE-LIF) Diagnostic* ELIZABETH L. FOLEY, *Princeton University* FRED M. LEVINTON, *Nova Photonics, Inc.* The Motional Stark Effect with Laser Induced Fluorescence (MSE-LIF) diagnostic will be used to measure magnetic field magnitude and direction in plasmas. The technique involves injecting a beam of neutral hydrogen into a plasma source, and using a collinear laser to excite the H-alpha (n=2 to n=3) transition in the beam neutrals. As the beam travels at a velocity v though the magnetic field, it perceives an electric field, E = v x B, in its reference frame. The subsequent fluorescence from the same transition is split and polarized due to the Stark effect, and the magnetic field magnitude and direction can be reconstructed from observation of the fluorescence. Previous work has used the motional Stark effect in observations of heating beams on tokamaks to reconstruct the magnetic field pitch angle profile, but the measurements were limited to fields above 0.75 Tesla by spectral broadening issues. The use of the laser will allow measurements of significantly lower fields, down to 0.05 Tesla, using the Stark spectrum, and recent results suggest that the technique can be adapted to measure fields as low as 0.0005 Tesla.

*Work Supported by DoE Grant DE-FG02-01ER54616 and a Hertz Foundation Fellowship

PT2 25 Diode lasers for ion flow and sheath physics studies in multiple ion species plasmas* GREG SEVERN, *University of San Diego* XU WANG, EUNSUK KO, NOAH HERSHKOWITZ, *University of Wisconsin-Madison* MILES TURNER, *Dublin City University* USD-UW COLLABORATION, USD-UW-DCU COLLABORATION Diode laser systems, comprising an optical amplifier Locked to a diode seed laser (Littman-Metcalf cavity), have recently improved the state of the art of measuring ion flow at the sheath-presheath boundary in single and multiple ion species plasmas. In the case of two ion species plasmas ($ArI + HeI$ plasmas, $P_{ArI} \sim 0.1mTorr, 0 \leq P_{He}/P_{Ar} \leq 25$, and $0 \leq n_{He^+}/n_e \leq 0.5$, $T_e \leq 2eV$), we showed that ArII ions exceed their individual Bohm speed by almost a factor of 2 at the sheath edge. The ion velocity distribution functions (ivdfs) became markedly distended on the low velocity side as the ions accelerated through the presheath on their way to the sheath edge, a phenomena consistent with the effects of charge exchange collisions, both resonant and non-resonant. New PIC code simulation results corroborate these basic findings and are compared with experimental results. A study of alternate ions to replace HeII so as to avoid the problems associated with Penning ionization is presented. Finally, since the optical amplifier for the desired wavelength is no longer available, we have opted for a single higher power diode laser in a Littrow cavity. We shall discuss our initial results.

*Work supported by DOE grant no.DE-FG02-03ER54728, and NSF grant no.

PT2 26 Gas and electron temperature and density measurements from laser scattering from inductively coupled oxygen and nitrogen plasmas* BILL GRAHAM, GARY CRAIG, CATHERINE THOMPSON, TOM MORROW, PHILIP STEEN, *School of Mathematics and Physics, Queens University Belfast,* The scattering of the second harmonic of a Nd:YAG laser (532nm) has been used to determine the electron and neutral gas energy distribution functions in an inductively coupled GEC reference reactor. The operating gases were oxygen, nitrogen and argon/oxygen and argon/nitrogen gas mixtures. The measured spectral profile of the laser light scatter from the centre of the discharge gap, at 90 degrees, to the incident beam direction contained components due to Thomson scattering from the plasma electrons and Rayleigh and Raman scattering from the gas atoms, molecules and

ions. The latter indicated the extent of gas heating in the discharge with gas temperatures rising from 300 K to 1000K as the input power was increased from to 300W. The electron energy distribution function (eedfs) was determined from the Thomson scattering component. This indicates that the eedfs in nitrogen and oxygen are biMaxwellian with the bulk of the electrons at a temperature of 1 eV and a higher tail of about 5 eV.

*Supported by the UK Engineering and Physical Science Research Council.

PT2 27 Negative hydrogen ion density measurements using CRDS R. FAULKNER, *Dublin City University, Ireland* F. SOBERON, *Dublin City University, Ireland* D. BOILSON, *CEA Caderache, France* M. B. HOPKINS, *Dublin City University, Ireland* A. R. ELLINGBOE, *Dublin City University, Ireland* H. P. L. DE ESCH, *CEA Caderache, France* R. HEMSWORTH, *CEA Caderache, France* Negative hydrogen ion formation and extraction is of interest to the fusion community as a source for neutral beam injection system. Negative hydrogen ion sources are also used as injectors for high energy accelerators. Laser photodetachment, in conjunction with Langmuir probes to detect currents of photodetached electrons, has often been used for spatially resolved relative negative hydrogen ion density measurements. Cavity ring down spectroscopy (CRDS) can be used to determine line-integrated, absolute negative hydrogen ion densities. CRDS is a laser-based absorption spectroscopy technique that can be applied to the detection of very dilute or weakly absorbing species. This technique measures the rate of absorption of a light pulse emitted from an optical cavity, consisting of highly reflective spherical mirrors which contains the absorbing sample. The sensitivity of this technique is dependent on mirror reflectivity where path lengths of several kms can be achieved. The current status of the CRDS technique which is being applied to the ARIS experiment at D.C.U. and the Kamaboko III source in Cadarache will be discussed.

PT2 28 INNOVATIVE PLASMA APPLICATIONS

PT2 29 Laboratory Simulation of Martian Entry Plasma* L. VUSKOVIC, S. POPOVIC, J. DRAKE, *Old Dominion U., Norfolk, Virginia* R. MOSES, *NASA LaRC, Hampton, Virginia* The aim of this research is to experimentally explore an approach to regenerate power during the Martian atmospheric entry. Understanding the basic processes involved in formation and sustaining of the entry plasma is necessary in order to evaluate optimum trajectories, and estimate reduction and redirection of heat. For instance, heat transfer from shock-heated heavy particles to electrons sustains nonequilibrium ionization-recombination process during the life of Martian entry plasma. Peak pressure in the plasma also changes during Martian atmospheric entry. To study these effects, a series of lab tests are underway that uses a supersonic flowing afterglow of a high-pressure microwave discharge in Martian simulant gas (MSG) to reconstruct the conditions in the boundary layer of a vehicle upon its entry into Mars atmosphere. MSG, composed of 95.5substitute for the Martian atmosphere. In the gas composition of MSG flowing afterglow CO is dominant, with significant portions of O, CO2, and O2. We will describe the supersonic flowing afterglow system and employed diagnostic techniques, and discuss the scaling validity of the simulation.

*Supported by NASA Langley Research Center.

PT2 30 Atmospheric pressure dielectric barrier glow discharge for surface treatment and deposition. PAUL PEETERS, *Eindhoven University of Technology, Department of Applied Physics, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands* EUGEN ALDEA, RICHARD VAN DE SANDEN, HINDRIK DE VRIES, *Fuji Photofilm B.V., Tilburg, The Netherlands* FUJI PHOTOFILM B.V. COLLABORATION, A setup has been build for surface treatment of, and thin film deposition on flexible substrates, using an atmospheric pressure dielectric barrier glow discharge. The flexible substrates (polymers) are moved across the electrodes in a roll-to-roll process. The gap between the electrodes is in the order of 1 mm, and is continuously flushed with a mixture of Argon and Air. In case of thin film deposition HMDSO vapor is added to the gas mixture. A sinusoidal voltage is applied to the electrodes, the frequency of which is in the range of 1 to 450 kHz. Thin transparent films have been deposited on PEN and PET foils, using HMDSO as a precursor. From ATR-FTIR analysis it can be concluded that the deposited films become more SiO2-like as the concentration of air in the plasma is increased. In addition the activation of PP has been investigated. Using mixtures of Argon and air, the surface energy of PP and PE substrates can be increased substantially. Contact angle measurements show that surface energies of up to 55 mJ/m^2 are attainable, depending on the applied dose (mJ/m^2).

PT2 31 DUSTY PLASMAS

PT2 32 Absorption of X-Rays by Nanoparticle Aggregates J.B.A. MITCHELL, J.L. LEGARREC, C. REBRION-ROWE, D. TRAVERS, B.R. ROWE, L. BIENNIER, *Universite de Rennes I* S. DI STASIO, *Instituto Motori, Italy* M. WULFF, *ESRF, France* In a series of recent synchrotron radiation experiments, [1-3] the absorption of high energy x-ray and VUV photons by flame generated soot nanoparticle aggregates has been examined. The structure of these aggregates is similar to that of dust grains found in interstellar clouds and processing plasmas. It is found that an intense ionisation process is produced by the absorption of an x-ray photon. The mechanism for this ionisation has been given by astrophysical models that predict that the dust grain disintegrate due to runaway electrostatic charging. The results of a small angle scattering measurement will be presented that reveal the diameters of the primary and sub-primary particles in the aggregates. 1. J. B. A. Mitchell et al Combustion and Flame, 131 (2001) 308. 2. J. B. A. Mitchell et al Astronomy and Astrophysics 386 (2002) 743. 3. J.L. LeGarrec et al Nucl. Instrumen. Meth. B 222 (2004) 130

PT2 33 PLASMA APPLICATIONS FOR NANOTECHNOLOGY

PT2 34 Modeling of silicon nanowire growth DEEPAK BOSE, *Ames Center for Nanotechnology* HELEN HWANG, *NASA Ames Research Center* T.R. GOVINDAN, *NASA Ames Research Center* Nanometer scale structures are being actively explored as alternative means to fabricate high density devices that are beyond the reach of conventional techniques. Silicon nanowire, in particular, is of interest because the role of silicon in semiconductor devices and its possible integration using existing technologies. Current nanowire growth methods include chemical vapor deposition and laser ablation. The one-dimensional growth is assisted by a metal catalyst droplet which acts to enhance gas decomposition and adsorption. Once the droplet supersaturates with silicon, a nanowire begins to grow. Recently, a low growth temperature was achieved using an RF plasma CVD system. In this work we present a nanostructure growth model based on the phase field approach. A multi-phase model with sufficient description of the catalyst assisted growth will be built to describe the nanowire growth in a PECVD system. In a phase field model, which is widely used in solidification processes, the free energy minimization equation is solved along with diffusion and heat transfer equations.

PT2 35 High brightness ion source for focused ion beam based on VHF inductively coupled plasma YOON-JAE KIM, DONG-HEE PARK, YONG-SEOK HWANG, *Department of Nuclear Engineering, Seoul National University* The focused ion beam (FIB) with conventional liquid metal ion source (LMIS) is not adequate as a microprobe for the nano-structure measurements such as nano-MEIS(medium energy ion scattering), because gallium ions can cause contaminations or damages to the structure of objects. For this reason, an rf ion source which is able to produce light ion beam (H+, He+) has been tested in order to investigate its feasibility as an alternative high-brightness ion source for FIB. Plasma characteristics of inductively coupled plasmas using hydrogen as a working gas are studied under various conditions by changing gas pressure, antenna geometry, and rf driving frequency, in order to find out optimum plasma conditions for high-brightness ion beam extraction. An rf ion source based on those results has been constructed, and beam currents and emittances are measured.

PT2 36 Density of N atoms in a nitrogen source used for the gallium nitride epitaxy N. SADEGHI, *University Joseph Fourier & CNRS, France* J. OSAKA, K. SASAKI, H. SUGAI, *Nagoya University, Japan* Nitrogen plasma sources are successfully used for N doping of different semiconductor materials by molecular beam epitaxy (MBE). However, the origin of specie responsible for doping is not yet very well established, even if N atoms have been proposed by several authors. We have used optical emission spectroscopy to characterize a commercial ICP nitrogen plasma source (SVTA-RF4.5) that we are using for the gallium nitride MBE. A small amount of krypton added as actinometer to the gas flow, permits to follow the evolution of N and N_2 densities with gas pressure and RF power. Our results indicate a high gas temperature (ranging from 1200 to 2000 K when the RF power increases from 100 to 300 W) and about 5000 K for the vibrational temperature for N_2. The degree of dissociation is also smaller than the previously reported value for this source. Changes on m/e=14 and 28 signals when mass spectrometry measurements are carried out in the MBE chamber, also reveal a degree of dissociation of a few percent.

PT2 37 Characteristics of Toluene Treatment by Combination of Surface Discharge and Ad-vance Oxidation Processes MITSUAKI SHIMOSAKI, *Saga University* NOBUYA HAYASHI, *Saga University* CHOBEI YAMABE, *Saga University* Recently, decomposition of the toluene has been studied using several types of discharges, and the decom-position was 70decomposition rate of toluene and to con-trol byproducts, combination of surface discharges and Advanced Oxidation Process was developed for the treat-ment of volatile organic compound. The oxygen radical was generated by irradiation of ultraviolet rays (253.7 nm) to ozone, which was able to decompose toxic substances such as toluene. UV rays from UV light tube irradiated to ozone which generated by the surface discharge to generate oxygen radical. Toluene was decomposed efficiently by the surface discharge and oxygen radical. The maximum decomposition rate of toluene was achieved to be ap-proximately 98 exceeded 3.5 kV. Measured byproducts were water vapor, carbon monoxide, carbon dioxide and formic acid. However, formic acid was generated in the case of low discharge power (below 3 kV), it was decomposed to water, carbon monoxide and carbon dioxide, when discharge power exceeded 3 kV.

PT2 38 Stable and unstable operation of a chlorine-based ICP C.S. CORR, *LPTP, Ecole Polytechnique, France* P.G. STEEN, *School of Physical Sciences, DCU, Ireland* W.G. GRAHAM, *Queen's University Belfast, Northern Ireland* Chlorine-based inductively coupled discharges are characterized using optical emission, electrostatic probes and probe-based photodetachment. Measurements of the negative ion fraction, the charged particle densities and the electron probability functions are presented. Instabilities are observed in the form of periodic modulations in the light output, floating potential, negative ion fraction and charged particle densities. When the discharge is tuned for zero reflected power instabilities are observed only in argon-chlorine mixtures and occur over limited operating conditions of input power, gas pressure and chlorine content. By variation of the matching conditions, an apparent pulsed plasma environment in a pure chlorine discharge is observed. Time-resolved measurements of the negative ion fraction show that there is a continuous transition between an electron-ion plasma in the on period and an ion-ion plasma in the off period. This pulsed plasma instability may be advantageous for industrial applications.

PT2 39 Experimental Study on Ozone Formation in Dielectric Barrier Discharge of Oxygen TAKASHI KIMURA, YOSUKE HATTORI, AKINORI ODA, *Graduate School of Engineering, Nagoya Institute of Technology* Atmospheric pressure oxygen discharge with dielectric barriers, which is one of successful attempts to obtain high O_3 production, was studied by using a time-modulated power supply. The discharge was produced between the parallel plate electrodes, whose surfaces were covered with Pyrex glass with 0.5 mm thickness, in the discharge gap of 1 mm, by applying a time-modulated sinusoidal voltage with the frequency of 1.5 kHz. The amplitude of the applied voltage was about 7.5 kV. The radius of upper and lower electrodes made of

stainless steel was 70 mm ϕ. Typical O_3 concentration and the production efficiency were about 850 ppm and 200 g/kWh, where the total flow rate was 4 ℓ/min and the dissipated power was 2 W. The ozone production efficiency obtained by a time-modulated power supply, which was a decrease function of the power injected into the discharge, was higher than that obtained by a C.W. power supply. The optimum on-time for obtaining the maximum value of the efficiency corresponds to the period of the sinusoidal voltage, while the efficiency does not depend on the off-time of the power supply except for the off-time shorter than about 10 ms. This work is partially supported by Grant-in-Aid from the Japan Society for the Promotion of Science.

PT2 40 Ozone Production by Double Discharge Method Using Partly Covered Electrode SHUNICHI KANEDA, NOBUYA HAYASHI, CHOBEI YAMABE, *Saga University* The double discharge method has been developed to obtain an atmospheric pulsed discharge with high spatial uniformity. However discharge volume and discharge power of this configuration are limited by occurrence of arc discharge. In order to revise the problem, a brand new double discharge type ozonizer with a metallic anode partly covered with the dielectric was proposed. The partly covered electrode stabilizes discharge by decrease of discharge current density, and it is enabled to consume higher discharge power without occurrence of arc discharge. Fundamental parameters such as discharge voltage and current waveforms, and ozone concentration were investigated to characterize the new double discharge type ozonizer scharge volume and discharge power enhanced to 180 dielectric, and the ozone concentration was increased from 300 ppm to 750 ppm and the generation yield was improved from 90 g/kWh to 100 g/kWh.

PT2 41 Treatment Carbon Dioxide Using Atmospheric Non-thermal Plasma Produced by Surface Discharge NOBUYA HAYASHI, HIROSHI YOSHIDA, SABUROH SATOH, CHOBEI YAMABE, *Saga University, Japan* Decomposition and fixation of carbon dioxide (CO_2) were studied using a non-thermal plasma produced by the surface discharge. The mixture gas of carbon dioxide and hydrogen or water vapor was introduced to a discharge reactor in order to deoxidize carbon dioxide and produce organic compounds. The effective condition of the treatment was investigated by controlling several parameters such as a discharge voltage, an input power and a gas flow rate. The decomposition rate of carbon dioxide and species of byproducts were determined by a FTIR spectroscopy. FTIR spectra of exhausted gases from a discharge reactor indicated that the maximum decomposition rate of carbon dioxide and the maximum energy efficiency were achieved to be 40% and 120 g/kWh, respectively, with at the discharge voltage of 11 kV. Major byproducts after the discharge treatment were determined to be carbon monoxide (CO), methane (CH_4) and dimethyl ether (C_2H_6O).

PT2 42 Mechanisms of plasma-photocatalyst interaction OLIVIER GUAITELLA, LINA GATILOVA, ANTOINE ROUSSEAU, *LPTP, Ecole Polytechnique CNRS 91 128 Palaiseau France* CHANTAL GUILLARD, FREDERIC THEVENET, *LACE - CNRS ucb LYON 1 69622 Villeurbanne cedex, France* JURGEN ROEPCKE, *INP-Greifswald, F.-L.-Jahn-Str. 19, 17489 Greifswald, Germany* In order to improve the understanding of the synergy of the plasma-photocatalysis combination for VOCs removal, in-situ measurements of infrared laser absorption spectroscopy are performed in a low pressure pulsed DC discharge. We report preliminary results concerning the oxidation of C2H2 as a function of the pulse duration, frequency and pulse current. Photocatalyst (TiO2) may be used as a sol-gel coating or as pellets inserted in the discharge tube. The influence of TiO2 on the O atom density produced in the plasma phase (measured by emission spectroscopy) is also reported. Infrared laser absorption results are compared with measurements performed using gas chromatography.

PT2 43 BIOLOGICAL AND EMERGING APPLICATIONS OF PLASMAS

PT2 44 Water permeability of polyethylene terephthalate track membranes modified in plasma of dimethylaniline LYUBOV KRAVETS, *Joint Institute for Nuclear Research, Dubna, Russia* SERGUEI DMITRIEV, *Joint Institute for Nuclear Research, Dubna, Russia* ALLA GILMAN, *Enikolopov Institute of Synthetic Polymeric Materials, Moscow, Russia* ALEXANDER DRACHEV, *Enikolopov Institute of Synthetic Polymeric Materials, Moscow, Russia* The surface properties and hydrodynamic characteristics of composite membranes consisting of a porous substrate, on which a polymer layer from a direct current discharge in a mixture of air and vapours of dimethylaniline was deposited, have been investigated. As a substrate, we used poly-(ethylene) terephthalate track membrane (PET TM) of the thickness of 10 μm and the effective pore diameter of 0.215 μm (pore density is $2 \cdot 10^8$ cm^{-2}). The performed researches show that when treating the membranes in plasma, two competing processes are observed: deposition of the polymer layer on a membrane surface, that testifies increase of the mass of sample, and etching of a polymeric matrix which causes growth of effective pore diameter. The last process is stipulated by presence of oxygen in the gas mixture. Decreasing the degree of overweight of the sample at increasing the treatment time leads us to a supposition that a dominating process in this case becomes the process of gas-discharge etching. In all cases, if treating PET TM, a drop of the water contact angle occurs, i.e. hydrophilization of the membrane surface takes place that is connected first of all with a grafting of polymer layer containing polar functional groups. The research in the hydrodynamic characteristics of the initial PET TM and the membranes modified in plasma at neutral and subacid pH value of filtrate leads to a linear dependence of their permeability upon the quantity of applied pressure. It is connected with a viscous character of the flow, that is, when the diameter of the pores of the membrane is much more than the size of the water molecules. This fact shows that the macromolecules of the deposited polymer layer in this case have a compact conformation, which does not hinder the water molecules infiltration. At a lower pH value of the filtrate, the picture cardinally changes. For modified in plasma membranes a diversion from the linear relation is observed. This means that in this case the dominating is a diffusive mechanism of permeation of water molecules through the membranes. It is caused by decreasing the membrane pore diameter which is explained by changing the conformation state of macromolecules of the deposited in plasma polymeric layer. At low pH values of the solution, the

macromolecules of this layer have an loose conformation stipulated by presence of a positive charge due to protonization of nitrogen atoms. Such a conformation state of macromolecules results in a noticeable decrease in the water permeability.

PT2 45 Corona Discharge Influence on Moulds* VLADIMIR SCHOLTZ, *Department of Physics, CTU FEE Prague, Czech Republic* It is known that the electric discharge has bacteriocid effect. We are interesting on influence of corona discharge on moulds and searching for it's fungicide effect. In this work we study the mould penicillium digitatum by using an easy apparatus, where may be situated two measured samples. One in the burning corona discharge and one in the area with ozone generated by this corona only. We expose the spores of penicillium digitatum on a metal plate and on a cultivating medium on cca 0.01mA, 5kV corona discharge and on generated ozone only for time cca two days. It is the time needed for sprouting of spores and growing of they to a visible size. The pilot results show, that the ozone generated by the corona discharge has none or very low influence on the sprouting and growing of the spores. Direct corona discharge inhibit the sprouting only, but does not kill the spores. In next experiments we will try to find some minimum inhibit and killing concentration of ozone and try to expose the sprout inhibition.

*This research has been supported by GACR grant No. 202-03-H162.

PT2 46 A Model Study of the Plasma Needle W.J.M. BROK, J.J.A.M. VAN DER MULLEN, G.M.W. KROESEN, *Eindhoven University of Technology, The Netherlands* The plasma needle is a small ($1mm$) non-thermal atmospheric RF plasma, which has received attention in the biomedical field for its capability to treat cell cultures and tissues in a very localised manner. In order to learn more about the plasma properties of the plasma needle, we studied it by means of a two-dimensional fluid model. Different geometrical arrangements were considered: the needle was positioned sufficiently far removed from a surface such that it could be considered a unipolar discharge; and it was brought close to surfaces of various electrical properties. In this paper we discuss the results of these simulations in terms of dissipated power, species densities and shape of the discharge as a function of input parameters like applied voltage and geometry. We found that electron densities are typically in the order of $10^{17} - 10^{18} m^{-3}$ and that even for very small (0.01%) admixtures of nitrogen the nitrogen molecular ion is the dominant ion. Furthermore, the electrical impedance of the plane near the needle has a significant effect on the densities of the various species and the dissipated power.

PT2 47 Sporicidal effect of an atmospheric pressure flowing afterglow JULIETTE LARBRE, ANNE-MARIE POINTU, *LPGP, Universit Paris-Sud, Orsay, France* MIHAI GANCIU, *NILPRP, Institute of Atomic Physics, Bucharest, Romania* PROGRAMME PLURIFORMATION COLLABORATION, A previously presented atmospheric post discharge (PD) in flowing N_2 is studied in view of decontamination applications. B. stearothermophilus spores are inserted in PD and emission spectrum in the treatment region is simultaneously observed. In ''pure'' N_2 the spectrum exhibits FPS of N_2 due do N recombination and some lines of CN and NH due to N_2 organic impurities. Adding O_2 in controlled increasing quantities to nitrogen progressively replaces CN and NH lines by a rich UV spectrum corresponding to NO excited states. In a specific N_2/O_2 ratio range it appears an intense green glow corresponding to $O(^1S).N_2$ excimer. Relative evolution of lines vs O_2 flux shows that it is possible to operate in three separate conditions for the number of potential bactericidal agents: N alone, N plus $O(^1S)$, N plus UV around 250 nm. Corresponding decreasing laws of surviving spores vs treatment time will be presented, evidencing the relative sporicidal efficiency of UV and active nitrogen and oxygen atoms.

PT2 48 CORONAS, BREAKDOWN AND SPARKS

PT2 49 Optical imaging of breakdown in a low-pressure argon discharge ERIK WAGENAARS, MARK BOWDEN, GERRIT KROESEN, *Eindhoven University of Technology, Department of Applied Physics, P.O. Box 513, 5600 MB Eindhoven, The Netherlands* Breakdown is an elementary process in plasma science, but the physics are still only poorly understood, mainly due to its rapid, transient nature. We investigated breakdown in a low-pressure argon discharge experimentally by making time-resolved images of plasma emission with an intensified charge coupled device (ICCD) camera. Several features of the breakdown, such as a light emission region in front of the anode and a light front crossing the discharge gap from anode to cathode were investigated. We also observed a pre-breakdown light flash, which occurred before the main breakdown stage, at the time when the applied voltage was below the static breakdown voltage. Although details remain unclear, this flash of light is thought to originate from surface charges left over from previous discharges. In addition, we measured the time delay of the discharge as a function of afterglow period, known as a memory curve. These measurements indicated that charges produced in a discharge were mainly lost in volume recombination processes in the first 10 μs of the afterglow.

PT2 50 Optical and electrical characterization of breakdown processes in compact fluorescent lamps MAXIME F. GENDRE, M.D. BOWDEN, G.M.W. KROESEN, *Eindhoven University of Technology* H.C.M. VAN DEN NIEUWENHUIZEN, M. HAVERLAG, J.W.A.M. GIELEN, *Philips Lighting - Central Development Lighting* The aim of the research is a better understanding of the ignition phase of compact fluorescent lamps via the study of the processes leading to electrical conduction in linear hot cathode lamps filled with rare gases at a pressures from 2 to 10 mbar. Square voltage pulses ranging from -200 V to -650 V were applied to the lamp cathode via a ballasting resistor while the anode was kept at ground potential. Optical and electrical diagnostics, by means of an ICCD camera and a specially designed capacitive probe, have shown that a localized ionisation wave starts at the cathode and propagates toward the opposite electrode with a gradually decreasing speed. The breakdown voltage was found to be the condition for this pre-breakdown wave to reach the anode, after which a second wave develops in the opposite direction with a higher speed. Then, the two electrodes are bridged by a continuous plasma that further develops until the load resistor limits the discharge current. The propagation of the ionisation waves was found to coincide with a change in the lamp wall surface potential.

PT2 51 Calculated Paschen curves for short gaps in atmospheric pressure air L.C. PITCHFORD, *CPAT, CNRS and Univ. P. Sabatier, Toulouse, France* A.V. PHELPS, *JILA, U. of Colorado and NIST* S.W. ROWE, F. GENTILS, *Schneider Electric, Grenoble* We use a Monte Carlo simulation to calculate electron multiplication in short gaps (100 microns or smaller spacing between parallel electrodes) in air at atmospheric pressure. The multiplication vs pd (product of gas pressure and gap spacing) is then used in the Townsend breakdown criterion to yield the breakdown voltage for different assumed values of the secondary electron emission coefficients. Electron reflection from electrodes, variations in the secondary electron emission energy, and relative humidity have have little influence on the breakdown voltage. For gaps lengths between 5 and 20 microns it is important to take into account the finite relaxation distance for ionization near the cathode. For gap lengths less than about 5 microns experiment suggests that breakdown via the Townsend mechanism does not occur because of a transition to field emission controlled behavior[1]. This transition and the effect of rounded electrodes will be discussed.

[1]J. M. Torres and R. S. Dhariwal, Nanotech. **10**, 102 (1999).

PT2 52 Multipoint-to-plane corona discharge light emission and electrical field comparison* JAN KOLLER, *Czech Technical University Prague* VITEZSLAV KRIHA, *Czech Technical University Prague* JAN PICHAL, *Czech Technical University Prague* LUDEK AUBRECHT, *Czech Technical University Prague* Results of experimental investigation of corona light emission for different point-to-plane electrode configurations are presented in this work. Corona discharge was burning in air at atmospheric pressure. Experimental results are compared with a model of electrical field. Results show discordance between distributions of light intensity and absolute values of electrical field intensities. Distributions of electric field axial deviation clarify mentioned discordance. Goal of this study is the electrode system optimization for the plasma treatment purpose.

*This research is supported by Grant Agency of the Czech Republic under contracts No. 202/02/D055 and 202/02/P139.

PT2 53 LASER MEDIA-PROCESSES

PT2 54 Singlet oxygen generation in gas discharge for oxygen-iodine laser pumping D.V. LOPAEV, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* O.V. BRAGINSKY, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* K.S. KLOPOVSKY, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* A.S. KOVALEV, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* YU.A. MANKELEVICH, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* N.A. POPOV, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* A.T. RAKHIMOV, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* T.V. RAKHIMOVA, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* A.N. VASILIEVA, *Skobeltsyn Institute of Nuclear Physics, Moscow State University* The possibility of development of effective discharged singlet oxygen (SO) generator (DSOG) for oxygen-iodine laser (OIL) is studied in detail. Researches of kinetics of oxygen atoms and oxygen molecules in the lowest metastable singlet states have been carried out in the different discharges and its afterglow (DC discharges, E-beam controlled discharge and RF discharges) in both CW and pulsed mode in a wide range of conditions (pressures, gas mixtures, energy deposits etc.). The models developed for all the discharges have allowed us to analyze SO generation and loss mechanisms and to find out the key-parameters controlling the highest SO yield. It is shown that in addition to spatial plasma uniformity at low E/N and high specific energy deposit per oxygen molecule, DSOG must be oxygen atom free to avoid fast three-body quenching of SO by atomic oxygen with increasing pressure and thereby to provide pressure scaling (in tens Torrs) for applying to real OIL systems.

PT2 55 HIGH PRESSURE GLOW DISCHARGES

PT2 56 Diagnostics of a High Pressure Helium Microplasma* QIANG WANG, *University of Houston* IVANKA KOLEVA, *University of Sofia* DEMETRE ECONOMOU, *University of Houston* VINCENT DONNELLY, *University of Houston* Gas and plasma diagnostics were performed in a slot-type DC microplasma (200 microns gap) discharge at high pressures. The gas temperature in a helium discharge was estimated by adding small quantities of nitrogen (<100 ppm) into the gas feed. Specific rotational bands of the N2 second positive system were carefully selected to avoid interference with emission from He atoms and He2 excimer. At 250 Torr pressure and 200 mA/cm2 current density, the gas temperature was Tg = 350 +/- 25 K. The measured gas temperature was almost independent (to within experimental uncertainty) of pressure (in the range of 150 Torr 600 Torr), and current density (in the range of 100 mA/cm2 400 mA/cm2). These measurements were consistent with a simple heat transfer model. Spatially resolved measurements of electron temperature were also performed using trace rare gas optical emission actinometry (TRG-OES). These measurements are greatly complicated by collisional quenching at the high operating pressures. Electron density and electron temperature profiles was deduced by comparing emission intensities from the Paschen 2px (x = 1-10) manifold of Ne, Ar, Kr and Xe trace gases. Results suggested that the electron temperature peaks in the cathode sheath region, while the plasma density peaks away from the cathode sheath. A self-consistent fluid model of a DC helium microdischarge was in agreement with the experimental data. The model was used to study the dependence of discharge characteristics on operating conditions (pressure, gap spacing, current density, etc.).

*Work supported by the department of Energy

PT2 57 Simulation of Radio-Frequency Helium Discharge Plasmas at Atmospheric Pressure AKINORI ODA, TAKASHI HASEGAWA, TAKASHI KIMURA, *Grad. School of Eng., Nagoya Inst. of Technol., Japan* YASUSHI OSHIKANE, *Grad. School of Eng., Osaka Univ., Japan* Radio-frequency and atmospheric pressure discharge plasmas are strongly desired as the plasma sources for material processing such as surface modifica-

tion, etching, deposition. In this study a one-dimensional fluid model of the discharge plasmas in heluim was developed and then the discharge propeties were analysed. The fluid model consists of the continuity equations for charged species (e^-, He^+, He_2^+) and neutral species (He, He(^{3}S), He(^{1}S)), the electron energy equation and the Poisson equation. The discharges were produced in the discharge gap of 1 mm by applying the sinusoidal voltage with amplitude of 150 V and frequency of 13.56 MHz to the metallic electrodes. From calculated spatial profiles of charged species density, a cup-like shape was formed in discharge space. The shape in the discharge was very similar to that in low-pressure capacitively coupled discharges in case of low input power. The discharge was sustained by electrons and He_2^+ ions with high plasma density of 10^{12} cm^{-3}. He^+ ion density was two order of magnitude lower than He_2^+ ion density. This work was partially supported by Grant-in-Aid from Japan Society for the Promotion of Science.

PT2 58 The Influence of Polymer Film on an Atmospheric Pressure Glow Discharge in Helium* GAGIK NERSISYAN, WILLIAM GRAHAM, *Queen's University Belfast, Belfast BT7 1NN, Northern Ireland, UK* Atmospheric pressure glow discharges (APGD) have potential in polymer surface modification. Here the affect of low density polyethylene (LDPE) film, placed on the electrodes and in the inter-electrode gap, on the development and the uniformity of pulsed APGDs in helium has been studied using short exposure time images and emission spectroscopy of the gap. The APGD was generated between two parallel, glass-ceramic plates, covering metallic mesh electrodes driven by a sinusoidal (5 kV peak to peak) voltage at a frequency of 30 kHz. The build-up of the APGD started from a weak luminous region near the anode followed by the formation of a bright negative glow. When the film was tightly pressed to one of the dielectric plates the intensity of the negative glow decreased and after about 5 minutes the discharge became spatially non-uniform. When the film was stretched through the middle of the gap, it behaved like a dielectric barrier splitting the gap into two APGD regions i.e. with a negative glow on both sides. The affect of the film on the emission spectroscopy and on the electric characteristics will be discussed.

*Supported by the UK Engineering and Physical Science Research Council

PT2 59 Modeling the kinetics in high-pressure glow discharges KENNETH STALDER, *STAR* ROBERT VIDMAR, *UNR* GAGIK NERSISYAN, *QUB* WILLIAM GRAHAM, *QUB* High-pressure glow discharges generated in both pure helium and helium-air mixtures have been studied using a plasma chemistry code originally developed for simulations of electron-beam produced air plasmas.* The code also contains numerous reactions relevant to helium. These glow discharges are developed by applying sinusoidal voltage waveforms between two parallel planar metallic electrodes covered by glass plates, with frequencies ranging from 1-50 kHz and electric field strengths up to 5kV/cm. The code simulates the plasma chemistry following periodic pulsations of ionization in prescribed E/N environments, currently simplified to time-independent values. Many of the rate constants depend on gas temperature, electron temperature, and E/N. In pure helium plasmas, rapid conversion of atomic helium ions to molecular helium ions dominate the positive ion kinetics and these species are strongly modulated. With air added, the positive ion kinetics are roughly the same, but rapid attachment processes convert many free electrons to negative ions. Metastable helium densities of about 10^{10} cm^{-3} also develop and influence the discharge via Penning ionization and other processes. The computational results will be compared to experimental results from QUB. *R. J. Vidmar, K. R. Stalder, paper FT2-6, 2003 GEC, San Francisco, CA

PT2 60 Self-organized Patterns in an Atmospheric Pressure Glow Discharge YUN YANG, *Wolfson School of Mech. & Manu. Eng., Loughborough University, UK* J.J. SHI, J.H. HARRY, J. PROCTOR, C.G. GARNER, M.G. KONG, *Dept of Electronic and Electrical Eng, Loughborough University, UK* In this contribution, we report experimental observation of self-organized patterns along the column of an atmospheric pressure glow discharge (APGD) generated with an excitation frequency in the kilohertz range. Such self-organized plasma structures have been observed in space plasmas and laboratory-produced vacuum glow discharges, but are not believed to have been reported previously for atmospheric glow discharges. Generated in atmospheric helium, these self-organised plasma structures typically compose of several double-layer regions each with alternating bright and dark layers. At all excitation frequencies from 10kHz to 100kHz, the layered structure appears to be static and stable and the layer thickness is about 0.3 – 1mm. It also has axial symmetry. Electrical measurement of such self-organized APGD indicates the existence of two distinctly different branches of the current-voltage characteristics (CVC) and an S-figure formed by the two CVC branches.

SESSION QW1: PULSED PLASMAS
Wednesday morning, 29 September 2004
Belfast Room, Bunratty Conference Centre at 8:30
Uwe Czarnetzki, University of Bochum, presiding

8:30
QW1 1 Evaluation of Self-Sputtering Time-Scale in Pulsed Magnetrons using Time-Resolved OES and Monte Carlo Calculations TAMARA MOISEEV, DAVID CAMERON, *Dublin City University, School of Electronic Engineering* Time-resolved Optical Emission Spectroscopy of Ar+ ions and Cu sputtered atoms in a pulsed DC magnetron discharge shows that the intensities of the exited Cu lines are maintained at almost constant levels for several us after the Ar+ lines intensity has decayed. This effect can be attributed to Cu self-sputtering. To assess the amount of self-sputtering and the time scale of this effect relative to the operating duty-cycle in a pulsed DC magnetron, the return time to the target of the sputtered metal ions has been evaluated through Monte Carlo calculations. The ON time of a pulsed DC magnetron plasma at 50kHz, pulse width 2016ns, 2A constant current run and 0.4Pa Ar gas pressure has been modelled for a magnetron with opposed rectangular copper targets. A computer code that simulates 3D charged particles trajectories in 3D electric and magnetic fields has been developed and used to simulate Cu ions trajectories in the plasma bulk. At each time step of 0.02us, the magnetic field is calculated using a routine based on the current sheet model and the cathode sheath thickness is calculated using the Child-Langmuir law and the corresponding I and V waveforms measured values. The return time to target for Cu ions has been evaluated and compared to the time-resolved OES measurements. The consequences of the self-sputtering and confinement time-scales are discussed in connection to the starting energy of Cu ions and the operating duty cycle of the magnetron.

8:45
QW1 2 Time-resolved Langmuir probe and optical investigation of a pulsed DC magnetron plasma ABE BELKIND, KURT BECKER, ALFRED FREILICH, JOSE LOPEZ, Z. ZHAO, WEIDONG ZHU, *Stevens Institute of Technology, Hoboken, NJ, USA* Pulsed DC plasmas are used for reactive sputtering of dielectrics. During the off-time of 1-10 us, the plasma partially decays, and is subsequently quickly restored during the following on-time. The properties of the pulsed plasma have been studied using time-resolved Langmuir probe measurements and optical plasma emission spectroscopy. Results from both sets of measurements will be reported. Time-resolved optical emissions of the sputtered metal (Al), of the carrier gas argon, and of the reactive atomic oxygen radical have been obtained and are correlated with the time-resolved conventional plasma parameters (electron temperature, plasma density, and plasma potential). The reactive sputter deposition of Al2O3 was used to analyze the pulsed plasma properties. Work supported by US Army and Advanced Energy Industries, Inc.

9:00
QW1 3 Optical studies of the spatio-temporal characteristics of a pulsed DC magnetron plasma JOSE LOPEZ, WEIDONG ZHU, ALFRED FREILICH, ABE BELKIND, KURT BECKER, *Stevens Institute of Technology, Hoboken, NJ, USA* Magnetrons used in the sputter deposition of dielectric films are often excited by pulsed Direct Current (DC) power by applying a slightly positive voltage to the target electrode during the off-time. It has been shown that the reverse voltage allows the removal of charges that accumulate on the dielectric layer that cover the target electrode during the sputter deposition of dielectric films. Therefore this technique has been effectively used to reduce arcing in the reactive magnetron sputtering of dielectrics. In an effort to better understand the effects of pulsing frequency and reverse time on the properties of pulsed DC magnetron plasmas used in reactive sputtering of alumina, we used time-resolved optical plasma emission spectroscopy employing a fast intensified CCD (ICCD) camera in addition to time and space averaged studies of the plasma. Emissions of argon (carrier gas), oxygen (reactive gas), and aluminum (target) were investigated. Work supported by the NSF.

9:15
QW1 4 Plasma diagnostics of a bi-polar pulsed magnetron discharge ALENA VETUSHKA, JAMES W. BRADLEY, *Physics Dept.,UMIST, Sackville Street, Manchester, M60 1QD, UK* This study presents time-resolved measurements of the basic plasma parameters, such as electron temperature T_e, plasma density n, plasma potential V_p and floating potential V_f measured using emissive and Langmuir probes in a bi-polar pulsed magnetron discharge. In the discharge driving waveform three phases could be identified: an ''on'' phase, a ''reverse'' phase and a positive ''overshoot.'' It was established that plasma potential closely follows the driving waveform always remaining more positive than it. During the positive ''overshoot'' it leads to the formation of very energetic ions, which may assist in the deposition process and bring additional energy to the growing film. During the ''reverse'' phase of the pulse, the plasma potential remains constant throughout the bulk of the discharge. This fact proves the collapse of $E \times B$ drift, however the other drifts still may be present. The electron temperature is found to be in the range of 1-3 eV, depending on the position during this phase. In the ''on'' phase, the plasma is indistinguishable from the DC case, with typical values for electron temperature in the range of 0.5-6 eV depending on position, however with two groups of electrons present outside the magnetic trap. The plasma density was found to be between 10^{15} to 10^{17} m^{-3}.

9:30
QW1 5 Temporal behavior of low pressure, pulsed plasmas in argon and boron tri-fluoride LUDOVIC GODET, SVETLANA RADOVANOV, ZIWEI FANG, *Varian Semiconductor Equipment Associates, Gloucester MA 01930, USA* CHRISTOPHE CARDINAUD, GILLES CARTRY, *Nantes University, France* DAMIEN LENOBLE, *ST Microelectronics, Crolles Cedex, France* ANDR GROUILLET, *ST Microelectronics, Crolles Cedex, France* Time dependent measurements of ion energy distribution, plasma potential, relative ion density and electron temperature are reported for a pulsed plasma doping system (PLAD). The pulsed, glow discharge is created by a negative pulsed voltage (0.3 to 3 kV) applied to a wafer in the presence of low pressure (10-40 mTorr) argon (Ar) and boron tri-fluoride (BF3). These plasmas are characterized by electron density in the 1010ions/cm-3 range with electron temperature of 2-5 eV. Time resolved, bulk plasma ion energy distributions are correlated with time resolved Langmuir probe measurements of plasma potential and electron density with particular focus on the plasma decay in BF3 plasmas.

9:45

QW1 6 Self -pulsing of an inductively coupled chlorine discharge V. J. LAW, *Dublin City University, Ireland* C. S. CORR,* F. GARCIA, *The Queen's University of Belfast, Northern Ireland* F. SOBERON, A. R. ELLINGBOE, *Dublin City University, Ireland* W. G. GRAHAM, *The Queen's University of Belfast, Northern Ireland* Light emission from an inductively coupled chlorine discharge is normally intense and constant in time. However under certain operating conditions, fluctuations occur. These can vary from a series of sharp bursts to a periodic behaviour. Here the interest is in regular oscillations with frequencies of up to 10s of Hertz. We have observed these oscillations not only in the light output but also in electrical measurements, which indicate that this modulation is a result of the tank circuit established by the capacitance of the matching network and inductance of the antenna. The negative ion measurements indicate that the oscillations produce a self-pulsed plasma system. Measurements are underway to look for modulation of the atomic chlorine density. These would establish the potential of these phenomena for use in pulsed etching applications. Funded by the HEA North-South Programme for Collaborative Research and SFI under grant number 02/IN.1/I147.

*Present Address: Ecole Polytechnique, France

SESSION QW2: LIGHTING II
Wednesday morning, 29 September 2004; Dublin Room, Bunratty Conference Centre at 8:30
Paul Swift, Dublin Room City University, presiding

Invited Papers

8:30

QW2 1 Chemi-ionization of Mercury in Lighting Environments.
LEE A. COLLINS, * *Los Alamos Nat. Lab.*

We report calculations of the chemi-ionization for the collisions of Mercury (Hg) atoms in the excited singlet and triplet P states (^{1,3}P), examining both the Penning and Associative Ionization mechanisms. This process provides an important loss mechanism in the modeling of fluorescent lamps with reactions affecting the ionization balance and excited-state distributions through subsequent recombinations. Potential energy curves for the excited neutral (Hg_2^{**}) and the ion (Hg_2^+) molecular states are generated using relativistic effective core potentials and full four-electron configuration interaction, based upon the orbitals of the ground state at each internuclear distance. We have examined the influence of core-valence correlation and the errors associated with the interaction curves will be discussed. For such heavy atomic systems, the spin-orbit interaction plays an important role, and its inclusion follows from an effective hamiltonian based on the atomic splittings[1]. We shall also present estimates of the cross sections for chemi-ionization using a black-sphere model in which ionization occurs only if the classical turning point lies within a prescribed internuclear distance. We have also determined resonant widths from Feshbach projection and Stieltjes imaging formulations. Research performed as a participant in the EPRI ALITE program and under the auspices of the U.S. Department of Energy through the Los Alamos National Laboratory.

*J.S. Cohen, B.I. Schneider, and R.L. Martin.

[1]J. Cohen *et. al. Phys. Rev.* **66**, 012717 (2002).

9:00

QW2 2 The R&D Issues in PDP Technology.
KI-WOONG WHANG, *School of Electrical Engineering, Seoul National University, Seoul, Korea*

PDP (Plasma Display Panel) is becoming one of the major flat display devices with screen sizes bigger that 30″ diagonal. Since PDP is an emissive device with a very short response time, its image quality is superb in comparison to those of the TFT-LCD or projection type display devices. However its luminous efficiency is still very low (2lm/W) mainly due to the inefficient way of plasma generation. Pulsed, coplanar, DBD (Dielectric Barrier Discharge) type plasma generation with high pressure (~ 500) Ne-Xe gas mixture accompanies a very strong ion heating and plasma-surface interaction. Recent researches show limited improvement in the luminous efficiency could be obtained through the changes in the pixel design, gas composition, driving method and material notably phosphor. But a completely new plasma generation mode may be needed to increase the current low luminous efficiency to the desired value of 4~ 5lm/W. Another important issue may be the cost of PDP. Aggressive cost reduction plans are called for to guard off the challenges from the LCD or projection display devices. Possible ways of improving the luminous efficiency and reducing the cost of PDP will be suggested and discussed.

Contributed Papers

9:30

QW2 3 Luminous plasmoid in an electrodeless HID lamp excited by circularly polarized microwaves JIN JOONG KIM, DONG HO WON, *Sejong University* JEONG WON KIM, SUNG HO HONG, *Taewon Lighting Laboratory* We report on the demonstration of a high-pressure luminous plasmoid of oblate-spheroidal shape in an electrodeless high-intensity discharge (ELS-HID) lamp excited by circularly polarized microwaves (CPMs). Conventional ELS-HID lamps are discharged in a TE11 mode in a circular microwave cavity, and as such they generate a prolate-spheroidal (PS) plasmoid in the bulb. In order to avoid formation of localized hot spots in the bulb owing to such a PS plasmoid, the bulb is mechanically rotated. In our ELS-HID lamps, the bulb (30 mm in diam), containing a few mg of a molecular radiator such as di-sulfur or indium bromide and 10 torr of argon, is placed stationary in a circular waveguide. CPMs are generated using a quarter-wave elliptical waveguide excited by a 2.45 GHz magnetron. In full power operation at 1 kW, the bulb is uniformly filled with a bright white-light plasmoid with the luminance in excess of 7E7 cd/m2. As the power is lowered so that the plasmoid does not fill the bulb, the formation of an oblate spheroid of plasmoid of uniform intensity is observed in the middle of the bulb, confirming rotating plasma discharges by CPMs.

9:45

QW2 4 Effect of Buffer Gas on Radiation Trapping of the Hg 254 nm Resonance Line M. T. HERD, K. M. MENNINGEN, J. E. LAWLER, *Univ. of Wisconsin* Fluorescent lamps are the most widely used discharge light source. Most (>50(fluorescent lamp) discharges is released as 254 nm radiation. Classic T12 lamps operate at buffer gas pressures of 3 Torr, while some new types of compact and miniature fluorescent lamps operate at higher buffer gas pressures. Buffer gas broadening affects the trapping of the 254 nm Hg resonance radiation. A detailed, quantitative understanding of 254 nm radiation trapping is essential in modeling the discharge, especially in modeling multistep excitation and ionization processes. The decay rate of the Hg 254 nm upper level was measured as a function of both Hg and Ar density in cylindrical, sealed fused silica cells. Time-resolved laser-induced fluorescence was used to obtain the decay rates for Hg density from 4.3E13 to 7.3E15 /cc (25 to 100 C cold spot temperatures) and Ar density from 0 to 9.7E17 /cc. These new experimental data are compared to Monte Carlo results from a highly realistic code which includes Doppler, resonance, buffer gas, and radiative broadening, as well as hyperfine and isotopic structure. A broadly applicable engineering formula will be derived from this study similar to that for the Hg 185 nm resonance [1]. [1] K. L. Menningen & J. E. Lawler, J. Appl. Phys. 88, 3190 (2000).

SESSION RW1: HIGH PRESSURE DISCHARGES

Wednesday morning, 29 September 2004; Belfast Room, Bunratty Conference Centre at 10:30
Albert Ellingboe, Dublin Room City University, presiding

Invited Papers

10:30

RW1 1 Characteristics of High-Pressure Microwave Glow Discharge in a Microgap Aimed at VUV Light Source.
AKIHIRO KONO, * *Nagoya University*

In continuous high-pressure discharge at high plasma densities, the gas and electron temperatures tend to be in equilibrium and the current path tends to constrict. However, using microdischarge with microwave excitation, we can produce a cw high-density non-equilibrium plasma extending one-dimensionally over some length. We are studying such a plasma aiming at producing a high-brightness VUV excimer light source. The plasma is produced in a microgap ($\sim$ 100 μm) between two 10-mm-long knife-edge electrodes at a very high power deposition ($\sim$ MW/cm^3). VUV emission from Ar_2 and Xe_2 was confirmed using discharge with Ar/He and Xe/He mixture gases. To understand the properties of the microgap discharge, detailed optical diagnostics are being carried out. Spatially resolved Thomson and Raman scattering measurements showed that the electron density in a 100 W He discharge is 3×10^{14} cm^{-3} and the gas temperature is 1200K. The gas temperature was also studied as a function of the gas flow rate through the microgap using N_2 $C^3\Pi$-$B^3\Pi$ optical emission. A rather surprising result is that the gas temperature is relatively insensitive to the gas flow rate even if the flow is rapid enough to replace the gas in the microgap within the characteristic time of diffusive heat conduction to the wall. This suggests the existence of a rapid heat transport mechanism in the discharge other than diffusive heat conduction. The existence of an extremely large gas-temperature garadient between the plasma and the wall may induce a rapid convective heat transport. A computational study of the heat transport mechanism in the microgap discharge is also in progress (Work supported by a Grant-in-Aid for Scientific Research of Priority Areas [15075205] from MEXT Japan).

*In collaboration with J. Wang and M. Aramaki.

11:00

RW1 2 On branching streamers and sprites: Channel head dynamics in laboratory and high atmosphere.
UTE EBERT, *CWI Amsterdam and TU Eindhoven, The Netherlands*

Streamers are weakly ionized channels appearing in the initial electric breakdown of long gaps; they form corona discharges and play a role in sparks and lightning. Their growth and branching is determined at their rapidly propagating heads where the electric field is strongly enhanced due to dynamical self-focussing; this creates exotic nonequilibrium

plasma in the heads. Streamer-like processes also occur in gigantic high altitude lightning when sprite discharges at heights of 40 to 90 km break up into tenthousands of propagating channels. I will review recent observations and then elaborate computations and theoretical concepts. Basically, already a single discharge channel has a multiscale structure with a thin ionization front surrounding a rather inert body. This structure has been observed in computations in the past decades, but it was recognized only recently that this structure also leads to spontaneous branching. The mechanism is a Laplacian instability that can occur similarly at other phase boundaries like liquid-fluid interfaces, solidification fronts etc. I will present computational results with adaptive grids and analytical approximations and solutions; and I will confront the new concepts with older phenomenological concepts for streamer and spark propagation and branching. For papers and co-authors, see http://homepages.cwi.nl/~ebert

Contributed Papers

11:30

RW1 3 Breakdown Characteristics of a Radio-Frequency Atmospheric Glow Discharge JIANJUN SHI, *Loughborough University* MICHAEL KONG,* *Loughborough University* Radio-frequency (rf) atmospheric pressure glow discharges (APGD) are a capacitive nonthermal plasma with distinct advantage of low gas temperature and long-term stability. In practice their ignition is challenging particularly when they are generated at large electrode gaps. To this end, this contribution reports a one-dimensional fluid simulation of gas breakdown over a large pressure range of 100 760 Torr so that key physical processes can be understood in the ignition phase of rf APGD. Our model is an electron-hybrid model in which electrons are treated kinetically and all other plasma species are treated hydrodynamically. Computational results suggest that as the pressure-distance product increases from 25 Torr cm upwards the breakdown voltage increases in a way that resembles the right-hand-side branch of a Pachen curve. Importance of secondary electron emission is shown as well as its dependence on gas pressure even though identical electrode material is assumed. With these factors considered, excellent agreement with experimental data is achieved. Finally frequency dependence of the breakdown voltage is calculated and again found to agree with experimental data.

*Corresponding author

11:45

RW1 4 Two-dimensional Simulation of the Interactions between Bulk Fluid Flow and Plasma Dynamics in direct-current Microdischarges PRASHANTH KOTHNUR, *The University of Texas at Austin* LAXMINARAYAN RAJA, *The University of Texas at Austin* Microdischarges have gained much attention in the plasma process community for a variety of applications. Recently, microdischarges have been proposed in applications that incorporate bulk fluid flow. For example, in one recent study, microhollow electrode plasma devices have been proposed for use as microflow reactors. Our motivation for this study comes from our proposed application in microthrusters for small satellite propulsion. The phenomena of intense, localized, controllable gas heating in microdischarges enables the development of an electrothermal class device capable of thrust levels in the mN range. While some estimates of properties of microdischarges are available, a detailed understanding of the plasma dynamics, chemistry and coupling with bulk flow is lacking. The focus of this talk is to explore the fundamental characteristics of microdischarges, and investigate interactions between plasma dynamics and bulk fluid flow using two-dimensional computational modelling. In view of our proposed microthruster application, the gas-heating aspect of microdischarges is explored in detail. The model incorporates a self-consistent representation of the plasma that includes a description of multi-species transport and chemistry, electric field, electron and heavy species energy distributions in the microdischarge. The Poisson's equation is solved for the electric field and species conservation equations for generation and transport of species in the discharge. The electron energy equation is solved to determine the electron temperature distribution and the heavy species energy equation is used to determine the gas temperature. Our studies indicate that the structure of the microdischarge is highly inhomogeneous, and electron temperatures of order several tens of electron volts are possible. Significant gas heating is predicted, with typical gas temperatures in the range 600-1000 K. The gas temperature is found to vary strongly with discharge current, but shows a relatively weaker dependence on the operating pressure. It is observed that the plasma dynamics are relatively insensitive to bulk fluid flow, confirming that these two phenomena are decoupled.

12:00

RW1 5 Low-Frequency Barrier-Free Atmospheric Glow Discharges JIANJUN SHI, *Loughborough University* XUETAO DENG, *Loughborough University* MICHAEL KONG,* *Loughborough University* Atmospheric pressure glow discharges (APGD) are currently one of the most exciting areas in gas discharge research. At low frequencies from 1–100kHz, APGD generation has been achieved so far with at least one of their electrodes insulated with a dielectric barrier. Without the dielectric barrier, it is often necessary to use higher excitation frequency in the megahertz range to sustain stable operation of APGD. In this contribution, we report the observation of stable barrier-free APGD operation generated between two bare electrodes and at a low frequency between 20kHz and 260kHz. Visual appearance of barrier-free APGD is uniform and free of any obvious streamers. Measured discharge current and voltage traces are smooth and without sharp spikes associated with filamentary plasmas. Dissipated power density is less than 1W/cm3, thus further confirming that they are glow discharges. To understand their generation mechanisms, a one-dimensional hydrodynamic model is used to highlight a new APGD mechanism distinctively different from both atmospheric DBD and radio-frequency APGD. To the best of our knowledge, this is the first observation of low-frequency barrier-free APGD in the kilohertz range and the first evidence that dielectric coating is no longer essential for APGD generation at any frequency.

*Corresponding author

12:15

RW1 6 Microdischarges as Sources of Radicals and Thrust* RAMESH ARAKONI, *Dept. Aerospace Engr., University of Illinois at Urbana-Champaign* MARK J. KUSHNER, *Dept. Elect. and Comp. Engr., University of Illinois at Urbana-Champaign* Microdischarge devices having dimensions of 10s to 100s μm are being investigated for lamps and displays. By virtue of their ability to operate near or at atmospheric pressure in arrays on a cw basis,

microdischarges are also attractive as sources of radicals and as sources of thrust for aeronautical control. In this paper, operation of microdischarge devices operating at 100s Torr to 1 atm will be computationally investigated using a 2-d plasma-hydrodynamics model. The class of devices of interest have cylindrical, hollow cathode designs with central holes for gas flow or planar back electrodes to maximize surface area. When operating at high pressures, momentum imparted to ions by the electric field is quickly transferred to the neutral gas, thereby providing a source of thrust. Speeds of 10s m/s can be produced in the throats of the devices with plasma densities of $10^{14}cm^{-3}$. When operated in air dissociation and excitation of O_2 provides an efficient source of radicals.

*Work supported by National Science Foundation and Air Force Research Labs

SESSION RW2: MATERIAL PROCESSING IN LOW PRESSURE PLASMAS II

Wednesday morning, 29 September 2004; Dublin Room, Bunratty Conference Centre at 10:30
Alex Patterson, Applied Materials, Inc., presiding

Invited Papers

10:30
RW2 1 Stable processing with unstable plasmas?
NEIL BENJAMIN, *Lam Research, Cushing Parkway, Fremont, CA 94538, USA*

Plasmas are employed for materials processing over a very wide range of conditions. For typical etch applications, these include plasmas generated in various ways with RF at various frequencies and power levels ranging from 100W up to 10000W. Mixed gas chemistries are used, at pressures ranging from mTorr to Torr, with multiple, often electron-attaching species present in significant proportions. These complex conditions are typically produced in production reactors that are hardly optimal for diagnostic access, so this is not a recipe for a quiescent lab plasma that may be conveniently studied. Inevitably a range of plasma instabilities and other unstable conditions may be encountered, often without immediate detection, as one spans the operating space. These unstable conditions may range from internal well known linear and quasi-linear plasma instabilities[1,2] to gross non-linear relaxation oscillations[3,4,5], parametric drifts and even plasma extinguishment. Many of these phenomena involve strong interactions with the materials being processed and the external hardware that supports the reactor module operation. We will discuss certain questions: how may one observe such conditions (if you cant see it, does it matter from the processing perspective?); is it advisable to continue processing regardless; what might the consequences be, good or bad, and how they may be controlled[6]? 1) T. H. Stix, Waves in Plasmas, American Institute of Physics, New York (1992), and The Theory of Plasma Waves, McGraw-Hill (1962). 2) N. Krall and A. Trivelpiece, Principles of Plasma Physics, McGraw-Hill (1973). 3) M. Tuszewski, J. App. Phys., 79 8967 (1996) 4) M. A. Lieberman et. al., Appl. Phys. Lett. 75, 3617 (1999) 5) A. M. Marakhtanov et..al., J. Vac. Sci. Tech. A, 21 1864 (2003) and references therein. 6) D.L.Goodman and N. M. P. Benjamin, J. Phys. D, 36 2845 (2003).

11:00
RW2 2 Multidimensional Plasma Sheaths over Electrically Inhomogeneous Surfaces.
DEMETRE ECONOMOU,* *University of Houston*

Multidimensional plasma sheaths are encountered in a number of applications including plasma immersion ion implantation, extraction of ions (or plasma) through grids, MEMS fabrication, neutral beam sources, and plasma in contact with internal reactor parts (e.g., wafer chuck edge). The sheath may be multidimensional when: (a) plasma is in contact with surface topography, and the size of the topographical features is comparable to or larger than the plasma sheath thickness, or (b) the surface is flat but inhomogeneous, i.e., a conducting surface next to an insulating surface. In either case, the flux, energy and angular distributions of energetic species incident on the substrate are of primary importance. These quantities depend critically on the shape of the meniscus (plasma-sheath boundary) formed over the surface. A two-dimensional fluid/Monte Carlo simulation model was developed to study multidimensional sheaths. The radio frequency (RF) sheath potential evolution, and ion density and flux profiles over the surface were predicted with a self-consistent fluid simulation. The trajectories of ions and energetic neutrals (resulting by ion neutralization on surfaces or charge exchange collisions in the gas phase) were then followed with a Monte Carlo simulation. Ion flow and energy and angular distributions of ions bombarding a flat but electrically inhomogeneous surface will be reported in detail. Ion flow over trenches and holes will also be reported. Work supported by the NSF, Sandia National Laboratories and NIST.

*Doosik Kim.

Contributed Papers

11:30

RW2 3 Measurement of plasma-surface interaction in CF_4/Ar RF-ICP by using CT-OES YASUFUMI MIYOSHI, MASARU MIYAUCHI, ATSUSHI OGUNI, TOSHIAKI MAKABE, *Keio University, Yokohama Japan* Highly selective SiO2 etch over Si is required to manufacture ULSI devices. Reactive ion etching using polymerizing fluorocarbon chemistries provides the process for selective dry etching of SiO_2 over Si. A number of species including@electrons, ions, and radicals are generated in the plasma processing by reactions in gas phase and on surface. A large amount of highly reactive fluorine atoms, fluorocarbon radicals, ions from the plasma interact with the substrate and produce etch products. These etch products, primarily SiF_4 and SiF_2, diffuse back into the bulk plasma where they are dissociated and ionized by electrons and the resultant products are transported and redeposited onto the substrate and/or surface. That is, the plasma structure will be quite different whether the surface is exposed to etching or not. It will be essential to investigate the spatio temporal characteristics of plasma structure during etching process. In our recent study, we have mainly measured spatio temporal structure of excited $SiF(A^{2+})$ and $F(3^4D_{7/2})$ in CF_4/Ar mixture driven by RF(13.56MHz)-ICP during Si etching, by using CT(Coumputerized Tomography)-OES(Optical Emission Spectroscopy) system. We discuss the plasma structure during Si etching as a function of LF(500 kHz) bias source.

11:45

RW2 4 A modeling of radial characteristics of feature profile in SiO_2 etching under topographical charging TAKASHI SHIMADA, *Keio University* TAKASHI YAGISAWA, *Keio University* TOSHIAKI MAKABE, *Keio University* As ULSI device elements shrink continuously, there exist various phenomena during plasma etching. In these circumstances, anomalous etching is a matter of the first importance to overcome. SiO_2 etching is carried out and modeled by using high energy ions accelerated to the wafer at 50 mTorr of CF_4(5%)/Ar in a two-frequency capacitively coupled plasma (2f-CCP). In our previous work, we have shown the various characteristics of the etching profile at different radial positions on a wafer due to the local charging [1]. At the wafer edge, anomalous profile of etching is obtained due to the asymmetric ion velocity distribution (IVD) with a wide range of incident angle [2]. In this work, we will discuss local characteristics of a feature profile evolution caused by the anisotropy of IVD. At the wafer edge, higher ions are injected from the outside to the wafer edge, while low energy ions are from the inside. In addition, it is shown that the local charging inside the trench contributes to the decrease of etch rate of SiO_2. [1]T.Shimada, T.Yagisawa and T.Makabe: 56 th GEC (2003) [2]T.Yagisawa, K.Maeshige, T.Shimada and T.Makabe: IEEE Trans. on Plasma. Sci., 32,90-100 (2004)

12:00

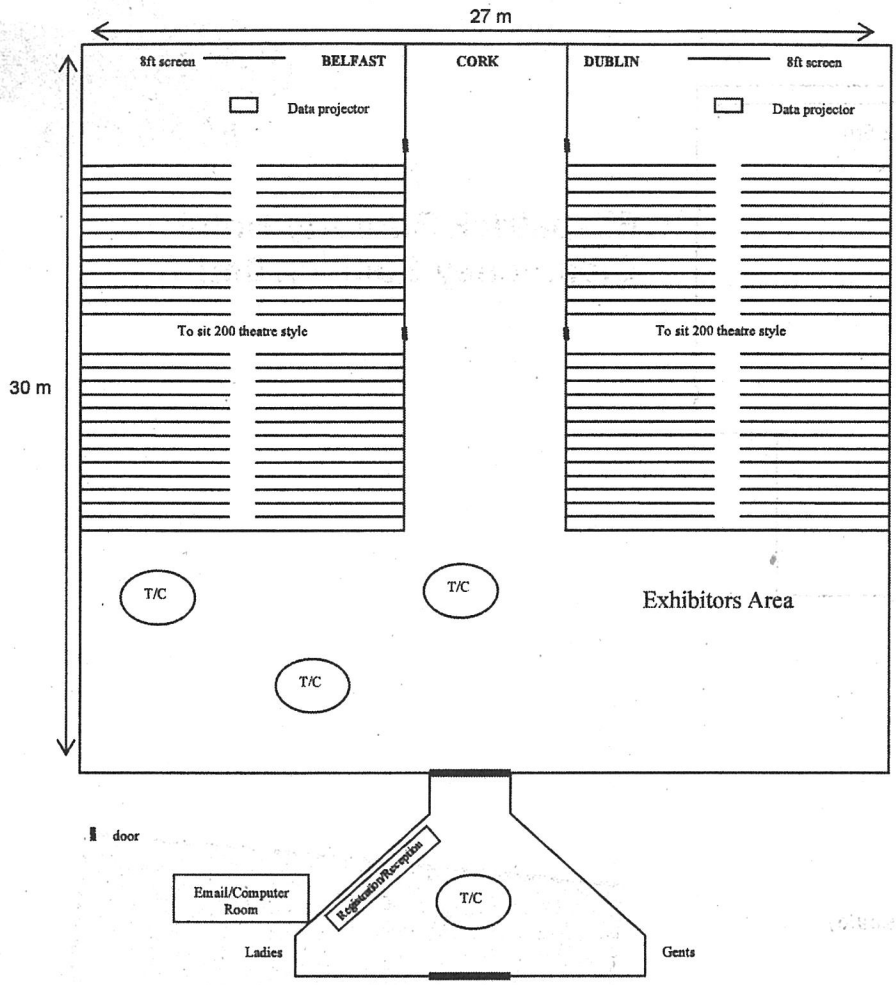
RW2 5 Carbon nanotubes (CNTs) functionalised by dielectric barrier discharges (DBD) in ordinary atmosphere THOMAS OKPALUGO, PAGONA PAPAKONSTANTINOU, HAYLEY MURPHY, JIM McLAUGHLIN, NORMAN BROWN, *Nanotechnology Research Institute (NRI), University of Ulster, Shore Road, BT37 0QB, Northern Ireland, UK* Wet chemical manipulations commonly used for CNT functionalisation, are known to leave defects and could damage the highly desirable structures of vertical aligned CNTs. In this work detailed experimental study elucidates the effects of DBD treatment parameters like power density, plasma composition, inter-electrode gap and treatment time on the electronic structure of carbon nanotubes. The CNTs before and after DBD treatments was characterised by employing Raman, FTIR, XPS, SIMS, SPM, and XRD techniques. XPS and SIMS depth profiling reveals true functionalisation. Atomic % of O peaked in few seconds under DBD and also at 0.5W of DBD power. Raman spectroscopy revealed defect induced dispersive-D position 1345.5 cm-1, the graphite related mode-G position 1572.1 cm-1, the highly dispersive defect induced D- overtone-G′ position 2691.6 cm-1 and the radial-displacement (Radial-breathing-mode) 116.6 cm-1 (RBM-MWCNT) and 146.4 cm-1, 160.4 cm-1 (RBM-SWCNT). From RBM frequencies further vital electronic information like the CNT chirality and conductivity is obtained following appropriate calculations. The MWCNTs and some of the SWCNTs were revealed to be metallic by Raman analysis and the effect of dopant atoms is investigated. For multiwall and non-isolated SWCNT we used model dependent pre-factor A constants obtained via reported calculations taking into account the inter-tubular coupling effect for CNT tube diameter calculation. This work is relevant for nanotube application in nanoelectronics

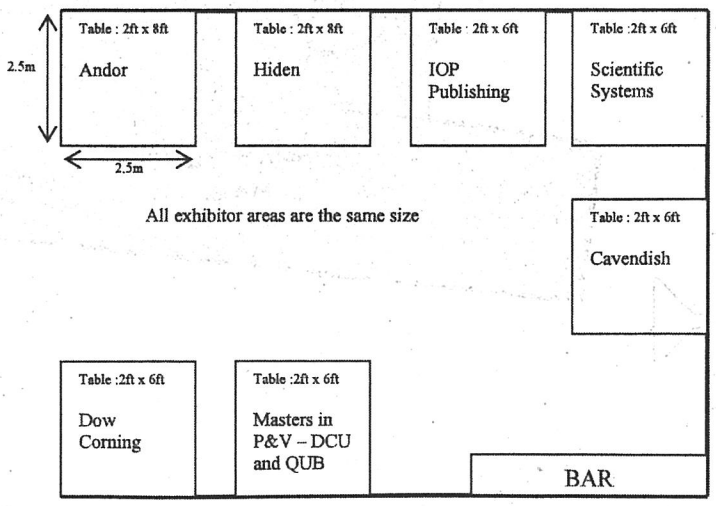
12:15

RW2 6 Synthesis of carbon nanotubes in Atmospheric Pressure PECVD TOMOHIRO NOZAKI, *Tokyo Institute of Technology, Mechanical and Control Engineering* TOMOYA GOTO, KEN OKAZAKI, LORENZO MANGOLINI, *University of Minnesota, Department of Mechanical Engineering* JOACHIM HEBERLEIN, UWE KORTSHAGEN We have developed atmospheric pressure radio frequency discharge enhaced CVD system for the catalytic growth of CNTs. APG, which is a kind of dielectric barrier discharge (DBD), is homogeneous and stable, because the dilution gas (He) represses the generation of filamentary discharge. In this study Atmospheric Pressure Glow discharge (APG) was generated without dielectric barrier using a radio frequency (RF:13.56MHz) power source. In the case of RF discharge, dielectric between metalic electrodes is not necessary since ions and electrons are trapped between electrodes, decreasing sustaining voltage of plasma. We tried to synthesize carbon nanotubes by using Atmospheric Pressure RF Glow discharge (APRFG) enhanced CVD. Substrate used in this work was Ni (20nm)/Cr (20nm) thin films on Si wafers deposited with RF sputtering. In the carbon nanotube growing process, He/H2/CH4 mixture was processed in the vaccum chamber operated at 760 Torr, while the electrode was heated up to 700. The identification of several radicals from optical emission spectroscopy (OES), the relationship between synthesis of CNTs and plasma characteristics will be presented.

NOTES

Fitzpatrick Bunratty Conference Centre





Exhibitors Area

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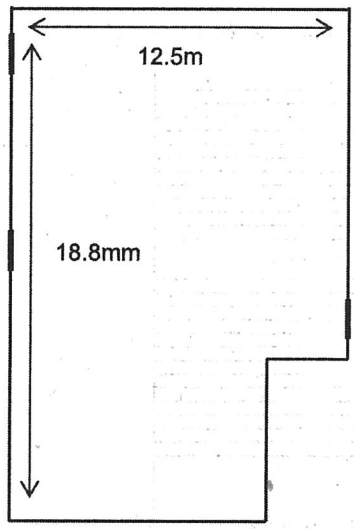
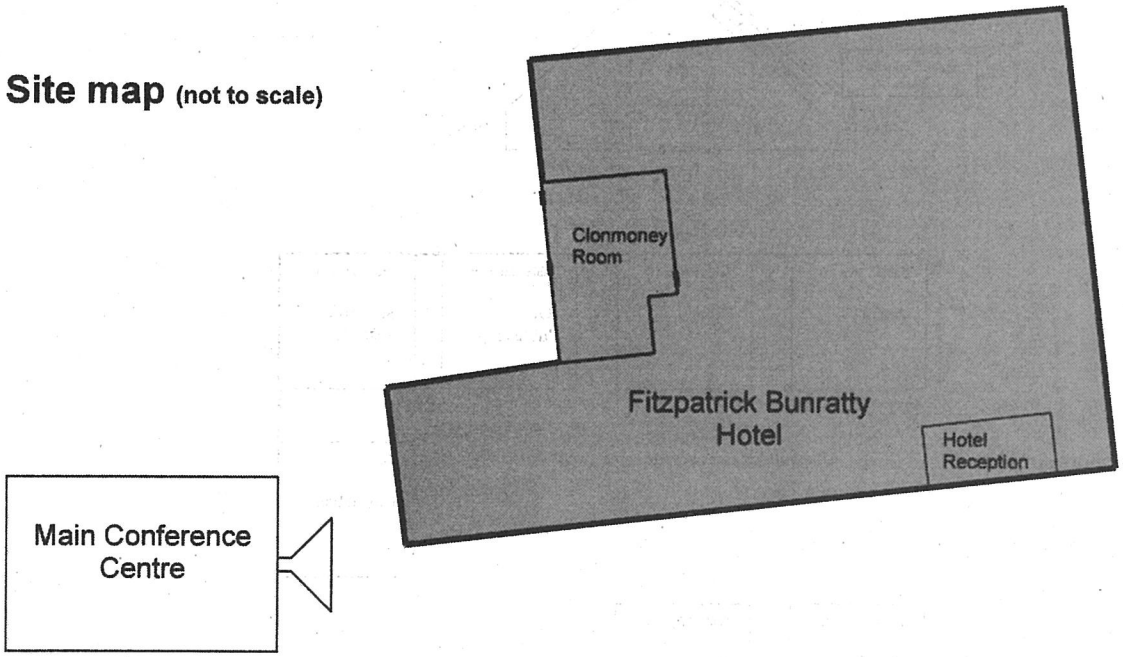


Fitzpatrick Bunratty Hotel
Clonmoney Suite (100m)

Site map (not to scale)



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Epitome of the 57th Gaseous Electronics Conference of the American Physical Society

19:00 SATURDAY EVENING
25 SEPTEMBER 2004

1A **Reception and Registration**
Belfast Room, Bunratty Conference Centre

8:30 SUNDAY MORNING
26 SEPTEMBER 2004

AS1 **Glows**
Belfast Room, Bunratty Conference Centre

AS2 **Plasma Chemistry**
Dublin Room, Bunratty Conference Centre

10:30 SUNDAY MORNING
26 SEPTEMBER 2004

BS1 **Plasma Applications for Nanotechnology I**
Winter, Tomohiro
Belfast Room, Bunratty Conference Centre

BS2 **Lighting I**
Haverlag
Dublin Room, Bunratty Conference Centre

14:00 SUNDAY AFTERNOON
26 SEPTEMBER 2004

CS1 **Particle and Electrical Diagnostics**
Belfast Room, Bunratty Conference Centre

CS2 **Ionization**
Ullrich
Dublin Room, Bunratty Conference Centre

16:00 SUNDAY AFTERNOON
26 SEPTEMBER 2004

DS1 **Optical Emission Diagnostics**
Bowden
Belfast Room, Bunratty Conference Centre

DS2 **Interactions With Molecules**
Williams
Dublin Room, Bunratty Conference Centre

19:30 SUNDAY EVENING
26 SEPTEMBER 2004

ES1 **Poster Session I**
Clonmoney, Fitzpatrick Bunratty Hotel

ES2 **Poster Session II**
Cork, Bunratty Conference Centre

8:30 MONDAY MORNING
27 SEPTEMBER 2004

FM1 **Plasma Applications**
Belfast Room, Bunratty Conference Centre

FM2 **Electron-Molecule Interactions**
Huo
Dublin Room, Bunratty Conference Centre

10:30 MONDAY MORNING
27 SEPTEMBER 2004

GM **The Will Allis Prize Lecture**
McConkey
Belfast Room, Bunratty Conference Centre

11:45 MONDAY MORNING
27 SEPTEMBER 2004

HM **Business Meeting**
Belfast Room, Bunratty Conference Centre

14:00 MONDAY AFTERNOON
27 SEPTEMBER 2004

JM1 **Plasma Applications for Nanotechnology II**
Belfast Room, Bunratty Conference Centre

JM2 **Dissociative Attachment/Dissociative Recombination**
Hotop
Dublin Room, Bunratty Conference Centre

16:00 MONDAY AFTERNOON
27 SEPTEMBER 2004

KM1 **Negative Ions & Instabilities**
Belfast Room, Bunratty Conference Centre

KM2 **Material Processing in Low Pressure Plasmas I**
Dublin Room, Bunratty Conference Centre

8:30 TUESDAY MORNING
28 SEPTEMBER 2004

LT1 **Biological and Emerging Applications of Plasmas**
Bowen, Burrow
Belfast Room, Bunratty Conference Centre

LT2 **Plasma Surface Interactions**
Dublin Room, Bunratty Conference Centre

10:30 TUESDAY MORNING
28 SEPTEMBER 2004

MT1 **Plasma Boundaries**
Belfast Room, Bunratty Conference Centre

MT2 **Capacitively Coupled Discharges**
Dublin Room, Bunratty Conference Centre

14:00 TUESDAY AFTERNOON
28 SEPTEMBER 2004

NT1 **Laser Diagnostics**
Hancock
Belfast Room, Bunratty Conference Centre

NT2 **Cold Collisions**
Stwalley
Dublin Room, Bunratty Conference Centre

16:00 TUESDAY AFTERNOON
28 SEPTEMBER 2004

PT1 **Poster Session III**
Clonmoney, Fitzpatrick Bunratty Hotel

PT2 **Poster Session IV**
Cork, Bunratty Conference Centre

8:30 WEDNESDAY MORNING
29 SEPTEMBER 2004

QW1 **Pulsed Plasmas**
Belfast Room, Bunratty Conference Centre

QW2 **Lighting II**
Collins, Whang
Dublin Room, Bunratty Conference Centre

10:30 WEDNESDAY MORNING
29 SEPTEMBER 2004

RW1 **High Pressure Discharges**
Kono, Ebert
Belfast Room, Bunratty Conference Centre

RW2 **Material Processing in Low Pressure Plasmas II**
Benjamin, Economou
Dublin Room, Bunratty Conference Centre

12:30 WEDNESDAY AFTERNOON
29 SEPTEMBER 2004

SW **Conference Lunch**
Castle Suite, Bunratty Castle Hotel

0003-0503(200409)49:5;1-3