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Program of the 46th Annual Gaseous Electronics Conference

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ON THE COVER: (TOP)—New and old APS staff say good-bye to the New York City headquarters. (BOTTOM)—Old APS headquarters address in New York City.

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19–22 October 1993—Montréal, Québec

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19–22 octobre 1993—Montréal, Québec

GENERAL INFORMATION

The Forty-Sixth Annual Gaseous Electronics Conference (GEC) was held in Montréal, Québec on 19–22 October 1993, hosted by the Département de Physique de l'Université de Montréal, in cooperation with the Bureau de consultation et d'organisation de congrès. The meeting is an annual Sponsored Conference of the Division of Atomic, Molecular, and Optical Physics of the American Physical Society. Financial support was provided by the Université de Montréal, the Gouvernement du Québec (Ministère des Affaires Internationales), the Natural Sciences and Engineering Research Council of Canada, U.S. National Science Foundation, and the U.S. Army Research Office. A major corporate sponsor was General Electric Company. We also acknowledge support from ASTEX, OSRAM, SAIREM (France), EXTREL, COMDEL, and HYDRO-QUÉBEC. An updated list of the sponsors was distributed to the participants. This year's GEC highlighted the following topics: Advances in Electron Collision Processes, Electron-Molecule Collisions, Low Energy Ion-Molecule Collisions, Collisions of Cold Atoms, GEC Reference Cell, Dusty Plasmas, Low and High Pressure ICP's, Thermal Plasmas and Plasma Torches, Magnetized and Magnetically Enhanced Plasmas, and Modeling and Simulation.

INFORMATIONS GÉNÉRALES

La quarante-sixième Conférence annuelle sur l'électronique dans les gaz (CEG) a eu lieu à Montréal, Québec du 19 au 22 octobre 1993, sous l'égide du Département de physique de l'Université de Montréal, avec l'appui du Bureau de consultation et d'organisation de congrès. La rencontre est une conférence reconnue par la "Division of Atomic, Molecular and Optical Physics" de l'American Physical Society. Nous tenons à remercier pour leur soutien financier important l'Université de Montréal, le Gouvernement du Québec (Ministère des Affaires internationales), le Conseil de recherches en sciences naturelles et en génie du Canada, et du côté américain, la National Science Foundation, l'Army Research Office et la compagnie GENERAL ELECTRIC. Ont également contribué au financement les compagnies ASTEX, OSRAM, SAIREM (France), EXTREL, COMDEL et HYDRO-QUÉBEC. Une liste complète des commanditaires a été distribuée sur place aux participants. Cette année, la CEG avait mis l'accent sur les sujets suivants: les avancées dans les processus de collisions électroniques, les collisions électron-molécule, les collisions ion-molécule à faible énergie, les collisions d'atomes froids, le réacteur de référence CEG, les poussières dans les plasmas, les décharges inductives à faible et haute pressions, les plasmas thermiques et les torches à plasma, les plasmas magnétisés ainsi que les plasmas intensifiés par un champ magnétique statique et, finalement, la modélisation et la simulation des plasmas.

Epitome of the 46th Annual Gaseous Electronics Conference Montréal, Québec — 19–22 October 1993

MONDAY, 18 OCTOBER 1993

14:00–22:00 Registration

19:00 Welcome Reception

TUESDAY, 19 OCTOBER 1993

8:00–10:00 AA Magnetized and Magnetically-Enhanced Plasmas Including ECR, Helicon and Surface-wave Discharges I. Chair: *M. R. Wertheimer*, Ecole Polytechnique de Montréal

AB Collision Processes and Reactions in Plasmas. Chair: *A. Garscadden*, Wright Patterson AFB

10:15–12:15 BA Dusty Plasmas. Chair: *H. M. Anderson*, University of New Mexico

BB Excitation, Ionization and Scattering. Chair: *S. Chung*, University of Wisconsin

13:30–15:45 CA Magnetized and Magnetically-Enhanced Plasmas Including ECR, Helicon and Surface-wave Discharges II. Chair: *D. B. Graves*, U.C. Berkeley

CB Advances in Electron Collisional Processes. Chair: *K. Becker*, City College of N.Y.

15:45–17:30 Posters Chair: *J. Margot*, Université de Montréal

DA Diagnostics

DB Magnetized and Magnetically-Enhanced Plasmas Including ECR, Helicon and Surface-wave Discharges III

DC Dusty Plasmas

DD Plasma Surface Phenomena

WEDNESDAY, 20 OCTOBER 1993

8:00–10:00 EA Microwave Discharges. Chair: *M. Chaker*, INRS-*Énergie et Matériaux*

EB Electron Transport in Gases. Chair: *J. W. Gallagher*, NIST

10:15–11:30 FA Pollutant Processing and Plasma Cleaning. Chair: *J. Hubert*, Université de Montréal

FB Cold Atom Collisions. Chair: *T. Walker*, University of Wisconsin

11:30–12:00 G Business Meeting. Chair: *J. Dakin*, GE Lighting

13:30–15:30 HA GEC Reference Cell. Chair: *J. Keller*, IBM Fishkill

HB Electron Molecule Collisions. Chair: *M. A. Dillon*, Argonne National Laboratory

15:45–17:30 Posters Chair: *M. Fréchette*, Hydro-Québec

JA Modeling and Simulation

JB Unique Plasma Systems

JC Lasers

JD Microwave Plasmas

JE RF Glow Discharges

JF Positive Columns

THURSDAY, 21 OCTOBER 1993

8:00–10:00 KA Inductively Coupled Plasmas I. Chair: *T. J. Sommerer*, General Electric Company

KB Recombination and Ion Collisions. Chair: *E. J. Mansky*, Georgia Institute of Technology

10:15–12:15 Posters Chair: *G. Sauvé*, Université de Montréal

LA Sheaths and Breakdown

LB Ion Transport and Ion Molecule Collisions

LC Electron Transport and Collisions

LD Inductively Coupled Plasmas II

13:30–15:30 MA RF Glow Discharges. Chair: *J. Ingold*, GE Lighting

MB Electron Collisions. Chair: *R. A. Bonham*, Indiana University

15:45–17:45 NA Inductively Coupled Plasmas III. Chair: *D. A. Doughty*, General Electric Company

NB Low Energy Ion-Molecule Collisions. Chair: *A. V. Phelps*, JILA

18:30–19:30 Social Hour/Cocktail

19:30 23:00 Conference Dinner/Banquet. Speaker/Conférencières. Speaker: *S. Leney*, Hydro-Québec

FRIDAY, 22 OCTOBER 1993

8:00–10:00 PA Thermal Plasmas and Plasma Torches I. Chair: *M. I. Boulos*, Université de Sherbrooke

PB Modeling and Simulation. Chair: *T. W. Johnston*, INRS-Énergie et Matériaux

10:15–11:45 QA Thermal Plasmas and Plasma Torches II. Chair: *D. C. Schram*, Eindhoven Univ. of Tech.

10:15–12:15 QB Sheaths and Breakdown. Chair: *J. F. Waymouth*, Consultant

13:30–15:45 RA Plasma Surface Interactions. Chair: *D. B. Graves*, U.C. Berkeley

RB Diagnostics. Chair: *J-M Gagné*, Ecole Polytechnique de Montréal

MAIN TEXT

REGISTRATION/INSCRIPTION
Monday afternoon/evening, 18 October 1993
Salone des Arts, Niveau Foyer, 14:00–22:00

WELCOME RECEPTION/RECEPTION DE BIENVENUE
Monday evening, 18 October 1993
Foyer du Grand Salon, Basilaire I, 19:00

SESSION AA: MAGNETIZED AND MAGNETICALLY ENHANCED PLASMAS, INCLUDING ECR, HELICON, AND SURFACE-WAVE DISCHARGES I
Tuesday morning, 19 October 1993
Grand Salon A, 8:00–10:00
M.R. Wertheimer, presiding

AA-1 Side by Side Comparison of Ion Energy Distribution Functions for Helicon and Multipolar ECR Sources in an HBr Discharge, G.W. GIBSON, JR.*, N. BLAYO, D. IBBOTSON, J.T.C. LEE, H.H. SAWIN*, I. TEPERMEISTER, AT&T Bell Telephone Laboratories - The downstream ion energy distribution functions (IEDF) of a Helicon source and a multipolar ECR source have been measured as functions of source power, neutral gas pressure, chuck power and radius. The sources were mounted on identical platforms and were connected by loadlock to shared wafer-handling robotics. The IEDFs were taken with a miniature (1.0"x0.125"x0.060") electrostatic retarding grid analyzer which could be scanned radially and which had energy resolution of better than 0.5 eV. Data were taken during the etching of poly-Silicon wafers in an HBr chemistry. The sources are compared in terms of ion flux, mean ion energy, ion energy spread and ion energy flux. Furthermore, evidence of the coupling of RF power from the chuck into the bulk plasma will be given.

*Massachusetts Institute of Technology

AA-2 Helicon Sources with Density Gradients*, F.F. CHEN and M. LIGHT, UCLA--When helical antennas are used to excite helicon waves for plasma production, the flatness of the density profile is often found to depend on whether the waves are right-hand (m = 1) or left-hand (m = -1) polarized. We have reduced the helicon equations for radially varying density profiles to a form amenable to simple computation. The second-order differential equation contains a singularity in its coefficients, which may have escaped previous investigators. Treating the poles with care, we find that the m = 1 mode has a broad field intensity profile, while the m = -1 mode has a much narrower profile. The new effect stems from the drift of electrons along the radial density gradient, causing a charge buildup whose phase depends on the sign of *m*. A positive feedback mechanism can occur, especially for m = -1, where ionization is intense at the peak of the rf field, thus narrowing the density profile and further narrowing the field pattern. Thus, the m = -1 mode will produce dense, narrow columns, while the m = 1 mode will create broad, uniform discharges. Measurements of the field patterns using a single-turn coaxial magnetic probe are in good agreement with the theoretical curves computed using the measured density profiles.

*Supported by the Wisconsin ERC, a Livermore PPRI minigrant, and the UCLA ATRI program of the AFOSR.

AA-3 3D-Structure of DC Magnetron Sputtering by Emission-CT Technique using a Robot, N.SHIMURA, A.ITOH* and T.MAKABE, Keio Univ. Yokohama Japan — DC magnetron discharges are widely used for thin film deposition. We have performed the automatic measurement of 3D-emission profiles in DC magnetron plasmas for sputtering by using a 4-axes scalar Robot. The essential principle is the emission selected-computer tomography (ESCT). The ray tracing is adopted to calibrate the absolute value of the net production rate of excited molecules with short radiative lifetime. The resultant spatial resolution will increase up to $1.0 \times 1.0\text{mm}^2$ under a sufficient emission intensity. ESCT technique is applied to the reactive sputtering in Ar/O_2 with Al target. Three lines, ArI(419.8nm)m ArII(434.8nm) and AlI(396.2nm) are selected for the ESCT analysis. The influence of the static magnetic field on the physical etching (sputtering) of the target is estimated indirectly by ESCT. Also the effect of a small prominence on the target surface is studied from the CT image.

*Permanent address: Shibaura Engineering Works Co. Ltd.

AA-4 Plasma Potentials in the Helicon Plasma Etching Reactor, A.J. PERRY, H. PERSING and R.W. BOSWELL, Space Plasma and Plasma Processing Group, PRL, RSPhys.S.E. ANU, Australia - During plasma etching of SiO_2 the energy of the ions (in the range 15 - 200 eV) incident on the wafer plays a critical role in determining the etch rate. The ion energy can be inferred from the waveform of the rf bias applied to the substrate but these measurements suggest that, under certain conditions, the plasma potential rises well above its usual value of around 15 V. Using emissive and langmuir probes we have tried to determine whether the rf power applied to the wafer drives the plasma to higher potentials. These experiments suggest that the changes in the plasma potential occur because polymers, deposited on the reactor walls, insulate the plasma from earth and it is the plasma created in the source that is moving to higher potentials.

AA-5 Radial Ion Transport in a Limited Axisymtric ECR Plasma: Effects of Magnetic Field Topology and Plasma Fluctuations, G.W. GIBSON, JR. and H.H. SAWIN, Massachusetts Institute of Technology - The radial transport of ions across magnetic field lines in a modified ASTeX S1500 ECR source has been investigated. An uniquely configured discharge chamber allows the boundary conditions of the experiment to be carefully controlled. The upper chamber is lined with anodized aluminum. Inside the liner is a 3" diameter quartz limiter which can be positioned axially without breaking vacuum. Microwaves enter through a quartz window and the plasma streams onto a wafer and faux chuck which, like the limiter, can be moved axially. The plasma thus has a sharp radial edge and minimal wall contact. Such a configuration allows the effects of magnetic field strength and topology to be investigated independent of plasma boundary conditions. A miniature (3"x0.125"x0.06") electrostatic retarding grid energy analyzer which can be scanned axially and radially was used to make high resolution (<0.5 eV) spatially resolved measurements of ion energy distribution functions. Langmuir probes were used to diagnose the plasma fluctuations in order to determine the extent to which they effect cross-field diffusion.

AA-6 The Power Balance of a Surface-wave-produced Plasma Confined by a Static Magnetic Field in Comparison with that of Other High Frequency (HF) Magnetoplasmas, J. MARGOT and M. MOISAN, U. de Montréal - We have performed measurements of the power balance, characterized by the power absorbed per electron θ, in plasmas produced by electromagnetic surface waves at various frequencies and gas pressures in the presence of an axial static magnetic field B_0 up to 2 kGauss. We find that, for a given gas pressure p, θ decreases with increasing magnetic field as a result of plasma confinement, as expected; further, no significant differences are observed with wave frequency. At low enough values of the product B_0p (typically < 1 Gauss.torr), θ depends only on the gas pressure while at higher values, it is then a unique function of B_0p. These results indicate that the diffusion mechanism varies from the classical ambipolar regime at low B_0p to the so-called anomalous (Bohm-like) regime at high B_0p. Our results for θ are compared with those obtained in other HF magnetoplasmas (ECR and non ECR (e.g. helicon) schemes) using the plasma density and the HF power values reported in literature. We find that the value of θ in these various plasmas is similar for given discharge conditions, whatever the mode of creation of the plasma and the operating frequency.

AA-7 Magnetic Field Enhancement of Electromagnetic Wave Penetration in Weakly Ionized Plasmas,* S.P. Bozeman and W.M. Hooke, U. of N. Carolina at Chapel Hill- The homogeneity and size of RF and microwave heated plasmas are often limited by the skin depth, d, of the electromagnetic radiation. To investigate increasing d by applying a steady magnetic field, B, we have adapted the theory for cold, collisionless plasma waves to include the effects of electron-neutral and ion-neutral collisions and determined d as a function of wave frequency, f, and collision frequencies for plane waves propagating at arbitrary angles with respect to B. The theory predicts that the most favorable scaling occurs for waves propagating nearly parallel to B and for $f \ll f_{ec}$ where f_{ec} is the electron cyclotron frequency. The skin depth also increases (though not as much) for propagation perpendicular to B provided that $f \ll f_{LH}$ where f_{LH} is the lower hybrid resonance frequency. Our RF magnetic probe measurements of wave penetration in an ICP (wave propagation nearly perpendicular to B) in Ar in the 0.2 to 20 Torr pressure range show an increase in d above f_{LH} and a damping of the effect of B with pressure. Observations of Stark line broadening in Ar in a microwave discharge (propagation parallel to B) show an increase in electron density with B at pressures as high as 20 Torr.

*Work Supported by Kobe Steel USA, Electronic Materials Center.

AA-8 Measurement of Space Resolved Ion Velocity Distribution in a Low Pressure Planar ECR Plasma Source, T. LAGARDE, F. CHATAIN*, Y. ARNAL, J. DEROUARD*, N. SADEGHI* and H. PERSING**, LPCPP, Université Joseph Fourier (Grenoble, France), Unité CNRS, France Telecom CNET, *L.S.P., Université Grenoble 1 - CNRS, **P.R. Lab., NAU Canberra- The purpose of this work is to provide some insight about the mechanisms which are responsible for the production and diffusion of the charged particles in a magneto-plasma. The components of the ion velocity drift along the three axes were measured using the Doppler shifted laser induced fluorescence (DSLIF) spectroscopy of Ar^+ metastable ions.[1] The reactor is a x=100, y=20, z=12 cm parallelipiped with a closed multipolar magnetic structure (magnetron type) with a linear antenna[2] along the x axis fed at 2.45 GHz. For a pressure of 10^{-4} torr and a power of 175 W, from Langmuir probe measurements we find n_e 5.10^{10} cm^{-3}, T_e 5 eV and V_p 12 V. DSLIF shows that ion velocities are small : $<v_x>$ is at most 1.5 km/s and $(v_x-<v_x>)^2$ corresponds to 0.3 eV. These results can be qualitatively understood by considering the motion of the ions in an inhomogeneous magnetic field.

[1] N. Sadeghi et al. J. Appl. Phys. 70, 2552 (1991)
[2] M. Pichot et al. Rev. Sc. Instrum. 59, 1072 (1988)

SESSION AB: COLLISION PROCESSES AND REACTIONS IN PLASMAS

Tuesday morning, 19 October 1993
Grand Salon C, 8:00–10:00
A. Garscadden, presiding

AB-1 Ion-Molecule Reactions in SF_6 Corona Discharges and Their Potential Relevance to Plasma Processing.* I. SAUERS, Oak Ridge National Laboratory - Work on SF_6 ion chemistry in corona discharge at high pressure (several kPa) indicate that ions are rapidly converted to product ions whose nature depends on impurities such as water and SF_6 decomposition products. This is true for both positive and negative ions. Depending on the various neutral species present, their concentration, and on the their residence time, conversion of SF_6 ions (SF_6^-, SF_5^-, F^-, SF_5^+) to product ions such as $SF_6^-(HF)$, SOF_5^-, $F^-(HF)_n$, $OH^-(H_2O)_n$, SiF_5^-, WF_7^- (when the electrode is W), $SF_5^+(H_2O)_n$, SOF_3^+, $H^+(H_2O)_n$, and $SF_5^+(SF_4)$ have been observed. Control in the formation of these ions could be utilized in plasma processing for example through the addition of additives (e.g. HF, H_2O, SOF_4, SiF_4, SF_4).

*Work supported in part by DOE under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

AB-2 Models of the Negative Differential Voltage-Current Ratio in Low-Current Hydrogen Discharges, A. V. PHELPS, JILA, U. of Colorado and NIST - A perturbation model based on ion-induced electron emission at the cathode quantitatively explains[1] steady-state differential voltage-current behavior of low-current (< 1 $\mu A/cm^2$), parallel-plane discharges in H_2 at E/n > 700 Td. This model is extended to include photon-induced electron emission at the cathode and two-step ionization via vibrationally excited H_2 and is compared with experiment at E/n < 300 Td. The photoelectron model includes calculated electron excitation rates, excited state quenching, far-uv transmission, spectrally-weighted photoelectron yields, and electron escape probabilities. The multistep ionization model includes calculated vibrational excitation rates, diffusion and quenching, and ionization coefficients for the excited states. The results are sensitive to the poorly known ion transit times and only photoelectron emission is close to explaining low E/n experiments[2].

[1]A. V. Phelps, Z. Lj. Petrović, and B. M. Jelenković, Phys. Rev. E 47, 2825 (1993).
[2]R. S. Sigmond, Proc. 4th Int'l. Conf. on Ionization Phenomena in Gases, ed. N.R. Nilsson (North-Holland, Amsterdam, 1960), p. 189.

AB-3 A Hybrid Model for Low Pressure Glow Discharges Using Equivalent Monte Carlo Representations for Charged and Neutral Particles. * Fred Y. Huang and Mark J. Kushner, University of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - Low pressure etching and deposition reactors are typically in a quasi-continuum/molecular flow regime in which kinetic effects for neutral radicals as well as charged species may be important. We have previously introduced a new modeling technique in which electrons, ions and excited states are equivalently treated using particle-mesh algorithms. In this method, we have an electron density of states including both discrete negative energies (ie., bound states) and positive energies (ie., continuum electrons). Heavy particles are treated as electrons in bound states having large effective masses. This technique has been incorporated into a kinetic-fluid hybrid model as the kinetic module. Results from the model are discussed for conventional glow discharges in etching mixtures (eg., CF_4/H_2). The kinetic distribution of excited states and hot atoms to the substrate will be presented.

* Work supported by SRC, NSF, and U. of Wisc. ERC for Plasma Aided Manufacturing

AB-4 **Decomposition of CF_4 and SF_6 by a non-equilibrium plasma and their interaction with polymeric targets.**

Y. KHAIRALLAH, F. AREFI, J. AMOUROUX,
Lab. de plasmas, ENSCP,11 Rue P. et M. Curie, 75005 Paris, France.

The decomposition of SF_6, CF_4 and their mixtures by a non-equilibrium plasma and their interaction with polyethylene films have been studied. The presence of oxygen and water vapor as trace contaminants and their role in the decomposition mechanisms were pointed out both by mass spectrometry and optical emission spectroscopy. The comparison of the results obtained by the calculations and those measured by surface and plasma diagnostic techniques brought evidence on the participation of the fluorine atoms in the heterogeneous mechanisms. Finally, the effect of the addition of a fluorine containing molecule such as CF_4 to SF_6 discharges on the energetic aspect of the discharge, the decomposition mechanisms and the fluorination processes will be discussed. The excitation efficiency of the electrons was correlated to the fluorine concentration as measured by actinometry and to its incorporation at the surface as shown by the XPS analysis.

EDF-DER is acknowledged for its financial support

AB-5 Chemical Kinetic Modelling of Ion and Neutral Compositions in a Thermal Plasma under Carbon Powder Injections, T.G. BEUTHE and J.S CHANG, Department of Engineering Physics, McMaster University-

A chemical kinetic model for the prediction of ion and neutral compositions in a thermal plasma under carbon powder injections had been developed. Numerical results were carried out under electron temperature from 0.5 to 2eV, gas temperature from 300 to 20,000K and carbon percentage mixture from 0 to 10% for reduced and atmospheric gas pressure. The results show that the positive carbon ion is only generated by thermal ionizations, and no significant negative ions are observed. Molecular argon ions Ar_2^+ is dominant instead of Ar^+ in gas temperature below 4000K. The effects of carbon percentage mixture on the ion and neutral compositions were discussed in detail.

AB-6 Modeling of RF Methane Discharges, E. Gogolides, C. Buteau, A. Rhallabi*, G. Turban*, NCSR "Demokritos" Athens GREECE, * IMN, Nantes, FRANCE. Plasmas of methane and its mixtures are used to treat oxidized archaeological items or other surfaces, and deposit carbon. The aim of this work is to aid in better understanding the charged species dynamics and the gas-phase kinetics of a CH_4 plasma, by successfully combining a discharge fluid model with a simple chemical kinetic model. Swarm data are used as input in a fluid model [1] which predicts the ion-electron densities, electric fields and ionization rates as a function of space and time in the RF period. Results show that the negative ion density in CH_4 is of order 10^{-2} to that of electrons, causing a capacitive behaviour similar to an electropositive gas. The effects of electrode spacing (2-6cm), gas pressure (80mTorr-1Torr) and RF current (2.2-3.4mA/cm², 0.06-0.15W/cm²) are studied and compared successfully with experimental data. The time-averaged, spatially-resolved electron density and energy, the set of cross sections for CH_2 and CH_3 dissociation [2], together with an assumption about the form of the electron energy distribution, are subsequently used as input in a simplified 1-dimensional kinetic model. The model predicts the CH_2 and CH_3 spatial profiles, which compare well with experimental data [3].

1 - E. Gogolides and H.H. Sawin, J.Appl.Phys. 72 (9), 3971-87, (1992)
2 - T. Nakano, H. Toyoda, H. Sugai, Jap.J.of Appl.Phys. 30 (11A), 2912-15, (1991)
3 - H. Sugai and H. Toyoda, J.Vac.Sci.Technol. A10 (4), 1193-1200, (1992)

AB-7 Ion Energy Distributions for Ar++ Ions formed in the Plasma Sheath region of an R.F Discharge.

R. SUROWIEC‡, J. REES‡, J. OLTHOFF and R. VAN BRUNT, ‡U. of Liverpool (U.K) and NIST, Maryland (USA) -

Recent investigations[1] of the ions produced in RF discharges in a G.E.C. reference test cell included observations of the energy distributions of the ions arriving at the grounded electrode. Among the data recorded were Ion Energy Distributions (IED's) for Ar++ ions produced in Argon plasmas. From the structure of the IED's observed, it was postulated that the ions were produced by electron impact ionisation in the sheath region at the grounded electrode. The work described here is a Monte Carlo simulation of the formation and transport of Ar++ ions across this sheath region and of the IED's to be expected. The IED's are compared with those observed experimentally and shown to be in good agreement. The simulations have been carried out for a range of experimental conditions and for various models of the sheath, including a time-varying sheath width.

[1]J. Olthoff, R. Van Brunt, S. Radovanov, J. Rees and R. Surowiec (unpublished).

AB-8 **Local profiles of the 2D-velocity distributions of Energetic ions and Neutrals in the Sheath region***, T.MAKABE, Keio Univ. Yokohama Japan — The ion and high energy neutral transports in the sheath region in a collision dominated-plasma are of key importance plasma processings. That is, the physical etching by energetic particles contributes strongly to two-kinds of processes, as is known as the sputtering and dry etching. Ion transport is mainly subject to the charge transfer collision and the elastic scattering with a thermal neutral, as well as the production by electron impact ionization. The fast neutral is formed by charge transfer and the energy decays by a successive elastic collision with a thermal neutral. Then, the cold gas approximation will be valid to study the 2D-velocity distribution in the sheath, where the ion energy is quite high as compared with neutrals. These massive and energetic particle transports are described by the Boltzmann equation. In this work, the local profile of 2D-velocity distributions of ions and fast neutrals are numerically investigated from the Boltzmann equation under the basis of the ion density and the field distributions in the sheath by RCT model. Case studies in RF discharges in SF_6 and Ar are reported.

*Works supported by a Grant-in-Aid for Science Research.

TUESDAY MORNING

SESSION BA: DUSTY PLASMAS
Tuesday morning, 19 October 1993
Grand Salon A, 10:15–12:15
H.M. Anderson, presiding

Invited Paper

BA-1 Summary of the NATO Workshop on Formation, Transport and Consequences of Particles in Plasmas, G. S. SELWYN, IBM Research Division, Yorktown Heights, NY-A NATO Advanced Research Workshop, dedicated to the topic of Dusty Plasmas with emphasis on microelectronics processing, was held at Chateau de Bonas, Castera-Verduzan (near Toulouse), France from August 30 to September 3, 1993. The meeting consisted of approximately 60 invitees from N. American, European, and Japanese universities, industry and government research institutions. Special emphasis was placed upon achieving a diversity of professional backgrounds to improve communications and to accelerate learning in this multi-disciplinary field. This presentation will review the major results and highlights of the meeting. The proceedings will be published in a special issue of *Plasma Sources Science and Technology* in 1994.

Contributed Papers

BA-2 Reactor Scale Transport of Dust Particles in Capacitively and Inductively Coupled Radio Frequency Discharges. * Seung J. Choi, Helen H. Hwang, Robert J. Hoekstra, Peter L. G. Ventzek, and Mark J. Kushner, University of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - The transport of particles ("dust") in low pressure glow discharges is of interest due to their role in contaminating wafers during plasma etching and deposition. The distribution of particles (10s nm to many microns) is determined by many forces including electrostatic, viscous ion drag, gravitational, thermophoretic, and neutral fluid drag. The transport of dust particles in rf glow discharges has been investigated using a series of computer models: a 2-d Monte Carlo-fluid hybrid model for ion fluxes, a PIC/MCC simulation for ion-dust cross sections, a fluid model for advective flow fields and a dust transport code. 2-d time dependent distributions of dust particles will be discussed for RIE and ICP discharges for various gas flows, powers and topography of the electrode. We found that wafer contamination occurs in high density plasmas due to large ion drag forces. Topography alters the distribution of particles in the plasma by perturbing sheaths.

* Work supported by NSF, Sandia Natl. Lab., SRC, and U. of Wisconsin ERC for Plasma Aided Manufacturing

BA-3 An Experimental Study of Particle Trapping and Spatial Distributions in RF Glow Discharges, J. E. Daugherty and D. B. Graves, Dept. of Chemical Engineering, U.C. Berkeley - Contaminative particles in radiofrequency glow discharges are subject to various forces (*e.g.* electrical, thermophoretic, convective drag, ion-particle momentum transfer) which are responsible for the observed particle spatial distributions and the transport of particles to the wafer surface. The focus of this study is on the relationship between measurable plasma parameters (including plasma density, potential, electron temperature, and neutral gas temperature), and the segregation of particles into localized regions of the discharge (*i.e.* particle "traps"). We have injected monodisperse polystyrene-latex particles into the plasma and observed their trapping locations. These traps appear to be caused by nearby topographical features in the plasma chamber such as a wafer or clamping devices, or by other electrical, mechanical, or thermal features in the system. We map out the location of particle traps with one- and two-dimensional elastic laser light scattering, and we explore the plasma conditions in the vicinity of the traps with Langmuir probe measurements and optical emission spectroscopy. The use of spheres with well characterized optical properties and size distributions greatly simplifies the interpretation of the light scattering results. We also compare our experimental results with model predictions of the plasma structure and the forces on particles in a discharge.

BA-4 Charge Fluctuations in a Dusty Plasma* C. S. CUI and J. GOREE, *Dept. of Physics, Univ. of Iowa*

Particulate contamination is a problem in plasma processing of semiconductor materials. Eliminating this contamination requires understanding some physical processes, such as charging, of these dust particles. A particle acquires an electric charge by collecting electron and ion currents from the plasma. These currents consist of discrete charges arriving at the particle at random intervals, causing the charge to fluctuate around an equilibrium value $\langle Q \rangle$. Many charging models neglect the discrete nature of the charge and the fluctuations. To study the fluctuations, we developed a numerical simulation of the collection of individual ions and electrons, yielding a time series Q(t) for the particle's charge. We analyzed Q(t) to obtain the power spectrum and the rms level of the fluctuations, as well as a distribution function of the charge. It is found that the fractional rms fluctuation varies as $0.5\,N^{-1/2}$, where $N = \langle Q \rangle / e$ is the number of electron charges on the particle. This inverse square-root power law is consistent with counting statistics.

* Work supported by NASA and NSF

BA-5 Dynamic Laser Light Scattering and Particle Flux Measurements in the GEC Reference Cell **H. M. Anderson** and **D. Behl**, University of New Mexico Particulate generation has been studied during reactive ion etching (RIE) of oxide wafers in CF_4/CHF_3 plasmas using the GEC Reference Cell, modified to resemble a Drytek Quad RIE commercial etch tool. The modifications to the Reference Cell involved installation of a quartz focus ring around the cathode and shortening of gap space between the electrodes. The addition of the quartz ring to the reference cell had a dramatic effect on the distribution of particles in the reference cell. Particles could now be readily detected by laser light scattering in a ring above the powered electrode, whereas without the focus ring, particles were confined below the plane of the electrode. Laser light scattering experiments reveal a time and reactor power dependence to the appearance of particles in the ring-like particle trap region. Variable lag times were observed for particle detection dependent on pre-etch cleaning of the chamber. Particle detection was also seen to be enhanced with the addition of CHF3 in the feed gas, but absent at either very low or very high applied voltages. Further results obtained during RIE of oxide wafers while simultaneously performing in situ dynamic laser light scattering with a sensitive PMT detector and a downstream particle flux monitor will be presented.

BA-6 Nucleation and Growth of Dust Particles in Discharge Plasmas, A. SATHEESH KUMAR* and A. GARSCADDEN, Plasma Research Group, WPAFB- The nucleation and the initial growth mechanisms of solid particles in inert gas plasmas are examined. Atoms or clusters of a few atoms may be released into the plasma by interaction of the plasma with the electrode surface via. 1) the formation of very small arc spots on the electrode surface, and 2) the sputtering of the electrode surface caused by the bombarding ions. The first process occurs more commonly in high-pressure arc discharges and, the second process occurs widely under low-pressure glow discharge plasma processing conditions. These vaporized or sputtered atoms form a condensable vapor. The expansion of the vapor formed by the arc spots is similar to that in shock waves, whereas sputtering results in an almost continuous vapor source. The one-dimensional flow equations along with the equation of state and a condensation rate equation have been solved to predict the mass fraction of the condensed species and the region of their formation. Nucleation rates and cluster sizes for several electrode materials are illustrated.

* National Research Council Associate

BA-7 Plasma-Dust Interactions of Mutually Shielded Particles in Low Pressure Glow Discharges. * Seung J. Choi and Mark J. Kushner, University of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - "Dust" contamination is a major concern in the plasma processing of microelectronics components. Particles (10s nm to many microns) negatively charge in glow discharges and are therefore subject to both electrical and fluid forces. These forces cause particles to accumulate in regions where the interparticle spacing may be less than the plasma shielding distance of the particles. We have developed a Pseudoparticle in Cell-Monte Carlo simulation for electron and ion transport in the vicinity of dust particles to investigate conditions where the sheaths of adjacent particles overlap. Results from the model will be discussed. We found that when two dust particles are aligned parallel to the electric field, the upstream particle (with respect to the electron drift) shadows the rear particle, resulting in a lower total charge on the rear particle. We also observe that the total charge on two dust particles decreases as the interparticle distance decreases and their mutual shielding increases.

* Work supported by NSF, Sandia Natl. Lab., SRC, and U. of Wisconsin ERC for Plasma Aided Manufacturing

SESSION BB: EXCITATION, IONIZATION AND SCATTERING

Tuesday morning, 19 October 1993
Grand Salon C, 10:15–12:00
S. Chung, presiding

BB-1 Absolute Experimental Electron Impact Coss Section for the Copper $4^2S \rightarrow 4^2P$ Resonance Transition* CONNOR FLYNN AND BERNHARD STUMPF, Dept. of Physics, University of Idaho. --- We have measured the linear polarization and the apparent excitation function [1] of the copper $4^2S \rightarrow 4^2P$ resonance transition (324.8, 327.4 nm) from threshold (3.8 eV) to 1000 eV. Relative experimental cross section data are normalized at an energy of 1000 eV with respect to first Born theory that includes the $4^2S \rightarrow 4^2P$ transition with an oscillator strength of 0.652 and cascading from the $(3d^{10}nd)^2D$ states with $n = 4$, ... 10. Our measured Cu $4^2S \rightarrow 4^2P$ cross section agrees very well with the ten-state close-coupling theory of Scheibner and Hazi [2] at low energies ($E < 8$ eV) and with the four-state close-coupling theory of Msezane and Henry [3] at intermediate energies (8 eV $< E <$ 100 eV). Absolute experimental cross sections for excitation of the magnetic sublevels of the 4^2P state are also given.

*Supported in part by NSF/Idaho-EPCoR under grant RII-8902065 and by Lawrence Livermore National Laboratory under contract B160497.

[1] C. Flynn, Z. Wei, and B. Stumpf, Phys. Rev. A, in press
[2] K. F. Scheibner and A. U. Hazi, private communication (1993)
[3] A. Z. Msezane and R. J. W. Henry, Phys. Rev. A 33, 1631 (1986)

BB-2 Azimuthal Effects in Excited State Scattering,* Z. SHI, C. H. YING, W. TAN, and L. VUŠKOVIĆ, Old Dominion U,– Elastic collisions of low energy unpolarized electrons with laser excited, polarized 3P sodium atoms are being studied. Electron energy of several eV is of the same order as the kinetic energy of the valence electron and collision time is comparable with the revolution period. "Parallel" or "antiparallel" motion of the valence and the projectile electrons in the scattering plane results in an asymmetry between the scattering cross sections for $\phi=0$ and $\phi=\pi$ at the same θ. Such an effect is more significant for large polar scattering angles dominated by smaller impact parameters. A new scattering system is built, which includes a low energy electron gun, interaction region with electron beam collectors, and a scattered electron detector with energy analyzers. Preliminary data will be compared with close coupling calculation[1].

* Research supported by U.S. National Science Foundation.
[1] H. L. Zhou, D. W. Norcross, and B. L. Whitten, Correl. and Polariz. Elec. and Atom. Coll. and (e,2e), Flinders University, Adelaide, IOP Conf. Proc. No. 122, edited by P. J. O. Teubner and E. Weigold, pp.39-48 (1992).

BB-3 Electron Impact Ionization of Excited Sodium,* W. TAN, Z. SHI, C. H. YING, and L. VUŠKOVIĆ, Old Dominion U,– We studied electron impact ionization of excited sodium in the energy range from the threshold to 30 eV by measurements of collisionally produced ions as a function of electron energy. A traveling wave laser field of circularly polarized light is utilized to prepare 3P state atoms. The fraction of excited-state atoms is determined by the displacement of the photon-recoiled atom beam in the plane perpendicular to its propagation. Assuming a Gaussian electron energy distribution, the total ionization cross sections of excited- a ground-state sodium are simultaneously determined from the measured quantities. The fitting function involved in the data analysis procedure is taken from Ref. 1. Results will be compared with absolute measurements[2] of ground-state and calculation[3] of ground- and excited-state ionization.

* Research supported by U.S. National Science Foundation.

[1] Y.-K. Kim, Bull. Am. Phys. Soc. 37, 1067 (1992).

[2] I. P. Zapesochnyi and I. S. Aleksakhin, Soviet Phys. JETP 28, 41 (1969).

[3] E. J. McGuire, Phys. Rev. A 3, 267 (1971) and 16, 62 (1977).

BB-4 Electron Impact Excitation from Metastable States of Helium and Neon,* D.C. CARTWRIGHT, G.CSANAK, R.E.H. CLARK, and J. ABDALLAH, Jr, Los Alamos National Laboratory - Differential and integral cross sections for excitation from the metastable states: 2^3S and 2^1S in Helium and $^3P_2$ and $^3P_0$ ($2p^53s$) in Neon, have been calculated using Distorted-Wave level approximations. For Helium, the individual cross sections to all higher S,P, and D states, and their sum, have been obtained by using the n-dependence determined from the lower-n states. The cross section sum from either Helium metastable state is two-orders of magnitude larger than the corresponding sum from the ground state. Initial results from an analogous study involving the two metastable states of Neon will be presented.

*Supported by the NSF/OIP, the DOE, and Univ. of California / Los Alamos Collaboration (CALCOR)

BB-5 Optical Detection of N_2^+ Ions Produced by Electron Impact on N_2.* R.B. SIEGEL and K. BECKER, City College of C.U.N.Y. - Neutral ground-state dissociation fragments produced by electron-molecule collisions can only be detected using optical techniques such as laser-induced fluorescence (LIF). We have recently completed the construction of a triple-beam apparatus (electron-beam, gas-beam and laser-beam) for measurements of electron-impact cross sections for the formation of neutral ground-state dissociation fragments from halogen-containing molecules. We used N_2 to test the performance of the apparatus and to demonstrate the proof-of-principle of the method. Results are reported for the cross section for the formation of N_2^+ ion from N_2 obtained by analyzing the 391 nm N_2^+ LIF emission produced by pumping the electron-impact produced ground-state N_2^+ ions with an excimer-pumped dye laser. The results are compared with the N_2 ionization cross section which is well-known from previous experiments.

*Work supported by the National Science Foundation (NSF) and the American Chemical Society-Petroleum Research Fund (ACS-PRF).

BB-6 Images of Photoelectrons from Atoms, Molecules, and Surfaces,* H. HELM, M. SAEED, M. J. DYER, and D. L. HUESTIS, SRI International, Menlo Park, Ca 94025--Photoelectrons generated at a point source with a discrete energy travel outward on the surface of a sphere that expands with time. For example, electrons produced at time t=0 with an energy of 1 eV can be found 20 ns later on the surface of a sphere of 25 mm diameter. This sphere can be projected onto a flat screen using an external electric field. A circular image results with a diameter that is proportional to square root the electron energy and a filling pattern that reveals the spatial distribution of the electrons on the surface of the sphere. In this way, the squared angular wavefunction of the free electrons is accessible to direct observation.

We have used this approach to investigate multiphoton ionization of helium, neon, and xenon[1] atoms; hydrogen and oxygen molecules; and metal surfaces in intense laser fields. Simultaneous visualization of the photoelectron energy and angular distributions facilitates the identification and classification of ionization mechanisms as well as modifications of the electronic structure of the target by the radiation field.

* Supported by NSF Grant No. PHY-9249199

[1] H. Helm, N. Bjerre, M. J. Dyer, D. L. Huestis, and M. Saeed, Phys. Rev. Lett. **70**, 3221 (1993).

BB-7 Metastable Production Following Electron Impact on CO_2 and CO*, L.R. LECLAIR, M.D. BROWN and J.W. McCONKEY, University of Winsor, Ontario, Canada - A special detector has been developped[1] based on Xe matrix isolation followed by fluorescence. This has been used in conjuction with time-of-flight spectroscopy to study the production of $O(^1S)$ and $CO(a^3\pi)$ by electron impact over an energy range from threshold to 1 keV. Data have been made absolute using $O(^1S)$ production from N_2O as a secondary standard. The maximum cross-section for production of $O(^1S)$ from CO_2 was measured to be 16.8×10^{-18} cm^2 at 50 eV. Full details of the techniques and all the data obtained will be presented at the Conference.

* Research supported by the Petroleum Research Fund administered by the American Chemical Society and by the Natural Sciences and Engineering Research Council of Canada.

[1] L.R. LeClair and J.W. McConkey, J. Chem. Phys., in press (1993)

SESSION CA: MAGNETIZED AND MAGNETICALLY ENHANCED PLASMAS, INCLUDING ECR, HELICON, AND SURFACE-WAVE DISCHARGES II

Tuesday afternoon, 19 October 1993
Grand Salon A, 13:30–15:30
D.B. Graves, presiding

CA-1 Plasmas Excited by Uniform Distributed Electron Cyclotron Resonance: Principle and Performance, T. LAGARDE, J. PELLETIER, Y. ARNAL, J. COCAGNE and F. FABIANO, Laboratoire de Physique et Chimie des Procédés Plasma, Université Joseph Fourier (Grenoble, France), Unité CNRS, France Telecom CNET - The principle of distributed electron cyclotron resonance (DECR)[1] which combines multipolar magnetic field confinement and microwave excitation at electron cyclotron resonance (ECR) is recalled. The advantages of the new design, the so-called uniform distributed ECR (UDECR)[2], over conventional DECR are presented in terms of plasma density and uniformity for a single applicator and for a set of height linear microwave applicators in a cylindrical configuration. The interest of closed multipolar magnetic field structures to improve the confinement of energetic primary electrons is experimentally demonstrated. In particular, the track- and comb-like magnetic structures are both well-suited to the cylindrical and planar UDECR configurations . With argon or krypton, plasma densities up to 10^{12} cm^{-3} are currently achieved at 2.45 GHz excitation frequency.

1 M. Pichot, J. Pelletier and Y. Arnal, US patent n° 4745337 (1988)
2 J. Pelletier, US patent n° 7 824 210 (1992)

CA-2 The Dissociation of Silane in a High-Density Silane-Oxygen Helicon Plasma, H. M. PERSING, R. W. BOSWELL, C. CHARLES, A. DURANDET, A. J. PERRY, Space Plasma and Plasma Processing Group, PRL, RSPhysSE, Australian National University - In experiments aimed at producing high-quality SiO_2 films for planar optical waveguide applications, a pressure rise of up to a fâctor of 10 has been measured when the high-density Helicon plasma is turned on. Optical spectroscopy and energy-selective ion and neutral mass-analysis show that even at low powers (less than 50 watts) the silane is highly dissociated. This has major consequences for the quality of thin SiO_2 films (very low hydrogen incorporation) and for the formation of dust.

CA-3 Thomson Scattering Measurements of Spatial Profiles of T_e and N_e in an ECR Discharge, H. MUTA, M. YOSHIDA, M.D. BOWDEN, K. UCHINO, K. MURAOKA, M. MAEDA, Y. MANABE, M. KITAGAWA, T. KIMURA and R.K. PORTEOUS, Kyushu U., Mitsubishi Heavy Industries, Matsushita Electric and Australian National U - We have previously reported incoherent Thomson scattering measurements of electron temperature T_e and density N_e in the centre of the source region of an argon ECR discharge[1]. In this paper, we report measurements of radial profiles of T_e and N_e in a similar ECR discharge chamber. The dependence of these profiles on the strength and configuration of the applied magnetic field was investigated and compared to the results of a 2-D simulation of the plasma. The density profile was observed to be smooth and monotonically decreasing from the plasma centre to the edge but the temperature profile was observed to be peaked near the plasma edge for some discharge conditions.

[1]M.D. Bowden *et. al.*, J. Appl. Phys. 73, 2732 (1993).

CA-4 Free Radical Distribution in an ECR Etching Reactor, M. MEYYAPPAN, Scientific Research Associates, Inc. - The ability to maintain a high density discharge at low pressures and absence of any serious damage-inducing self bias make ECR an attractive technique for etching semiconductors. In an effort to understand the complex physical and chemical processes inside an ECR chamber, a number of diagnostic techniques are employed[1] to measure concentration of free radicals. We have developed a model to aid in the interpretation of the diagnostic experiments. The model consists of mass balance equations for constituent species. The diffusion process is represented by an effective diffusion coefficient combining ordinary diffusion, and Knudsen diffusion when mean free path is comparable to reactor dimensions. Analytical solutions have been obtained for the radially-averaged equations. The model has been applied to a CF_4 plasma and distribution of various free radicals as a function of process parameters has been calculated.

[1]N. Hershkowitz and H.L. Maynard, American Vacuum Society 39th Natl. Symp., Nov. 1992.

CA-5 Time and Spatially Resolved Optical Emission in a Helicon Reactor, A.R. ELLINGBOE, R.W. BOSWELL, J.P. BOOTH*, N. SADEGHI*, Space Plasma and Plasma Processing, The Australian National University, Canberra, Australia - Short lifetime Argon ion line (λ=443 nm, τ=20 ns) emission strengths have been measured as a function of axial and angular positions (integrated over the radius). The modulation is found to travel in the axial dimension at the same speed as waves launched by the antenna. Implications for Landau damping and power deposition will be discussed.

*Laboratoire de Spectrométrie Physique, Université Joseph Fourier, Grenoble, France.

CA-6 The structure of the presheath in an ECR plasma, S.L. GULICK, B.L. STANSFIELD, C. BOUCHER, C. KHODR, D.A. POIRIER, INRS-Energie et Matériaux, Varennes, Québec-We have attempted to develop a self-consistent picture of an Argon plasma interacting with an Aluminum target. The plasma is created in an ECR source, and flows along a relatively uniform magnetic field. The spatial distributions of the density, temperature and potential are measured using Langmuir probes. The ion velocity distribution is measured at various positions in the presheath by Laser Induced Fluorescence. Far from the target, the ion flow velocity is low, but it increases as we approach the surface. These results are compared to those from a 1D fluid model assuming isothermal electrons and cold ions. An important element is the ionization source term due to recycling of the atoms from the surface. The experimental and numerical results are generally in good agreement, although the measured ion distribution function is broadened due to the production of cold ions via ionization.

CA-7 Theory of the plasma-sheath transition in a magnetic field, K.-U. RIEMANN, Institut für Theoretische Physik, Ruhr-Universität Bochum, D-44780 Bochum, Germany. In the limit of a small Debye length ($\lambda_D \to 0$) the plasma boundary layer in front of a negative absorbing wall is split up into a collision-free planar space charge sheath and a quasineutral presheath where the ions are accelerated to ion sound speed (Bohm criterion). Usually the presheath mechanism depends decisively on collisional friction of the ions, on ionization or on geometric ion current concentration. If the ion dynamics in the presheath is dominated by a magnetic field (nearly) parallel to the wall, an additional effect must be considered to provide an ion transport to the wall. The special cases of an ion transport by field lines intersecting the wall at a small angle [1] and of an ion transport by collisions [2] result in somewhat contradictory conclusions. To resolve the contradiction we investigate a simple hydrodynamic model of the presheath accounting for an oblique magnetic field *and* for collisions. We discuss the limiting cases [1] and [2] and show that a strong magnetic field alone is not able to provide a presheath mechanism, but that it 'compresses' the collisinal presheath into a thin layer with a characteristic extension of the ion gyroradius ρ_i.

[1] R. Chodura, Phys. Fluids **25**, 1628 (1982)
[2] J. Behnel, Report 85-O2-118 SFB 162 Bochum/Jülich (1985)

CA-8 **Relation between Sputtered-Film Quality and Inner Plasma Characteristics of DC Magnetron***, T.MAKABE, A.ITOH†and N.SHIMURA, Keio Univ. Yokohama, Japan — Magnetron sputtering is very simple process, and covers the major part of the large area thin film deposition. The quantitative control of film composition in addition to the thickness is required for the magnetron in the field of reactive sputtering and compound metal target. In these circumstances, there are not so many investigations on the relation of the inner magnetron plasma structure to the quantitative film property. In this work, we describe the self-consistent procedure to estimate the film composition and the thickness by using the plasma/target surface/substrate surface equations of active particles based on the 3D-CT image observation by Robot. A case study is performed in the oxidized-Al thin film deposition in Ar/O_2 reactive DC-magnetron sputtering. The predicted radial composition and the film thickness are compared with experimental, and we find farely good quantitative agreement between them.
*Work supported by a Grant-in-Aid for Sci. Research No.05237104
†Permanent address: Shibaura Engineering Works Co. Ltd.

SESSION CB: ADVANCES IN ELECTRON COLLISIONAL PROCESSES
Tuesday afternoon, 19 October 1993
Grand Salon C, 13:30–15:45
K.H. Becker, presiding

Invited Papers

CB-1 Absolute Low Energy Electron Scattering Cross Section Measurements S.J. Buckman, R.J. Gulley, D.T. Alle, M.J. Brennan and M.J. Brunger☛ Electron Physics Group, RSPhysSE, Australian National University - A number of recent experiments in our laboratory on both absolute total and differential cross sections (DCS) for electron-molecule/atom scattering will be discussed. Particular emphasis will be placed on measurements below 5 eV, and in the case of the DCS experiments, both elastic and vibrational excitation cross sections will be presented. Where possible, comparison with other experimental and theoretical results will be made. Gases which have been studied include N_2, Ne, Xe, H_2S, SO_2, and N_2O. A brief discussion of some of the many pitfalls involved in such measurements will also be included.

☛ Present Address: School of Physical Sciences, The Flinders University of South Australia, Bedford Park, 5042, South Australia.

CB-2 Theoretical Studies of Low Energy Electron - Molecule Collisions* T. N. RESCIGNO Lawrence Livermore National Laboratory - With the additional degrees of freedom associated with nuclear motion, low energy e⁻-molecule collisions present a body of physics far richer than that found in electron-atom scattering. Numerical difficulties, however, make the problem much more difficult and *ab initio* theoretical studies of molecular collisions have lagged e⁻-atom studies by a considerable amount. I will review recent progress in variational treatments of e⁻-molecule scattering using the Kohn method, with particular emphasis on the low-energy region where target correlation and polarization effects are important. I will discuss our recent studies of threshold vibrational excitation in H_2 and CH_4, as well as studies of electronically inelastic scattering in CL_2 and H_2O..

* This work was performed under the auspices of the U.S. Department of Energy by LLNL under contract W-7405-ENG-48.

Contributed Papers

CB-3 Inelatic Low-Energy Electron Collisions with Laser-Excited Rubidium Atoms. Z. WEI, C. FLYNN AND B. STUMPF, Dept. Physics, University of Idaho. --- First experimental cross section data for Rb $5^2P(J{=}3/2,\ M_J{=}3/2) \to 6^2D$ electron excitation have been obtained using the optical excitation function method in a crossed atom and electron beam arrangement. The initial state for electron impact is created as a pure spin and angular momentum state $|L{=}1,\ S{=}1/2,\ M_L{=}1,\ M_S{=}1/2\rangle$ by optical pumping with a circularly polarized diode-laser beam, tuned to the $F'=3 \to F=4$ hyperfine transition of the $5^2S_{1/2} \to 5^2P_{3/2}$ resonance line (780 nm) of ^{85}Rb.
The role of simultaneous $5^2S \to 6^2D$ direct electron excitation from the ground state, measured previously [1], $^2F \to 6^2D$ cascading, anisotropy of observed $6^2D \to 5^2P$ fluorescence, and normalization to first Born theory at high energies are carefully discussed.

*Supported by NSF/Idaho-EPCoR under grant RII-8902065

[1] Z. Wei, C. Flynn, A. Redd, and B. Stumpf, Phys. Rev. A **47**, 1918 (1993)

CB-4 **Electron-Metastable Atom Collision Theory*, E. J. Mansky *School of Physics, Georgia Tech.*** **The current status of theoretical techniques used to compute cross sections for the electronic excitation of atoms *initially* in an excited or metastable state is reviewed. A detailed discussion of the relative merits of fully quantal versus semiclassical treatments of the scattering will be given. Results of semiclassical multichannel eikonal calculations for the electron impact excitation of *He* initially in the $2^{1,3}S$ and $2^{1,3}P$ states will be presented and compared to recent measurements of Lin *et al.*, of the integral cross sections for the excitation of the $n = 3, 4$ levels of helium from the $2^{1,3}S$ states. The inclusion of electron exchange effects within the multichannel eikonal theory will be discussed and the role played by interchannel couplings in general, and the $4^{1,3}F$ states in particular, will be given.**

* Work supported by AFOSR grant no. 89-0426.

CB-5 A Charge Exchange Target for Measuring Cross Sections of Electron Excitation Out of Metastable Levels.* MARK E. LAGUS, JOHN B. BOFFARD, L. W. ANDERSON, and CHUN C. LIN, U. of Wisconsin - Previous measurements of electron excitation out of metastable levels are limited to electron energies low enough that excitation out of the ground level cannot occur since in the target the metastable number density is much less than the ground level number density. In order to measure the excitation cross sections out of metastable levels at higher energies it is necessary to develop a target where the metastable number density is higher than or comparable to the ground level number density. To accomplish this we use a metastable target produced by charge exchange of a fast He^+ ion beam incident on an alkali target. The charge exchange process is nearly resonant into the 2^1S or 2^3S metastable levels of He so that the formation of the He metastable atoms is favored over the ground level atoms. We have used this new target to measure electron excitation cross sections out of both metastable levels up to 150 eV by the optical method. The effects of ground level contamination on these measurements are eliminated.

*Supported by the NSF Grant PHY-9005895.

CB-6 Resonant Dissociative recombination of H_3^+* A.E. OREL University of California, Davis B. H. LENGSFIELD III IBM Alamden and K.C. KULANDER Lawrence Livermore National Laboratory - Recent experiments by Larsson *et al.*[1] have confirmed the prediction[2] of a high energy (~9eV) peak in the cross section for dissociative recombination of H_3^+. This peak is caused by four resonant states of H_3. Electron scattering calculations using the complex Kohn method provide the resonance positions and widths as a function of internuclear separation. This information was used as input to a wave packet calculation for the dissociation dynamics. Substantial autoionization occurs during dissociation due to the large widths of the resonant states. The shape and magnitude of the calculated resonance cross section agrees with experiment.

* This work was supported by NSF PHY-90-14845 and performed under the auspices of the U.S. Department of Energy by LLNL under contract W-7405-ENG-48. Computer time was provided by the San Diego Supercomputing Center.

1 M. Larsson, H. Danared, J.R. Mowat, P. Sigray, G. Sundström, L. Broström A. Filevich, A. Källberg, S. Mannervik, K.G. Rensfelt, and S. Datz, Phys. Rev. Lett, 70, 430 (1993)
2 K.C. Kulander and M.F. Guest J. Phys. B 12, L501 (1979)

CB-7 Ionization and Simultaneous Excitation of Helium Atoms by Electron Impact*. K. BARTSCHAT, Drake University and A. RAEKER, University of Münster, FRG. — A recently developed method [1, 2] for calculating total and single differential (with regard to energy loss) cross sections for electron and positron impact ionization within the R-matrix (close-coupling) method has been applied to electron impact ionization of helium. This approach includes channel coupling, autoionizing resonances and a multi-configuration expansion of the initial state in an *ab initio* manner. Results for ionization and simultaneous excitation to various (nl)–states of He^+ from the $(1s^2)^1S$ ground state as well as metastable initial states will be presented.

[1] K. Bartschat and P.G. Burke, J. Phys. B **20** (1987), 3191
[2] K. Bartschat (1993), Comp. Phys. Commun. **75**, 219

* Work supported by the National Science Foundation, the Research Corporation, NATO, and the Deutsche Forschungsgemeinschaft.

SESSION D: POSTER SESSION
Tuesday afternoon, 19 October 1993
Grand Salon B, 15:45–17:30
J. Margot, presiding

DA: DIAGNOSTICS

DA-1 Characterization of Impurities in a Low Power Pulsed Discharge* G.F. GOMES, M.E. KAYAMA, C.J.B. PAGAN, M.A. ALGATTI, E.A. ARAMAKI and R.P. MOTA, UNESP-FEG-DFQ, Guaratinguetá, SP, Brazil - The impurities introduced by electrode erosion during a low power discharge were characterized by high resolution spectroscopy. The experiment was carried out in a Z-Pinch using brass electrodes. Inductive radio frequency discharge (frequency 10 MHz, power 10 W) was used for pre-ionization of residual gas. The discharge was performed using a capacitor (8.5 μF, charge voltage 5.0 kV) and a two-electrode spark-gap triggered by 15 kV thyratron pulse. The ringing current profile had 17 μsec period and 14.0 kA peak current. The total charge and current density on the electrode were 0.33C and 3.1 kA/cm^2 , respectively. The gas used were Argon and Nitrogen with filling pressure in the range of 25-105 mTorr. The spectroscopic measurement was carried out in a 2 meter spectrograph (dispersion 7.3 Å/mm) using photographic emulsion. The measurements indicate lines of ArI, ArII and ArIII. The impurity lines from electrode material were 3247.54Å, 3273.96Å of CuI and 3345.02Å, 3282.33Å, 3302.59Å of ZnI.

* Work supported by CAPES (Brazil).

DA-2 Gas Phase Atomic Hydrogen Sensor, * Z. YU, D. SHAW, D. KOBOBEL and G. COLLINS, Colorado State University - Atomic hydrogen has been plasma generated to form arsenic hydrides, AsH_x, used in GaAs epitaxy.[1] The technique we employ to quantify atomic hydrogen generation in the plasma is based on the chemical reaction of atomic hydrogen with a prepared silver oxide surface, $2H+AgO \rightarrow Ag+H_2O\uparrow$. A microbalance is used to quantify this reaction, resulting in an atomic hydrogen detection sensitivity of 10^{12} atoms/cm^2·sec. The flux of hydrogen atoms from a 50 W microwave hydrogen plasma and from a 50 W hydrogen disc plasma[2] were 10^{19} atoms/cm^2·sec and 10^{18} atoms/cm^2·sec respectively. The detailed dependence of atomic hydrogen flux on plasma operating conditions and distance from the sources will be presented.

*Work supported in part by NSF Grant DDM - 9108531, and NREL Contract XM-0-19142-9.

[1]B.Pihlstrom, L.Thompson, D.Shaw, J.Lurkins and G.Collins, J.Electronic Materials, 22, 81(1993).
[2]D.Shaw, T.Sheng, Z.Yu, G.Collins and N.Adachi, Jpn. J. Appl. Phys. 31, 24(1992).

DA-3 Spectroscopic measurements in a C_2H_2/H_2 hot filament diamond CVD system,* K.L. MENNINGEN, H. TOYODA, M.A. CHILDS, L.W. ANDERSON, AND J.E. LAWLER, University of Wisconsin. - The time evolution of the methyl radical (CH_3) density, acetylene (C_2H_2) mole fraction, and filament properties, as well as the diamond growth rate and film quality, are measured in a hot filament CVD system when C_2H_2 and H_2 are the input gases. The CH_3 density and C_2H_2 mole fraction depend greatly on the degree of filament surface poisoning. The results obtained when C_2H_2 and H_2 are the input gases are compared to those obtained when CH_4 and H_2 are the input gases. Under such conditions that the filament surface is not poisoned, the CH_3 concentrations are similar if the input gas contains an equivalent amount of carbon in the form of either C_2H_2 or CH_4.

*Work supported by the Army Research Office.

DA-4 Two-photon LIF and VUV absolute atom density measurements in a H_2 discharge, J. AMORIM*, M. TOUZEAU, G. BARAVIAN, J. JOLLY, LPGP (CNRS), U. of Paris-Sud, Orsay, France and J. LOUREIRO, Univ. Tec. Lisboa(IST), 1096 - Lisboa - Portugal- Multiphoton Laser Induced Fluorescence (LIF) and Vaccum Ultraviolet Absorption (VUV) are employed in order to measure hydrogen atom concentration in a dc glow discharge. An absolute calibration of the LIF signal is obtained by absorption on the L_α line. The atom temperature values are deduced from LIF Doppler profiles. In typical operating conditions of a positive column (0.5 – 5.0 Torr pressure range and 1 – 50 mA discharge current), the atom density varied from 10^{13} cm^{-3} to 10^{14} cm^{-3}, and the atom temperature between (336±43) K to (1580±90) K. The experimental data are compared to the results of a kinetic model, where the electron energy distribution function, the vibrational distribution function of $H_2(X^1\Sigma_g^+,v)$ molecules, the concentrations of dissociated atoms H(1s) and negative ions H^- have been self-consistently calculated by solving the Boltzmann equation coupled to a system of rate balance equations.

* partially supported by CNPq/MAer - Brazil.

DA-5 Comparison of Different Excitation Schemes for Two-Photon Excited Laser Induced Fluorescence Spectroscopy in Atomic Hydrogen, U. CZARNETZKI, K. MIYAZAKI, T. KAJIWARA, K. MURAOKA, M. MAEDA, and H. F. DOBELE*, Kyushu University, *Universitat Essen - Two-photon excited laser induced fluorescence spectroscopy in atomic hydrogen was performed under various excitation conditions. A flow tube reactor provided well reproducible atomic hydrogen densities of the order of 10^{14} cm^{-3}. The laser bandwidth (0.8 cm^{-1} and 11 cm^{-1}), the polarization (unpolarized, linear and circular polarized) as well as the excitation wavelength (2 x 205 nm to n = 3 and 193 nm + 195 nm to n = 4) and the observation wavelength (Balmer alpha and beta) have been varied. The experimental results for the different schemes are compared with each other and with theoretical predictions. Application was made to the determination of absolute and spatially resolved atomic hydrogen densities in an RF-discharge operated in silane.

DA-6 H Atom Detection in a DLC Deposition Plasma*, R. CHESHIRE, W.G. GRAHAM, M. HIGGINS, T. MORROW, V. KORNAS† and H.F. DÖBELE†, Queen's Univ. Belfast - Since atomic hydrogen can play a crucial role in many plasma processes the determination of its ground state density in processing plasma is important. We report on the application of two-photon LIF in connection with a commercial DLC film deposition system. Two 205 nm-photons excite ground state atoms to the n=3 state and the light from the subsequent decay to the n=2 state (H_α) is observed. The 205 nm beam is produced by mixing of 615 nm and 307.5 nm dye laser generated radiation in a BBO crystal with energy up to 1 mJ. Special emphasis is given to absolute concentration measurements. A hot filament atom source is used for in-situ-calibration which in turn is calibrated itself using the NO_2 titration technique. Commissioning measurements, made in hot filament sources and a magnetron, will be reported.

*Work supported by EC BRITE project BE-4647-90

†Univ. Gesamthochschule Essen

DA-7 Laser-Induced Fluorescence Spectroscopy of Laser Ablation Plasma, S. BOILY, M. CHAKER, Y.HUAI, S. GULICK, J. C. KIEFFER, B. STANSFIELD and J. MARGOT*, INRS-Énergie et Matériaux, Varennes, Qc, * U. de Montréal, Qc -

Time-of-flight laser-induced fluorescence spectroscopy has been used for the characterization of the SiC plasma produced by an excimer KrF laser (λ=249 nm, E=100 mJ, τ=12 nsec) in the context of laser ablation deposition studies. The spatio-temporal evolution of the fluorescence signal was obtained by exciting the ground state Si $3p^2\ ^3P_0 \rightarrow 4s\ ^3P_1^0$ transition at 251.43 nm and observing the fluorescence of the $4s\ ^3P_1^0 \rightarrow 3p^2\ ^3P_2$ transition at 252.85 nm. This allows us to quantify the velocity of the neutral silicon Si^0 and then the spatial evolution of the velocity distribution function with the laser intensity (10^8 - 10^9 W/cm^2). These results were compared with those obtained by time-resolved emission spectroscopy measurements.

DA-8 **Measurement of Electron and Negative Ion Densities in a RF SF_6 Plasma**, A. KONO, M. ENDO and T. GOTO, Nagoya Univ., Nagoya 464-01, Japan — Electron and negative ion densities in a RF (13.56 MHz) SF_6 plasma have been measured in a pressure range of 30-700 mTorr using microwave-cavity-resonance and laserphotodetachment techniques. A 10-cm diam. disk was electrically separated from one of the bottoms of a cylindrical microwave cavity (14.6-cm inner diam., 2-cm high); the disk and the rest of the cavity thus served as a quasi-parallel-plate RF electrode system. At a RF power of 10 W, the electron density (N_e) peaked at SF_6 pressure of ~50 mTorr, where $N_e=7\times10^8$ cm^{-3}; the N_e value decreased down to 1×10^8 cm^{-3} as the pressure was increased up to 700 mTorr. The negative ion density (N_n) peaked at ~200 mTorr, where $N_n=3\times10^{10}$ cm^{-3}. The N_n/N_e ratio was ~20 at 50 mTorr and it monotonically increased up to ~110 as the pressure was increased up to 700 mTorr. The decay of N_e and N_n in the afterglow was also measured. The initial decay of N_n was found to be very fast (time constant of ~10μs) and thus could not be ascribed to the ion-ion recombination process. The mechanism of this rapid decay is under study. *Work supported by the Ministry of Education, Science and Culture and by Kurata Research Grant.

DA-9 Quenching of Two-photon Excited H(n=3) Atoms by Several Plasma-relevant Gases,* A.D. TSEREPI, E. WURZBERG, B.L. PREPPERNAU, and T.A. MILLER, The Ohio State U.-Absolute calibration of LIF signals in high pressure plasmas requires knowlegde of the efficiency of the quenching of the fluorescence by various gases present in these environments. Quenching rate coefficients have been measured for hydrogen atoms in the $3s^2S$ and $3d^2D$ states by H_2, O_2, N_2, Ar and He. A constant H-atom source is provided by the photolysis of C_2H_2 by 205 nm light, two photons of which are subsequently absorbed by the photofragment atoms to prepare the states under investigation. The fluorescence intensity and its temporal decay are measured as a function of quencher gas concentration in order to determine quenching rate coefficients. A model assuming quenching and l-state mixing is used to fit the data and to evaluate the rate constants over a wide range of pressures. The results are compared to previous measurements over a more restricted range of pressures[1].

*Work supported by Air Force Wright Laboratories.

[1]J. Bittner *et al*, Chem. Phys. Lett. **143**, 571 (1988).

DA-10 Vacuum Ultraviolet Laser Absorption Spectroscopy of Hydrogen Discharges *-- A. T. YOUNG, K. N. LEUNG, and D. M. PONCE, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720, and D. WAGNER and H. F. DÖBELE, Institut für Laser-und Plasmaphysik, Univ. GH Essen, 45117 Essen, Germany, -- Low pressure plasmas have found use in a wide variety of applications, such as in ion sources. The chemical physics occurring in these plasmas, however, is not always well understood. In order to better understand these processes, Vacuum Ultraviolet (VUV) laser absorption spectroscopy has been used to measure the atomic and molecular densities and temperatures in low pressure (< 3 x 10^{-2} mbar) hydrogen discharges. Both filament driven and inductively-coupled rf plasmas have been studied. VUV light has been generated using two methods, Four Wave Sum Mixing, which has been used for measurements in the wavelength range from 93 nm to 125 nm, and Stimulated Raman Scattering, which has been used at wavelengths ≥ 120 nm. Measurements of the absolute H and internal-state-specific H_2 densities have been made under a variety of discharge conditions for both types of plasmas. These measurements will be compared and contrasted.

* This work has been supported by the U.S. AFOSR, the US DOE under contract No. DE-AC03-76SF00098, the German DFG through SFB191, and a NATO Collaborative Research Grant.

DA-11 Fast EEDF Probe Measurements Using DC Coupled Stepped Signal, F. M. DIAS, CEL Lisbon Technic. U. - We present an inexpensive, combined intermodulation-numerical differentiation system that provides fast on-line analogic EEDF measurements with the advantage of convolution inversion. The measured signal only requires numerical smoothing for the calculation of higher order derivatives, *i.e.*, we do not need to smooth the probe characteristic. We present results of measured EEDFs in a surface wave sustained coaxial discharge. With the frequency constraints imposed by large capacitances in the system-experiment interfacing devices, the second derivative measurement is accomplished in 300 μs. Without averaging over multiple data points and with the limitation of a 12-bit acquisition board, a 3-decade EEDF range is achieved. This is made possible by taking advantage of the optimum transfer function provided by the analogic 3-point differentiation technique and using a finite amplitude stepped probing signal. As a direct result of the system high speed we did not experienced any problems of probe contamination, so no extra time was needed to clean the probe between successive data acquisitions.

DA-12 Eedf Measurements in a H_2/C_2H_2 Plasma,* W. G. GRAHAM, Queen's Univ. Belfast, R. DOYLE and M. B. HOPKINS, Dublin City Univ. and T. O'BRIEN, Eolas, Dublin- The electron energy distribution function (eedf) in an H_2 /C_2H_2 plasma, used for the deposition of diamond-like carbon, has been measured using a passively-compensated electrostatic probe technique. Deposition of material on the probe and its supporting structures can induce changes in the probe characteristic which are unrelated to the plasma behaviour. Here the plasma was created in a assymetric, single electrode system, driven at 13.56 MHz. The electrostatic probe was positioned about 1cm from the electrode. The probe's digitally-based data acquistion system allowed rapid and separate measurement of each energy point in the eedf immediately after probe cleaning. Nonsequential energy measurements meant that any hysterisis effects could be observed. Although changes in the spatial structure of the plasma, following 7% C_2H_2 addition to the H_2 plasma, complicate the interpretation, cooling of the high energy tail of the eedf is apparent.

* Work was supported by EC BRITE project BE-4647-90.

DA-13 Probe Measurements Using an Emissive Probe as a Reference Electrode, K.OHE and T.KIMURA, Nagoya Inst. Tech. Japan.

A tiny emissive probe(EP) of 0.06 mmϕ and 10 mm length is used as a reference electrode in probe measurement using a cylindrical single probe of 0.06 mmϕ and 4 mm length. The electron energy distribution function (EEDF) is detected in a He homogeneous positive column of 50 mmϕ and 800 mm length, filled with $p = 0.32$ torr and operated at I_d from 5 mA to 80 mA. The probe $V_p - I_p$ characteristics is detected by sweeping the probe bias voltage using a 20 Hz ramp voltage with 50 V_{pp}. After digitizing both I_p and V_p, and averaging them 128 times, the EEDF is obtained from the second derivative of I_p with respect to V_p by a digital filtering method using the finite impulse response[1)]. The EEDF detected by the EP as the reference agrees with that by the cathode as the reference. A fairly good agreement between them is obtained by suppressing a small voltage difference between the plasma and floating potentials of EP due to the EP wire temperature by a feedback system using another tiny single probe. The present method is applicable to electrodeless discharge plasmas with minimum disturbance.

1. T.Kimura, A.Yoneya and K.Ohe, Jpn.J.Appl.Phys. 30 1877 (1991)

DA-14 Plasma Monitoring System Using the Triple−Probe Method, T.UMEZAWA, K.SHINOHARA, Nihon Koushuha Co. Ltd., Yokohama, Japan and S.TEII, Musashi Institute of Technology, Tokyo, Japan. Plasma has been widely used for material processings such as etchings, depositions and sputterings in the fields of thin film and semi−conductor productions. For controlling the quality of these productions, plasma parameters must be monitored to kept always uniform in space and unchanged with time. For this purpose, a plasma monitoring system using the Triple−Probe method with an ion bomberment circuit has been developed. This system enables us to display continuously the electron temperature Te and the electron density Ne for a long time in reactive gas discharge. Experiments have been carried out both in Silane and Methane gaseous plasmas. The obtained data and the basic circuit used will be presented.

DA-15 Mass Spectroscopy of Growth Precursors in Thermal Plasma CVD of Diamond Films,* H. J. YOON, P. G. GREUEL D. W. ERNIE, and J. T. ROBERTS, U. of Minnesota - Instrumentation has been developed for mass spectrometric analysis of the growth precursor species impinging on growing films in high-pressure, high-power thermal plasma CVD. Growth precursor species are extracted from the plasma through a supersonic convergent-divergent nozzle located in the substrate into a two-stage differentially pumped mass spectrometer system. The system is designed to minimize alteration of species composition during the extraction/analysis processes, with threshold ionization mass spectroscopy utilized for the reliable detection of radical species. This presentation will focus on the system's design and its application to the study of diamond film deposition onto molybdenum substrates from a 3.3 MHz inductively coupled torch operating between 100 to 800 Torr in $CH_4/H_2/Ar$ mixtures. Results will be presented demonstrating the system's ability to reliably monitor growth precursor neutral and radical species. Measurements of precursor species (e.g., CH_n) as a function of discharge conditions and resulting film quality will be presented and the implications of these results for film growth mechanisms will be discussed.

*Work supported by NSF Grant No. ECD-8721545, Engineering Research Center for Plasma-Aided Manufacturing.

DA-16

Spatially-Resolved Mass Spectroscopy of Hydrocarbon Species in the Boundary Layer During the Deposition of Diamond Thin Films* K. R. STALDER and W. HOMSI, SRI International, Menlo Park, CA 94025—We report on continuing investigations of high-pressure arcjet plasmas. In addition to optical-emission and laser-induced-fluorescence studies,[1] we are studying the spatial variation of the hydrocarbon species that impinge upon the surface. Previous measurements of non-spatially-resolved mass spectra showed a linear conversion of methane to acetylene, and erratic methyl radical signals, the latter of which could be due to turbulent boundary layer chemical reactions. Both CH_3 (M/e=15) and C_2H_2 (M/e=26) are thought to be important species leading to diamond formation. We continue to observe these species, and their fragments. We also observe significant concentrations of M/e=28 and 29, which are probably C_2H_4 and C_2H_5, respectively. Spatially-resolved mass scans are achieved by mounting the arcjet source on a large x-y-z translator that enables the arcjet's stagnation point to be scanned around the sampling orifice in the deposition substrate.

[1]K. R. Stalder and J. B. Jeffries, Diamond and Related Materials 2, 443 (1993)

*Work supported by ARO under Contract DAAH04-93-K-0001

DA-17

Spectroscopic and Video Observations of Fullerene Production Arcs, D. C. LORENTS, K. R. STALDER, D. M. KEEGAN, R. S. RUOFF, and R. M. MALHOTRA, SRI International, Menlo Park, CA 94025 - Spatially resolved spectroscopic studies of a carbon arc operating under fullerene production conditions have been made across the visible wavelength range using an imaging Optical Multichannel Analyzer. C_2 Swan bands are observed to be the major visible emissions although strong CI and CII as well as He I atomic lines are also observed. Video and photographic studies of the arc characteristics show the Swan-band emissions to be concentrated most intensely near the anode but also to appear strongly in regions well outside the electrode gap region. Vibrational and rotational temperatures of these bands provide information on the temperatures in various regions of the arc. The characteristic spatial structure of the arcs observed in the Swan-band light suggests that they are excited by electrons whose trajectories are controlled by the local electric and magnetic fields. The arc exhibits complex and interesting temporal behavior that has been observed with a video camera using short exposure times. Video film taken through a Swan-band filter clearly shows the dominant spatial features of the C_2 emissions.

*Work supported by Sandia National Laboratories.

DA-18 Optogalvanic Single-color Multiphoton Ionization Spectroscopy of Uranium in a Hollow Cathode Discharge, S. LÉVESQUE, F. BABIN and J.-M. GAGNÉ, École Polytechnique de Montréal- Single color multiphoton ionization spectra of atoms can be obtained using the fast pulsed (~10^{-9} s) optogalvanic signal generated by photoionization in the dark space of a hollow cathode discharge. Such spectra have been measured for uranium in the spectral range of rhodamine 6G with a high laser bandwidth excitation (0,3 cm^{-1}). In the process of ascribing an ionization scheme to each line through the known levels of uranium, many possibilities appear. In order to help us select the correct scheme, we perturbed the atomic level population distribution by optical pumping of the 16900.37 cm^{-1} level ($^7M_7$). The spectrum obtained this way show many new strong lines. We try to explain these lines by a three photon resonant or quasi-resonant scheme, using known levels of uranium, or by a two photon scheme from the 16900.37 cm^{-1} level. In both perturbed and unperturbed spectra, many ionization schemes are still possible for each line. For this reason we have performed higher resolution scans of selected lines (in particular 5915.4Å) in order to confirm the existence of more than one scheme for many lines.

DA-19 OH Dynamics in High Energy Pulsed Air Discharge * ALEXANDER ERSHOV and JACEK BORYSOW, Physics Department, Michigan Tech. University - Time transients of the number density of hydroxyl radical ground state ($X^2\Pi(v = 0)$) formed in the DC high energy pulsed corona discharge were measured by means of laser-induced fluorescence. Frequency doubled tunable dye laser was tuned to one of the rotational lines of the $A^2\Sigma \leftarrow X^2\Pi$ ($v' = 1 \leftarrow v'' = 0$) band near 282 nm while emission at 309 nm, within $A^2\Sigma \rightarrow X^2\Pi$ ($v' = 0 \rightarrow v'' = 1$) band, was observed. The discharge peak current, I, varied from 10^{-2} to 10 A, and the time duration was from 500 ns to 50 μs. The discharge was operating at the atmospheric pressure and at 10 Hz repetition rate. The population of $v'' = 0$ of OH reaches the steady state within first 20μs of the discharge and is independent on current for $I \geq 0.2A$. The significant build up of $v'' = 0$ state population was observed after the discharge pulse. Hydroxyl ground state number density reaches maximum value approx. 100 μs after the discharge and is up to three times larger than during the discharge pulse.

This increase of $v'' = 0$ population is attributted to the vibrational relaxation within $X^2\Pi$ state.
* Supported by The State of Michigan Research Excellence Fund

DA-20 Laser Induced Fluorescence Measurements of the Electric Field in an RF Sputtering Discharge, M.D. BOWDEN, Y.W. CHOI, K. MURAOKA and M. MAEDA, Kyushu U.- The electric field in the sheath region of an RF sputtering discharge was measured using a laser induced fluorescence technique. With this technique, a normally forbidden transition in the BCl radical becomes partially allowed in the prescence of an electric field and detection of the fluorescence intensity of this transition allows the electric field to be determined[1,2]. The discharge was operated in pure BCl_3 gas and in an Ar/BCl_3 gas mixture. The electric field distribution in the sheath region was measured for a range of gas pressures and input RF power. The ultimate aim of this experiment is to determine the relationship between the electric field distribution near the RF electrode and the velocity distribution of atoms which are sputtered from the electrode surface.

[1]C.A. Moore, G.P. Davis and R.A. Gottscho, Phys. Rev. Lett. 52, 538 (1984).
2. Y. Yamagata *et. al.*, Jpn J. Appl. Phys. 30 166 (1991).

DB: MAGNETIZED AND MAGNETICALLY ENHANCED PLASMAS, INCLUDING ECR, HELICON, AND SURFACE-WAVE DISCHARGES III

DB-1 Laser Diagnostic Measurements of Electron and Ion Velocity Distributions in an ECR Discharge, M.D. BOWDEN, F. KIMURA, T. YONEDA, K. UCHINO, K. MURAOKA, M. MAEDA, Y. MANABE, M. KITAGAWA, T. KIMURA and R.K. PORTEOUS, Kyushu U, Matsushita Electric and Australian National U. Laser induced fluorescence has been used to measure the temperature and velocity distribution of ions in an argon ECR discharge. Measurements made in the source showed that the ion temperature was 0.15 eV and was not dependent on the conditions of the discharge such as gas pressure and microwave input power. The ion velocity distribution was also measured in the reactor region as a function of distance from the substrate. These measurements were compared to previously obtained measurements of electron temperature and density[1] and also to the results of a 2-D simulation of ECR plasmas[2].

[1]M.D. Bowden *et. al.*, J. Appl. Phys. 73, 2732 (1993).
[2]R.K. Porteous and R.W. Boswell, Proc. 45th GEC, 170 (1992).

DB-2 One Dimensional Modeling for Magneto-Microwave Plasma Using the Monte Carlo Method, M. IKEGAWA, Y. KAKEHI, and J. KOBAYASHI, Mechanical Engineering Research Laboratory, and R&D Promotion Office, Hitachi Ltd.- 1-D simulator for a magneto-microwave plasma used in semiconductor manufacturing equipment such as etching reactors and CVD reactors was developed combining a Monte Carlo particle plasma model and an electromagnetic wave (2.45 GHz) damping model.[1] In this simulation a plasma production mechanism with electron cyclotron resonance and electromagnetic wave damping can be analyzed. For argon gas pressures of 0.13, 0.67, and 9.3 Pa, simulation results show that the plasma density distribution is strongly pressure dependent. As the gas pressure increases, the maximum moves from the ECR point towards the incident microwave.

[1]M.Ikegawa, Y. Kakehi, & J. Kobayashi, Jpn. J. Appl. Phys. 31 (1992)p2030.

DB-3 Radial Modelling of a Surface-wave-produced Plasma Confined by a Static Magnetic Field, M. FORTIN and J. MARGOT, Université de Montréal - We present a self-consistent radial model for a cylindrical plasma column sustained by an electromagnetic surface wave in the presence of an axial, static and uniform magnetic field. Our model is based on that previously elaborated by Ilic[1] for a DC discharge. It requires solving the first three moments of the Boltzmann equation for both electrons and ions and it yields the radial profiles of the density and velocity of charged particles, of the space-charge electric field as well as of the electron and ion temperatures. The coupling between the plasma and the wave electric field occurs through the equation for the power balance per electron. Our presentation focuses on the influence of the discharge parameters (gas pressure, intensity of the magnetic field, wave frequency and plasma vessel diameter on the spatial distribution of the plasma characteristics. The calculations are performed for an argon plasma by assuming the electron energy distribution function to be Maxwellian and direct ionization to occur by electron impact on the atoms in their ground state.

[1]D.B. Ilic, J. Appl. Phys. 44, 3993 (1973)

DB-4 A Two-Dimensional Model of an Axisymmetric Electron-Cyclotron-Resonance (ECR) Plasma Processing system,*K.A. ASHTIANI, J.L. SHOHET, and W.N.G. HITCHON, Engineering Research Center for Plasma-Aided Manufacturing, University of Wisconsin-Madison-A two-dimensional particle-in-cell model of an ECR plasma processing system is developed in a cylindrical coordinate system, (r, z). The code is fully kinetic and treats both electrons and ions as particles. Each charged particle in the simulation has three velocity components, (v_r, v_θ, v_z). However, the variations in the azimuthal direction are ignored due to symmetry. An ECR heating scheme based on a single-particle solution of the particle trajectories in a Doppler-broadened resonance zone is utilized. The microwave fields are analytically calculated based on an extension of the WKB theory. Collisions with background neutrals are treated by a Monte-Carlo technique. In addition to being implicit, the model utilizes novel techniques to speed up the overall execution time of the code.[1] Two dimensional contours of plasma parameters such as density and potential will be presented and results will be discussed.

*Work supported by NSF Grant No. ECD-8721545.
[1]W.N.G. Hitchon, T.J. Sommerer, and J.E. Lawler, IEEE Trans. on Plasma Science, Vol. 19, No. 2, 113 (1991).

DB-5 Simulations of a Magnetically Enhanced, Capacitively Driven Etching Reactor, * R.K. Keinigs, R.J. Faehl, M.E. Jones, Los Alamos National Laboratory, Los Alamos N.M. 87545 - Results from two-dimensional particle-in-cell / Monte Carlo simulations of a generic magnetically enhanced, capacitively driven etching reactor are presented. The simulations are performed in a rectangular x-z geometry with a weak externally imposed dipole magnetic field. The B-field lies in the x-y plane, transverse to the driving electric field, and the field strength is chosen such that the electrons are magnetized and the ions are unmagnetized. Argon collisional cross-sections are employed in the Monte Carlo routines. The simulations provide qualitative information on the sheath structure at various angles to the magnetic field. The results of these simulations indicate how azimuthal etching asymmetries might arise in such a reactor. Ion phase space plots yield information pertaining to ion energy distributions across the powered electrode. How these qualitative features change as a result of changes in gas pressure and electric field strength will be presented.

*Work supported by U.S. Department of Energy

DB-6 Longitudinal Distribution of Plasma Density in the Low Pressure Glow Discharge with Transverse Magnetic Field, L PEKKER, Photran Corp., Lakevill Minnesota - In the magnetron sputtering systems the confinement of elections is provided by transverse magnetic field. The influence of the magnetic field on the movement of ions in these systems can be ignored. As the ion free path is usually greater than the distance between anode and cathode-target, we can consider the movement of ions to the cathode without collisions. Based on these assumptions a one dimension model of the glow discharge was developed. Numerical results for the parameters typical for the magnetron sputtering systems are presented and disscused.

The conditions under which the cathode fall, in such glow discharge will disappear and the influence of magnetic field on the cutoff of the discharge is also discussed.

DB-7 A Long Mean-Free-Path Model of Neutral Transport and Chemistry in an ECR Etching System,* R.E.P. HARVEY, W.N.G. HITCHON, G.J. PARKER, Engineering Research Center for Plasma Aided Manufacturing, University of Wisconsin - Madison - In many low neutral-pressure (≤ 2 mtorr) systems the mean-free-path of a neutral particle may be of the order of the dimensions of the system. Fluid models of neutral transport are not valid in these cases; therefore, a long mean-free-path model of transport of neutral particles has been developed. A propagator matrix[1] is set up indicating the fraction of particles originating in the cell at (r´, z´) which experience their next collision in the cell at (r, z). The matrix depends only on the particles mean-free-path and the dimensions of the system. The propagator matrix is iterated with neutral source rates, allowing for chemical reactions, to obtain a steady-state density of neutral species. The model is part of a hybrid model of the ECR etch system in CF_4.

* Work supported by NSF grant # ECD-8721545

[1]W.N.G.Hitchon, D.J.Koch, and J.B.Adams, J. Comp. Phys. 83, 79 (1989)

DB-8 Spectroscopic diagnostics in an oxygen RF Helicon plasma, A. GRANIER, G. TURBAN, B. GROLLEAU, LPCM, Institut des Matériaux de Nantes, 44072 Nantes, FRANCE. Optical emission spectroscopy is performed in a low pressure (1-50 mTorr) RF (13.56 MHz) helicon reactor in oxygen. First, the validity of actinometry, using argon as actinometer, is discussed and the variations of the actinometric signal with the pressure and the RF power are compared to those obtained in DECR plasmas[1] and microwave plasmas created by surface waves[2]. In particular, it is shown that the oxygen atom density linearly increases with the RF power (from 20 to 500 W). Second, the weak atmospheric band of neutral molecular oxygen, located at 760 nm (forbidden transition from $O_2(b^1\Sigma)$ (v=0) to $O_2(a^1\Delta)$ (v=0)), is recorded and yields the rotational temperature of $O_2(b^1\Sigma)$ which is expected to be close to the translation gas temperature. Temperatures in the range 300 to 400 K are so deduced.

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[2] A. Granier, D. Chéreau, K. Henda, R. Safari and P.Leprince, submitted to J. Appl. Phys.

DB-9 Investigation by Means of Optical Emission Spectroscopy of SF_6 and SF_6/O_2 Surface-wave Magnetoplasmas under ECR Conditions, L. ST-ONGE, J. MARGOT and M. CHAKER*, U. de Montréal - We examine the emission spectrum of a surface-wave-sustained SF_6 discharge operated at 2450 MHz and submitted to an axial static magnetic field, the intensity of which is close to that for ECR (875 Gauss). Various atomic and ionic lines of F and S are observed. The relative fluorine atom concentration is determined as functions of external conditions (gas pressure, magnetic field intensity, wave power) through actinometry measurements. At a fixed axial position in the reactor, the yield of F atoms per SF_6 molecule decreases by a factor of 3 when increasing the gas pressure from 0.1 to 5 mtorr, the operating range of our ECR system. Nonetheless, globally we observe a net increase of F concentration with pressure. We also observe the F atom density to increase with increasing wave power. The increase of the magnetic field intensity from 840 to 960 Gauss results in a decrease of the F concentration, except for a small peak around 895 Gauss. Finally, the addition of O_2 to SF_6 yields a maximum F density for $[O_2/O_2+SF_6]$=25%.

*INRS-Énergie et Matériaux

DB-10 Density and Uniformity of Large Planar Plasma Sources Excited by Uniform Distributed Electron Cyclotron Resonance, A. DURANDET *, K. TYNELIUS - DIEZ *, T. LAGARDE and J. PELLETIER, Laboratoire de Physique et Chimie des Procédés Plasma, Université Joseph Fourier (Grenoble, France), Unité CNRS - In the conventional cylindrical configuration of plasma reactors, the capability of processing substrates of large dimensions requires the generation of large volumes of plasmas. In such a configuration, a large volume of a uniform high density plasma cannot be achieved. Obviously, a uniform planar plasma source is better adapted than the cylindrical configuration in the case of treatment of planar substrates. The uniform distributed electron cyclotron resonance (UDECR) plasma reactor, where linear microwave applicators can sustain standing waves of a constant amplitude along the multipolar magnetic structure, may be used to create large planar plasma sources. The capabilities of this technique are illustrated at 2.45 GHz excitation frequency with a 40 cm x 50 cm plasma reactor, equipped with four parallel UDECR applicators in a planar configuration. We present the density and uniformity of an Ar plasma as a function of gas pressure and microwave energy. Plasma densities saturate at the critical density (n_c = 7.5 x 10^{10} cm^{-3} at 2.45 GHz).

* Métal Process (Meylan, France)

DB-11 Spatial Profiling of Ion and Neutral Excitation in Noble Gas Electron Cyclotron Resonance Plasmas*, R.L. RHOADES and S.M. GORBATKIN, Oak Ridge National Laboratory. Due to the complex nature of ECR plasmas, spatial variations can be driven by microwave modes, gas kinetics, and many other factors. In an effort to characterize these variations, spectroscopic techniques were used to profile the spatial distribution of emission from various noble gas neutrals and ions (Kr, Ar, Ne, He, and combinations thereof). Plasmas were generated in a commercial two-coil mirror-field system with typical microwave input powers of 750W. In argon, the profiles {Ar(696.5nm) and Ar^+(488nm)} were slightly center-peaked at 0.25 mTorr with a gradual transition to a very hollow appearance at 1.0 mTorr. Neon {Ne(585.3nm) and Ne^+(377.7nm)} showed a similar trend from 2.5 mTorr to 10.0 mTorr. In general, ion profiles showed slightly stronger variation than neutral profiles, with the majority gas dominating the overall shape of the profile in mixtures. These measurements along with probe data provide insight into the role of neutral depletion in the formation of hollow emission profiles.

* This research was sponsored by the Division of Materials Sciences, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

DB-12 CF, CF_2 and CF_3 Radical Densities in On-off Modulated ECR-CHF_3 Plasma , M.HORI, K.TAKAHASHI and T.GOTO, Dept. of Quantum Eng., Nagoya University - The CF, CF_2 and CF_3 radical densities were investigated using infrared diode laser spectroscopy (IRLAS) in a down stream of CHF_3 electron cyclotron resonance (ECR) plasma with changing on-off period of microwave source. CHF_3 pressure was fixed at 0.4Pa, the microwave on-power at 300W and the CHF_3 gas flow rate at 5sccm. Microwave was on-off modulated by a pulse generator. The pulse width was kept constant at 100ms and on-period of the microwave was changed from 15ms to 100ms. The radical measurement was carried out at 2cm above the substrate plate placed at 22cm downstream from the ECR Plasma region. In an on-period of 15ms and off-period of 85ms, the CF_3 and CF radical densities were estimated to be $4 \times 10^{13} cm^{-3}$ and $1 \times 10^{12} cm^{-3}$, respectively. The CF and CF_2 radical densities decreased rapidly and reached a steady state with increasing on-period, while the CF_3 radical density was varied slightly.

DB-13
Experimental Determination of the Maximum X-ray Production in an ECR Processing Plasma by Using Response Surface Methods* K.H. Chew, J.L. Shohet, E. Barrios, L. Ponce-de-Leon, and S. Bisgaard. Engineering Research Center for Plasma-Aided Manufacturing, U. of Wisconsin-Madison-Electron cyclotron resonance(ECR) processing plasmas have been previously shown to produce low-energy x rays[1]. This radiation may cause damage to the wafer being processed. The x- ray production, both in terms of energy and total number of photons, depends on many plasma parameters. In order to determine the potential for damage of a wafer being processed, one would need to know what values of these parameters produce maximum x-radiation. Response surface methodology (RSM) is used to find the parameter levels which enhance or minimize a particular operational condition. An ECR plasma reactor is used for this experiment. The x-ray detection apparatus consists of a Si(Li) detector with a beryllium window, a pulse processor, and a pulse-height analyzer. Initial x-ray measurements show a maximum energy of 17 keV at an operating power of 1 kW with the most intense x-rays coming from points where the magnetic field lines pass through the resonant zone and cross the chamber wall. Response surface models are generated for air, nitrogen, and CF_4.

* This work was supported by the National Science Foundation under Grant No. ECD-8721545

1. T.J. Castagna, J.L. Shohet, D.D. Denton, and N. Hershkowitz, Appl. Phys. Lett. 60 2856 (1992)

DB-14 Langmuir Probe Results on an MBE Plasma Ion Source, M. J. BUIE*, H. L. SPINDLER**, J. B. GEDDES and M.L. BRAKE, Department of Nuclear Engineering, Univ. of Michigan, and M. DAHIMENE , Wavemat, Inc., Plymouth, MI - Density and temperature uniformity measurements have been made using double Langmuir probes on an electron cyclotron resonance plasma ion source used for molecular-beam epitaxy. The ECR ion source is a Wavemat MPDR® 610 resonant cavity based system utilizing permanent magnets with a microwave excitation frequency of 2.45 GHz. The probe position is varied in the axial and radial direction downstream of the ion source to determine the spatial uniformity of the ion beam. Power levels are varied from 50 to 300 Watts for flow rates ranging from 2.5 to 30 sccm for argon pressures ranging from < 0.1 mTorr to 3 mTorr. These results will be compared to optical emission spectroscopic measurements.

* IBM Manufacturing Fellow 1992-1993
** GE Fellow 1992-1993

DB-15 Ion energy control in an ECR ion source,* T. AKITSU, E. OGAWA,[a] H. MIYASHITA, M. MIZUNO, and H. MATSUZAWA, Yamanashi University. JAPAN- In a grid-less ECR ion source, the ion beam energy was controlled with a positively-biased multicusp beam-guide that was set closely around a beam extracting aperture. The ion energy spectrum showed reasonable correlation with the voltage drop at the target sheath. The multicusp stabilized low frequency oscillations inside the source plasma. At pressures lower than 4.7×10^{-2} Pa, the superposition of the DC cross-field discharge caused significant increase in the extracted ion beam current.

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* Work realized by the courtesy of the ANELVA LTD. Dry Etching Division.

DB-16 Investigation of the Etching Selectivity of W, SiC and Resist in a Surface-wave-sustained Discharge under conditions close to Electron Cyclotron Resonance (ECR), F. BOUNASRI, M. MOISAN, J. MARGOT, M. CHAKER* and M.A. EL KHAKANI*, U. de Montréal - We present initial results concerning the application of a surface-wave-sustained ECR plasma to the etching of W, SiC and thin films of SAL - resist deposited on Si substrates. We focus mainly on the influence of the gas pressure (0.1-5 mtorr), percentage of O_2 in SF_6 (10-90%), magnetic field intensity, and microwave power upon the etching selectivity of W, SiC and resist. As an example, our results show that the etching selectivity for W/SiC increases rapidly with the discharge total pressure, reaching 16 at 5 mtorr; the highest value of selectivity in the present work is obtained with W/resist at 4.5 mtorr with pure SF_6 where it reaches 25. Addition of oxygen to the discharge increases the selectivity for W/SiC and resist/SiC.

* INRS-Énergie et Matériaux

DB-17 Etching of Amorphous $Si_{1-x}Ge_x$ Films in a Helicon Reactor, H. M PERSING, A. J. PERRY, and R. W. BOSWELL, Space Plasma and Plasma Processing Group, PRL, RSPhysSE, Australian National University - Previous etching of SiGe alloys has focused on the etching of crystalline films using conventional Reactive Ion Etching (RIE) [1,2]. In contrast, the Helicon reactor allows etching at low pressures. Undoped $Si_{1-x}Ge_x$ films with $0.05 \le x \le 1.0$ were evaporated onto Si(100) wafers. These films were etched in a Helicon reactor using CF_4, CHF_3, SF_6, and $CFCl_2$ chemistries. The etch characteristics were measured as functions of etchant flow rate (neutral density), rf power (ion density), and substrate bias voltage (ion energies). The implications of these results for device fabrication will be discussed.

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[2] G. S. Oehrlein, Y. Zhang, G. M. W. Kroesen, E. de Fresart and T. D. Bestwick, Appl. Phys. Lett. 58 (20), 20 May 1991, 2252.

DB-18 Deposition in the Helicon Reactor with $SiCl_4$. H.M. PERSING, M.A. JARNYK , R.W. BOSWELL, K.G. ORRMAN-ROSSITER*, and J.S. WILLIAMS, Plasma Research Laboratory, Australian National University, *Materials and Microelectronics Technology Centre, Royal Melbourne Institute of Technology — Experiments in the helicon reactor have demonstrated that etching in a $SiCl_4$ plasma competes with a deposition process. Ex-situ RBS and AES analyses of the deposited films indicate a SiO_x composition. The etch profiles in mask-shadowed regions show that the deposition is strongly dependent on the neutral flux whereas the removal of the deposited material is a function of the ion-energy flux. Under conditions of low ion-energy flux, conditions experienced by the sidewalls, deposition dominates and etching is inhibited. Increasing the ion-energy flux by changing the applied bias voltage or changing the plasma potential increases the etching component of the process. Temperature measurements of the helium back-cooled samples show that the sample temperature varies between 20 and 100°C. Over this range, temperature effects are not observed.

DB-19 ECR-Plasma Enhanced Deposition of Protective Coatings for Space Structures* J. BLEZIUS, M. OLIVIER, A.K. GHOSH and A. SINGH, MPB Technologies Inc. and National Optics Institute - Long duration exposure of space structures in low earth orbit environment deteriorates materials due to multiple effects of atomic oxygen interaction, UV radiation, extreme thermal cycling as well as micrometeoroid impacts. In this paper the development of protecting coatings based on ECR-plasma enhanced deposition of various materials (P-SiO_2, P-SiON, P-DLC_{AU}) are described. The advantages of ECR plasmas with regard to efficient microwave energy coupling into the plasmas, low temperature deposition of films, high deposition rates etc., will be discussed. The scalability of the process for larger structures will be outlined.

* Work supported by Canadian Space Agency.

DB-20 Magnetic field enhanced nitrogen atom beam source, J. GEDDES, R.W. McCULLOUGH, D.P. HIGGINS, J.M.WOOLSEY and H.B. GILBODY, The Queen's University of Belfast, U.K. - The dissociation of nitrogen in a 2.45 GHz microwave discharge has been greatly enhanced by the application of a magnetic field perpendicular to the oscillating electric field. The degree of dissociation (of up to 0.67) in the emergent nitrogen beam was found to be strongly dependent on magnetic field strength, nitrogen pressure and microwave power. Observations have been interpreted in terms of microwave absorption resonances.

DC: DUSTY PLASMAS

DC-1 The Effects of Dust Particles on Ion Energy Distributions in rf Glow Discharges. * Helen H. Hwang, Seung J. Choi and Mark J. Kushner, University of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - The transport of dust particles in radio frequency (rf) glow discharges is often dominated by momentum transfer from ions through a viscous ion drag force. The ion energy distribution (IED) resulting from the penetration of ions through large accumulations of dust at sheath edges can be significantly altered by this momentum transfer. We have theoretically investigated the effects of dust particles on IEDs in rf etching glow discharges using a Monte Carlo-Fluid hybrid model, and results from that study will be reported. The model uses Monte Carlo simulations (MCS) to obtain electron and ion energy distributions, and a fluid model for charge densities. The transport of dust particles is included in the fluid model using ion-dust momentum transfer cross sections generated by an off-line PIC simulation. Ion-dust particle collisions are also included in the MCS. We will discuss IEDs in dusty plasmas for conditions of the GEC reference cell.

* Work supported by U. of Wisc. ERC for Plasma Aided Manufacturing, SRC, NSF, and Sandia Natl. Lab.

DC-2 **Particulate growth and detection in RF plasmas*** G. PRABURAM, J. GOREE, *Dept. of Physics, Univ. of Iowa*

Sub-micron size carbon particulates are grown in an argon rf plasma with graphite electrodes. The dust grains are levitated by the sheath electric field several millimeters from the electrodes. They stratify into layers according to their size, and each layer is less than 1-mm thick. The plasma device is a capacitively-coupled rf parallel-plate configuration with 7-cm diameter electrodes, f = 13.56 MHz and ≈ 100 W power.

Also, we have carried out a numerical study of various schemes of measuring particle size and density by Mie scattering of laser light. Assuming spherical dielectric particles, we have computed the scattering cross section and extinction coefficients as a function of particle radius for various values of laser wavelength, refractive index and polarization. We have tested these for sensitivity to systematic experimental errors such as scattering angles that are slightly mis-aligned.

* Work supported by NSF and NASA

DC-3 Forces on Dust Particles in RF Discharges* D. WINSKE, M. E. JONES, R. K. KEINIGS, R. A. GERWIN Los Alamos National Lab., M. DALVIE, G. S. SELWYN, M. SURENDRA IBM T. J. Watson Res. Ctr.– Particulate contaminants in rf sustained plasma processing reactors remain a significant problem. Laser scanning measurements have demonstrated that these dust particles migrate to well-defined regions of the discharge; the traps have characteristic, long-lived boundaries. We analyze in detail the various forces on the dust: electric, gravitational, neutral-dust drag, and ion-dust drag, including the effects of the size of the dust grains compared to their relative spacing and the Debye length. The dynamics of dust particles subject to these forces are investigated using one- and two-dimensional fluid discharge models to determine the steady state macroscopic parameters. The dust tends to reside at the edge of the sheath where the dominant electric and ion-dust drag forces balance, producing structures similiar to those observed.

*This work was performed under the auspices of the U.S. Dept. of Energy.

DC-4 Plasma Process Monitoring using Spatially-Resolved Optical Emission and Diode Laser Spectroscopy **H. M. Anderson** and **D. Behl**, University of New Mexico, **A.C. Stanton**, Southwest Sciences, Inc. Real-time plasma etch process monitoring, based on sensors which measure plasma properties which directly relate to the desired wafer features, is critical to the future competitiveness of the U.S. microelectronics industry. This paper reports on work with multiple fiber port, spatially resolved optical emission spectroscopy and lead-salt diode laser absorption spectroscopy for use as plasma monitoring sensors. Both the GEC Reference Cell and a TCP-modified Lam Research AutoEtch reactor were used in these experiments involving oxide wafer etching in fluorocarbon gases. Monitoring of CF_X and COF_X radicals along with broadband optical emission is shown to be an accurate measure of plasma etch characteristics.

DD: PLASMA SURFACE PHENOMENA

DD-1 Reflection coefficient of N_2 metastable molecules at the boundary surface, S. SUZUKI, H. ITOH, H. SEKIZAWA and N. IKUTA*, Chiba Inst. Tech., Tokushima U.*, Japan. --- The effective lifetime of N_2 ($A^3\Sigma_u^+$) metastable molecules has been measured in our laboratory using boundary condition of the third kind considering the reflection coefficient[1,2]. Experiments are done in pure N_2, N_2/CO, N_2/O_2, and N_2/CH_4. According to the analyses of effective lifetimes, we could determine the reflection coefficients but the values of them vary with time and the kind of mixture gas. The XPS observation has proved the change of concentration of surface substances[3]. In mixture gases, gradual change of surface materials are observed, and the constancy of the surface conditions seems not be expected. The reflection coefficients and the effective lifetimes are influenced largely by the history of surface conditions.

[1]S. Suzuki, H. Itoh, N. Ikuta and H. Sekizawa, J. Phys. D(Appl. Phys.), 25, 1568(1992).
[2]S. Suzuki, H. Itoh, H. Sekizawa and N. Ikuta, J. Phys. Soc. Jpn., 62, 2694 (1993).
[3]S. Suzuki, H. Itoh, H. Sekizawa and N. Ikuta, Trans. IEE of Japan, 113-A, 1993. (in Japanese)

DD-2 Measurements of Surface Deactivation of Vibrationally Excited $N_2(X,v)$ on Various Materials Using 3D-BOXCARS. P. P. YANEY, K. A. RIMKUS* and J. W. PARISH, U. of Dayton**. -- A flowing-gas discharge tube was developed to provide a range of molecular residence times of the gas in the discharge from more than 800 ms to 40 ms. For these measurements, the tube was operated at 30 mA and 15 Torr. The scanning 3D-folded BOXCARS technique was used with a probe volume of ≈ 6 mm long by ≈ 100 μm diameter. The studies on N_2 were carried out to the fourth hot band (v = 4 to 5) with aluminum, pyrex and other specimen materials. The deactivation coefficient obtained for pyrex of $\gamma \approx 3.6x10^{-4}$ was essentially independent of v. However, our measurements with aluminum show almost a linear dependence on v with the v=1 value of $\gamma \approx 4.9x10^{-4}$ and a v=4 value of $\approx 34x10^{-4}$. The v=1 value obtained for pyrex is in fair agreement with the previous calorimetric value of $4.6x10^{-4}$.

* In partial fulfillment of the requirements for the M.S. degree in Electro-Optics.

** Supported by USAF Contract F33615-93-C-2303.

DD-3 Emission of High Energy ($\approx$1MeV) Charged Particles during implantation of 5keV Protons on Palladium and Titanium foils. A.R. CHINDARKAR, A.S. PAITHANKAR, A.M. BHAGWAT*, G.R. NAIK*, S.K. IYYENGAR and M. SRINIVASAN**, APPD/*RSSD/**NtPD, BARC, BOMBAY INDIA 400085. - Experimental observations of the anomalous emission of high energy ($\approx$1MeV) charged particles, when 5keV protons impinge on Palladium and Titanium foils are presented. Thin (100 μm) foils of Pd and Ti were implanted with a 5 keV proton beam produced by an RF ion source. The probe type ion beam extractor of diameter 3mm and length 13mm was employed to give current density at the target foil to about 0.1mA/cm² and the total ion flux of $\approx 10^{18}$ ions/hour. For the measurement of the low intensities of high energy charged particles, the integrating property of CR-39 SSNTDs films was made use of. The energy estimate indicates that about 30-40% of the particles emitted have energy > 0.9 MeV. The results of the experiment show positive and reproducible evidence of emission of high energy charged particles.

DD-4 Influence of Nitrogen on the Oxygen Dissociation in a D.C. Discharge.* C.V. SPELLER, A.R. DE SOUZA and J.L. MUZART, Depto. de Física/LABMAT-UFSC, Brazil - The effect of the addition of molecular nitrogen on the oxygen dissociation is investigated in a low pressure gas discharge. The dissociation efficiency was measured as a function of N_2 concentration for $0.3 < p < 3$ Torr in discharge tubes of $6 <$ diameter < 21 *mm*. It is shown that for a few percent of nitrogen the oxygen dissociation degree varies by a factor ranging from 1.5 to 10, depending on the nitrogen concentration, tube diameter and total pressure. The interpretation of the results clearly indicates that the observed effect is due to a wall diffusion loss decrease. This could be attributed to the occupation of recombination sites on the wall, thus leading to a decrease of the wall recombination process, as suggested previously[1].

*Supported by PADCT/FINEP, FUNCITEC and CNPq (Brazil).

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DD-5

The Use of Thin Silver Films as a Monitor for Oxygen Atoms*

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Monitoring of oxygen atom concentrations can be important in a variety of applications including discharges, photolysis systems and upper atmospheric/low earth orbit (LEO) studies. In LEO oxygen atom measurements must be made under conditions when the space platform is bombarded by oxygen atoms at orbital velocity, ~ 8 km/s. We have utilized our laboratory fast oxygen atom source to investigate the efficiency of oxidation of thin silver films by energetic oxygen atoms. Parameters varied include oxygen atom velocity, film temperature and film thickness. Measurements will be presented of transient observations of film oxidation using both resistance measurements and quartz crystal monitor evaluation of mass change.

* This work supported in part under NASA Johnson Space Center contract NAS9-18526 and USAF Phillips Lab/Geophysics Directorate contract F19628-88-C-0069.

SESSION EA: MICROWAVE DISCHARGES
Wednesday morning, 20 October 1993
Grand Salon A, 8:00–10:00
M. Chaker, presiding

Invited Paper

EA-1 Studies of Surface-Wave Induced Plasmas at Atmospheric Pressure in Helium Mixed Gas Plasmas for Elemental Analysis, J. HUBERT, S. BORDELEAU, C. TRAN KHANH, S. MICHAUD, C. BARBEAU* and J. MARGOT*, Chemistry and Physics*, U. de Montréal - Low power microwave induced plasmas have been extensively studied as atomization, excitation or ionization sources for elemental analysis. Several devices were used to sustain these microwave discharges including the surfatron. However, there are only a few reports on the use of higher power microwave discharges (> 300 W) for elemental analysis. Our presentation describes the use of a waveguide-surfatron launcher coupled with a water cooled discharge tube to achived a high power (up to 1 kW) surface wave plasma at atmospheric pressure. The plasma gases are mixtures of helium and several atomic or molecular doping gases. The physical characteristics of these plasmas used in elemental analysis are examined. We also report the emission characteristics of several metals and non metals as a function of the plasma composition and absorbed power. Finally, examples of the analytical use of these mixed gas plasmas in the area of elemental analysis will be presented.

Contributed Papers

EA-2 **2D Modeling of Microwave Plasma Enhanced Diamond CVD.**, B. Lane, *Plasma Dynamics*, Belmont, MA 02178 and *ASTeX, Inc.*, Woburn, MA 01801, E. Hyman, K. Tsang and A. Drobot, *Science Applications International Corporation*, McLean, VA 22102, and Richard Post, *ASTeX, Inc.*. We present results from a 2D self-consistent numerical model of microwave plasma assisted CVD reactors for diamond deposition in the 1-100 torr regime. Such modelling requires the treatment of (a) the microscopic coupling of electromagnetic energy to electrons and thence to the neutral gas, (b) the local gas phase neutral and charged particle chemistry of hydrogen, carbon and oxygen, (c) the macroscopic diffusive flows, species densities and temperature profiles and (d) the macroscopic microwave field pattern in realistic cavity geometries in the presence of plasma. These processes are tightly coupled: (i) the temperature and neutral density profiles depend on the heat deposition pattern which depends on the microwave coupling which in turn depends on the neutral density profile; (ii) the plasma density pattern depends on the electromagnetic field pattern which in turn is strongly influenced by the plasma. The problem thus requires a simultaneous, self consistent solution of all the above processes. We present 2D (R-Z) self-consistent simulations of the electromagnetic field pattern, electron density, temperature, atomic and molecular hydrogen and selected hydrocarbon species densities in an ASTeX High Growth Rate (HGR) reactor.

EA-3 Laser Diagnostics of Atomic Hydrogen and Oxygen Production in Diamond Deposition Microwave Plasmas, B.L. Preppernau,* K.D. Pearce, and T.A. Miller, Laser Spectroscopy Facility, The Ohio State University, Columbus, Ohio - This research involved the application of two-photon allowed laser-induced fluorescence (TALIF) to the study of atomic hydrogen and oxygen production in an industrial scale microwave plasma discharge apparatus. Absolute two-dimensional atomic hydrogen and oxygen concentration profiles were measured in an ASTEX HPMM microwave plasma diamond deposition reactor during actual diamond growth. Measurements were made in plasmas fed by the standard CH_4/H_2 diamond growth mixture as well growth mixtures based on acetone and O_2. The plasmas were operated at 1200 Watts microwave power, 40 Torr total pressure, and a substrate heater temperature of 830 C. Particular attention was paid to refining the concentration calibration technique and in determining a correction to account for the collisional quenching of excited state fluorescence in high pressure gases. Typical concentrations exceed 10^{17} per cm^3 for these atomic species.

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EA-4 Long microwave field applicators for plasma generation: review, classification and main features, Z. ZAKRZEWSKI* and M. MOISAN, U. de Montréal - Linear (extended in one direction) microwave field applicators can be used to sustain without the need for a static magnetic field discharges long with respect to the free space wavelength. These discharges find applications, for example, in the plasma processing of large surfaces that can be made to move transversely in front of the field applicator (conveyor feeding) or to activate gaseous medium in high power gas dynamic lasers. A classification of these discharges is proposed, based on the characteristics of the wave sustaining the plasma, distinguishing between traveling wave discharges (slow and fast wave structures) and standing wave discharges (resonant structures). Examples of practical realizations of discharges in the various proposed categories are briefly presented (more in the poster session). The influence of the discharge mechanisms, wave characteristics and waveguiding structures upon the stability of the discharge and the plasma properties (including uniformity) is also analyzed.

*Permanent address: Polish Academy of Sciences, IMP-PAN, 80-952 Gdansk, Poland.

EA-5 Characterization by Emission Spectroscopy of a Microwave Sustained Plasma (TIA torch design) Operated in Open Air, A. GICQUEL*, J. HUBERT, M. MOISAN, A. RICARD**, G. SAUVÉ and L. ST-ONGE, U.de Montréal - We have contributed to the development of a plasma torch system where the gas flows through the inner conductor of a coaxial-like field applicator at the tip of which it gets ionized. This torch allows axial injection of working gases at flow rates of the order of 10 l/min. We will report the data obtained at 2.45 GHz and 500 W with He or Ar as the carrier gas using a 1 mm bore nozzle. The gas temperature T_g was determined by probing the rotational spectra of N_2 and N_2^+ radiative states of the ambient air nitrogen. These two probes, which give similar values, show that T_g increases over the first few mm away from the nozzle tip, typically from 1000 to 3400 K in He and 2500 to 3700 K with Ar. The properties of H_2 in He mixtures were also investigated. It was found that a H_2 fraction of only 1% in the carrier gas increases T_g significantly. The electron density was measured through Stark broadening of the H_β line, yielding a value that decreases from 2 to 0.5 x 10^{15} electrons/cm^3 when going away from the nozzle tip.

* U. Paris-Nord **U. Paris-Sud

EA-6 Plasma Resonance Heating Effects in Surface Wave Sustained Plasmas, YU.M. ALIEV, A.V. MAXIMOV, Lebedev Institute, Russian Academy of Sciences, Moscow, Russia, H. SCHLÜTER, U. KORTSHAGEN, Exper. Physics II, Ruhr-University, Bochum, Germany and A. SHIVAROVA, Faculty of Physics, Sofia University, Sofia, Bulgaria — The radial temperature distribution of electrons and ions in surface wave sustained plasmas are studied accounting for the nonlocal heating effects caused by the enhanced radial electric field component in the presence of a plasma resonance. The case of resonance width larger than the electron mean free path is considered. It is shown that due to the resonance the maintenance of the discharge may be largely due to the enhanced radial component of the surface wave. On the basis of hydrodynamics the temperature of electrons and ions are predicted to have maximum values near the wall of the discharge tube. The resonance situation is also discussed in the frame of a nonlocal kinetic approach with radially varying electron distribution functions.

EA-7 High density microwave atomic source for dosing surfaces, G. C. H. ZAU, G. W. GIBSON and H. H. SAWIN, Massachusetts Institute of Technology - A new atom source based on a coaxial waveguide microwave cavity has been developed for dosing surfaces. All the tuning elements for the microwave cavity are external to the vacuum environment. This allows easy tuning of the cavity and eliminates the need for complex vacuum feedthroughs. The source also eliminates the transport losses of the traditional flow-through atom sources by generating the atoms in vacuum close to the reaction site and emitting them directly at the site. As a result, >90% dissociation has been achieved for chlorine feed gas.

SESSION EB: ELECTRON TRANSPORT IN GASES
Wednesday morning, 20 October 1993
Grand Salon C, 8:00–10:00
J.W. Gallagher, presiding

EB-1 Electron Transport in Helium at High E/N, JOHN INGOLD, GE Lighting, Cleveland, OH 44112–The five-moment method[1] is used to predict electron transport in helium at high E/N where inelastic effects are more important than elastic effects. Theoretical results for average velocity, average energy, and Townsend's ionization coefficient α are compared with those of Riemann.[2] It is concluded that the five-moment method gives good qualitative results at high E/N.

[1]J. H. Ingold, Phys. Rev. A **40**, 3855 (1989).

[2]K.-U. Riemann, Phys. Rev. A **46**, 4717 (1992).

EB-2 Electron Drift Velocities in Molecular Gas-Rare Gas Mixtures,* A. GARSCADDEN and R. NAGPAL, Plasma Research Group, WPAFB- Using realistic model cross sections for the buffer rare gas and the diluent molecular gas, experimental trends in the drift velocity (w_d) data for gas mixtures are explained. Observed data shows that there is a region at low E/N where w_d for the higher concentration of the molecular gas in the mixture are lower than those for the lower concentration. It is shown that this is due to an interplay between the effects on the electron distribution by momentum transfer frequency (ν_m) in the cartesian space and by the inelastic collision frequency (ν_{in}) in the velocity space. For Ramsauer rare gas buffer, w_d decrease because ν_m increases at lower electron energies to the left of the minimum while for non-Ramsauer rare gas buffer, the effect will occur only when the total effective ν_m increases. Model calculations in ref. 1 fail to explain these phenomena, since they would always predict a increase in w_d when the magnitude of the inelastic cross section is increased.

* Work Supported by the Wright Laboratory.
[1] Z. Lj. Petrovic, R. W. Crompton and G. N. Haddad, Aust. J. Phys. 37, 23 (1984).

EB-3 Analysis of the arrival-time spectra of electron swarms, H. DATE, H. HASEGAWA, K. KONDO, M. SHIMOZUMA and H. TAGASHIRA, Hokkaido Univ., Anan Tech. Col., Tomakomai Tech. Col., Hokkaido Univ. and Hokkaido Univ.- Arrival-time distributions of electrons, which are measured in usual time-of-flight(TOF) experiments, have been analyzed by a Boltzmann equation method[1] in nitrogen. In the analysis, the electron swarm parameters directly defined by the arrival-time spectra were calculated with using the electron collision cross sections, and the results were compared with those by a TOF experiment at E/N values, 100,160, and 200 Td. The parameters consist in the newly introduced-continuity equation deduced by the interchange of space and time in the conventional continuity equation. By solving the new continuity equation, the arrival-time distributions were represented also to be compared with those by the experiment. The calculated parameters and the estimated distributions are in good agreement with the experimental results.

[1]H. Date, K. Kondo, S. Yachi and H. Tagashira, J.Phys.D: Appl.Phys. 25 442 (1992)

EB-4

WITHDRAWN

EB-5 Validity of the Boltzmann Equation Analysis for Electron Transport Using The Momentum Transfer Cross Section II R.YOKOYAMA H.Gotoda and N.IKUTA, Tokushima Univ.Jpn.----- Accompanied with a recent examination[1)] of usual Boltzmann equation analyses for the electron transport under elastic collisions, test analyses are further performed in Reid's inelastic ramp model gas[2)] using the FTI method. Differential elastic cross section assumed here is $q(\chi)=q_{0a}(1+a\cos\chi)$, "a" the anisotropy index of -1/2 ~ 1, and the integral cross section q_{0a} is given by a constant momentum transfer cross section q_m as $q_{0a}= q_m/(1-a/3)$. Regardless of anisotropies in the velocity distribution, it is found that the mean energy and the drift velocity can be obtained accurately by the usual pseudo-isotropic analysis (PIA). However, the transverse diffusion coefficient D_T can not be given by PIA because it varies seriously by changing "a". This fact shows that ND_T at a given E/N can not be determined by the momentum transfer cross section q_m but are given by the integral cross section. Consequently, collision cross sections so far derived from D_T/μ data obtained in usual circumstances with anisotropic scatterings may have to be reanalysed.
1) N.Ikuta and H.Gotoda: J.Phys.Soc.Jpn.to appear 1993.
2) Ivan D.Reid: Aust.J.Phys.32(1979)231.

EB-6 Transport Coefficients in Argon and Krypton with trace impurities of H2, D2, CO, CO2, and H2O, J. L. Pack* and R. E. Voshall, Gannon University, Erie, PA, Using a method described previously the distribution function of electron energies for electrons in argon and krypton with trace impurities has been obtained by a numerical solution of the Boltzmann equation. The electron drift velocity w, longitudinal difussion coefficient DL/μ, and transverse diffusion coefficient DT/μ are computed. A comparison of calculated and experimental values of these coefficients give good agreement in hydrogen argon mixtures. Calculations show that impurity levels in excess of 200 ppm of H2, D2, or N2 are required to cause a 10% change in w in the area of the Ramsauer minimum in either noble gas. Impurity levels of 2 ppm of CO, CO2, or H2O cause a change in w of 7% in the same range of E/N. As these impurity levels are typical of Reagent grade gas Samples, further purification is necessary for accurate measurements.
* Present address: John L. Pack, 3853 Newton Drive, Murrysville, PA 15668

EB-7 Monte Carlo Simulation of Electron Swarm in Strongly Attaching Gases at Low E/N, M. YOUSFI, A. HENNAD, Univ. Paul Sabatier, CNRS, CPAT, Toulouse, FRANCE. It is known that electron distribution function and swarm parameters are calculated from Monte Carlo method by following electron seeds from initial conditions till their disappearance either by collisions (e.g. attachment) or by passing beyond the limits of simulation domain (arrival to anode or reaching maximum time allowed for simulation, etc...). At low E/N in the case of strongly attaching gases such as SF_6 having high attachment cross sections at low energy (for reaction: e+ SF_6 —> SF_6^-), most of electron seeds, after a few free flights, can be attached. In this case, Monte Carlo simulation is not able to calculate hydrodynamic swarm parameters with enough precision, because as time increases, the number of simulated electrons drastically decreases thus enhancing the statistical fluctuations. Furthermore, if E/N is too low all electrons can be attached thus completely stopping the simulation. In this communication, an improved Monte Carlo method is proposed to overcome this drawback. It is based on an additional fictitious ionization process with constant ionization frequency which artificially increases the number of simulated electrons. Then, using a simple relation between the electron distribution function of the fictitious gas (including the additional ionization process) and the real gas, the electron density and swarm parameters of the real gas (e.g. SF_6) can be obtained at low E/N values.

EB-8 High-Resolution Electron Energy Distribution Function in a RF Glow Discharge,* Chwan-Hwa Wu and Chihwen Li, EE Dept, Auburn U., A two-dimensional electron-kinetic and ion-fluid simulation model coupled with Poisson's equation has been developed for helium radio frequency (RF) glow discharges. The new kinetic Generalized Monte Carlo Flux (GMCF) model handles the computations similar to that of Boltzmann equation, but it uses one transition matrix to compute the collision terms in two dimensional velocity space cells (v: speed and μ: velocity angle).[1,2] Assuming a cylindrically symmetric geometry, the 2D simulation results illustrate the field, ionization rate, densities, electron current density, and electron mean energy in the radial (r)-axial (z) space. From the analysis of the electron energy distribution function, the electrons around the sheath close to the radial wall have a higher energy tail than the electrons in the center. The higher energy tail caused by the nonequilibrium radial transpot effects due to radial fields generates more ionization events and makes higher densities in the radial sheath-bulk boundary.

* This work is supported by NSF under ECS-9009395.

[1] G. Schaefer and P. Hui, J. Comput. Phys. **89**, 1 (1990).
[2] C. Li and C. Wu, 45th Annual Gaseous Elec. Conf., **36** (1992).

SESSION FA: POLLUTANT PROCESSING AND PLASMA CLEANING

Wednesday morning, 20 October 1993
Grand Salon A, 10:15–11:30
J. Hubert, presiding

FA-1 Coronal Discharges in Air,* P. A. VITELLO, B. M. PENETRANTE, AND J. N. BARDSLEY, LLNL - Non-thermal plasmas generated through streamer coronas are of current interest due to their application to pollution control devices. A streamer coronal discharge produces non-thermal energetic electrons which, through dissociation and ionization processes, generate active radicals that in turn react with toxic molecules. Non-thermal plasma techniques can be used to destroy many types of hazardous molecules. For a given chemical gas mixture, the energy distribution of the electrons produced as the streamer bridges the gap between the electrodes is determined by the spatial and temporal evolution of streamer coronas. Streamers propagate due to a highly non-linear space charge driven ionization wave. We have developed a multi-dimensional coronal discharge model that can be applied to arbitrarily shaped electrode structures. We have applied this code to study some of the issues related to finding the optimum working conditions for streamer corona reactors. Our results show that the radial components of the electron flow and the space charge field are very important in providing an accurate picture of the streamer morphology. Results are shown for point-to-plane simulations with a 2 cm gap in air for various voltages.

*This work was performed at LLNL under the auspices of the U. S. DOE under Contract Number W-7405- ENG-48.

FA-2 Some Reactions in Pollutant Treatment Discharges. T.H. TEICH, Swiss Federal Institute of Technology, Zürich. - While the final result of gas treatment by discharges can largely be assessed by IR absorption, the primary reactions initiated by electron collisions are not so readily surveyed, although insight into these reactions might indicate approaches to increased efficiency of the treatment process. In order to obtain information on at least *some* of the species initially involved and on the time scale of their reactions, sensitive measurements of light emission (190 - 830 nm) from a pulsed corona discharge[1] have been expanded. The emissions from the constituents of a standard flue gas (N_2, CO_2, H_2O, O_2, NO) have been explored and the states $N_2(D)$, $N_2^+(B)$, $N_2(C)$, $CO_2^+(A\,^2\Pi)$, $CO_2^+(A\,^2\Sigma^+)$, OH(A), NO(A) and NO(B) identified as suitable candidates for detection. Time-gated spectra combined with systematic changes in gas composition provide some hints as to the origin of the excited states and yield also rough quenching data as required for optical assessment of excited state initial concentrations. The emission history of particular excited states is then further explored by time-correlated photon counting and compared to relative energetic electron concentration which manifests itself, for instance, by N_2(D-B) or N_2(C-B) emission.

[1]T.H. Teich, 45th Annual Gaseous Electronics Conference, Boston, Paper HB-4 (1992)

FA-3 Strategies for NO_x Cleanup from Air Streams Using Dielectric Barrier Discharges. * Ann C. Gentile and Mark J. Kushner, University of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - Efficient processes for the removal of NO_x from exhaust gases due to the combustion of fossil fuels is of increasing interest due to stringent EPA limits on allowable emissions. Strategies for plasma remediation of NO_x using both reduction ($N + NO \rightarrow N_2 + O$) and oxidation ($NO_2 + OH \rightarrow HNO_3$) techniques are being developed as an energy efficient cleansing method. The dry reduction technique is preferred since there is no acidic waste product. We have developed a plasma chemistry computer model for atmospheric pressure gas streams excited by dielectric barrier discharges to investigate optimum methods to remove NO_x from air. We will report on efficiencies for removing 100s ppm of NO_x while varying water content and power deposition. Comparisons will be made to experiments by Chang et. al.[1]

[1] M. B. Chang, M. J. Kushner and M. Rood, J. Env. Eng. 119, 414 (1993)

* Work supported by Los Alamos National Laboratory and the National Science Foundation.

FA-4

WITHDRAWN

FA-5 Plasma Cleaning by Ion Cyclotron Resonance for Plasm Source Ion Implantation.* J.L. SHOHET M.J. KUSHNER** and E.I WICKESBERG, Engineering Research Center for Plasma-Aide Manufacturing, Univ. of Wisconsin-Madison.--Utilization of io implantation techniques, as well as other processing involving plasma often requires the elimination of unwanted ion species. Convention implantation techniques use a mass spectrometer filter of an ion bean In order to permit effective use of plasmas, which can allo implantation over wide areas, unwanted ion species must be remove Ion Cyclotron Resonance Mass separation is particularly useful in thi regard. In order to examine the feasibility of this technique, a Monte Carlo numerical simulation which demonstrates the effectiveness c this technique was undertaken. O_2^+, N_2^+, Ar^+ and Ne^+ are equall distributed in a 5 cm x 50 cm cylindrical region imbedded in a 15 x 1 x 100 cm rectangular chamber. A uniform external d.c. magnetic fiel of 875 Gauss is oriented parallel to the axis of the cylinder, with frequency-swept (20 kHz-100 kHz in 1 msec) circularly polarized r. electric field of 1 V/cm oriented perpendicular to the d.c. magneti field. Collisions are included for all ions for elastic and inelasti charge exchange and the simulation was run for two pressures, 0.1 an 0.5 millitorr. In all cases, when the r.f. field approached the io cyclotron resonance frequency of a particular ion, removal of the io species took place. By eliminating the sweep component of a particul ion, no evidence of enhanced transport of that species was observed.

*Work Supported by NSF under Grant ECD-8721545
**University of Illinois, Urbana, IL

SESSION FB: COLD ATOM COLLISIONS
Wednesday morning, 20 October 1993
Grand Salon C, 10:15–11:30
T.G. Walker, presiding

Invited Papers

FB-1 Excited State Trap Loss Collisions.* P.L. GOULD, C.D. WALLACE, T.P. DINNEEN, K.Y.N. TAN, and A. KUMARAKRISHNAN, U. of Connecticut- We have measured rate constants for cold collisions which lead to ejection of rubidium atoms from a laser trap. Dramatic differences between ^{85}Rb and ^{87}Rb are seen[1,2] which are attributed to the different hyperfine structures of both ground and excited states. The temperature dependence of the collisional rate constant can be investigated by exploiting the variation of temperature with trap laser intensity.

*supported by DOE, PRF, and NSF.

[1]C.D. Wallace *et al.*, Phys. Rev. Lett. **69**, 897 (1992).
[2]P. Feng *et al.*, Phys. Rev. A **47**, R3495 (1993).

FB-2 Frequency Shifts due to Ultra-cold Atom Collisions, KURT GIBBLE, Yale University - It was anticipated that laser cooling of atoms to 2 μK would improve the accuracy and resolution of laser and microwave spectroscopies by 2 to 3 orders of magnitude. In state-of-the-art room temperature Cs frequency standards, the 9 GHz ground state hyperfine transition is measured with a fractional accuracy of 3×10^{-14}. Since all of the formerly known systematic effects that limit the accuracy increase either linearly or as some higher power of the atom's velocity, the accuracy of a laser cooled Cs standard should be $\approx 10^{-16}$. However, at μK temperatures, the de Broglie wavelengths of the atoms are much larger than the scale of the interatomic potential so that collision cross sections can be as large as $\lambda_{dB}^2/2\pi \approx 10^{-10}$ cm^2. Here, collisional frequency shifts in a laser-cooled Cs fountain are measured to be -1.4×10^{-12} corresponding to a cross section of 0.5×10^{-10} cm^2.[1] I also expect to report experimental results showing a potentially strong magnetic field dependence of these cross sections for fields smaller than 0.2 G. The field of ultra-cold collisions will also be reviewed.

[1]K. Gibble and S. Chu, Phys. Rev. Lett. **70**, 1771 (1993).

Contributed Paper

FB-3 The Effects of Hyperfine Interactions on Collisions Between Optically Trapped Atoms*. T. WALKER, D. HOFFMANN, M. PETERS, and J. TOBIASON, University of Wisconsin-Madison -- We report measurements of excited-state collision rates of optically trapped ^{85}Rb and ^{87}Rb. The collision rates have been measured in the vicinity of the $P_{3/2}$ and $P_{1/2}$ states of both isotopes. By studying the collision rates as a function of the frequency of light used to cause the collisions, we obtain collision spectra that reveal the importance of hyperfine interactions on the collision dynamics. In certain frequency ranges the collision rates for the two isotopes are nearly identical, while in others we find substantially reduced rates for ^{87}Rb (large hyperfine interaction) as compared to ^{85}Rb (small hyperfine interaction). For the $P_{1/2}$ states, where hyperfine splittings are large compared to the characteristic frequency scale for these collisions, the shapes of the spectra more closely correspond to those expected from simple models that neglect hyperfine interactions.
*Supported by the NSF (PHY-9257058 and PHY-9213666) and the Packard Foundation. T. W. is an Alfred P. Sloan Fellow.

SESSION G: BUSINESS MEETING
Wednesday morning, 20 October 1993
Grand Salon A, 11:30–12:00
J. Dakin, presiding

SESSION HA: GEC REFERENCE CELL
Wednesday afternoon, 20 October 1993
Grand Salon A, 13:30–15:30
J.H. Keller, presiding

Invited Paper

HA-1 Nonlinear Electrical Phenomena in the GEC Reference Cell and in Industrial Reactors,* P. MILLER, B. ARAGON, K. GREENBERG, M. KAMON, R. PATTESON, P. POCHAN, L. ROMERO, and B. SMITH, Sandia National Laboratories - The initial interlaboratory comparison of Reference-Cell plasmas emphasized rf voltage and current measurements. Plasma properties were found to be dependent on rf circuit impedances at harmonics of the 13.56-MHz excitation frequency as well as on power, pressure, etc. The dependence was due to the nonlinear interaction of the plasma with the rf generator, cables, and matching network. This finding led to studies of performance problems common to industrial etching reactors. Electrical diagnostics and methodologies that had been developed with the Reference Cell were applied to the production problems. We developed understanding of and control over subharmonic generation and we developed cures for chamber-to-chamber variability in etch rate and dc bias.

*Work supported by the U.S. Dept. of Energy and SEMATECH.

Contributed Papers

HA-2 Radial Concentration of Atomic Hydrogen in the GEC Reference Cell -B.Ganguly and P.Bletzinger, Aero Propulsion and Power Directorate, WPAFB, Ohio-- The radial concentration profile of atomic hydrogen has been measured as function of substrate loading with silicon wafers with diamond, diamond-like-carbon coating and uncoated in a GEC reference reactor operating over a range of 1 to 9 Torr H_2 pressure and 100 W rf power. A phase-locked two-photon laser induced fluorescence technique was used to measure atomic hydrogen concentrations[1]. The radial concentration profiles have been measured at several axial locations and as close as 2mm from the grounded electrode. The wafer loading was found to slightly modify the radial profile as compared to the bare aluminum electrode. At pressures above 5 Torr the discharge becomes annular, however the radial atomic hydrogen concentration profile was still uniform.

1. A.D.Tserepi, J.R.Dunlop, B.L.Preppernau and T.A.Miller, J.Vac.Sci.Techn.,10,1188 (1992).

HA-3 The UK GEC Reference Reactor,* N. StJ. BRAITHWAITE, Open Univ. UK. and W. G. GRAHAM, Queen's Univ., Belfast. N. Ireland. - A GEC Reference Reactor is currently under construction. The reactor will have a top moveable electrode, the bottom electrode will be powered and both will have alumina insulators. Paralleling the construction there is a programme to develop accurate electrical characterisation of the reactor. The reactor will also be equipped with a compensated Langmuir probe, ion mass and kinetic energy analysis through the bottom electrode and a time resolved optical emission diagnostic. When commissioned the reactor will act as a user facility for the UK low temperature plasma physics community with a particular role as a test bed for new diagnostic techniques. Progress on construction, commissioning and electrical characterisation will be reported.

* Work supported by the Science and Engineering Research Council of Great Britain and Northern Ireland.

HA-4 Two-Dimensional Simulations of RF Glow Discharges in the *GEC* Reference Cell, D.P. LYMBEROPOULOS and D.J. ECONOMOU, University of Houston. Two-dimensional fluid simulations of 13.56 MHz argon glow discharges in the GEC Reference Cell geometry were performed. Metastable species were included in a self-consisted manner. Spatio-temporal variations of electron energy and density, ion and metastable density, excitation and ionization rates were predicted. The electron density was found to peak in the radial direction. The metastable density profiles showed "hot spots" in both axial and radial directions at 1 torr pressure. These hot spots disappeared at low pressures. Ion and neutral flux non-uniformities along the electrodes were also predicted.

HA-5 Ion Energy Distributions for Multicomponent Gas Mixtures in the GEC Reference Cell. * Helen H. Hwang, Florence L. Foy and Mark J. Kushner, University of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - The ion energy distribution (IED) incident on wafers in rf discharges is important in determining the isotropy of etching microelectronic devices. In gas mixtures both exothermic (eg., $He^+ + N_2 \rightarrow N_2^+ + He$) and endothermic (eg., $N_2^+ + He \rightarrow He^+ + N_2$) ion molecule reactions alter the IED. Endothermic reactions cause the IED to be cut-off at the threshold energy for the inelastic process. A computer model has been developed to examine the effects of endothermic ion kinetics in rf discharges using the GEC reference cell. The model is a hybrid model combining electron and ion Monte Carlo simulations with a fluid simulation for charge densities and electric fields. Results for IEDs will be discussed for $He/CF_4/H_2$, He/N_2 and Ar/H_2 gas mixtures as a function of gas pressure and rf voltage; and for symmetric and asymmetric discharges.

* Work supported by U. of Wisc. ERC for Plasma Aided Manufacturing, SRC, and NSF

HA-6 Ion Energy Distributions and Balmer Alpha (H_α) Excitation in Ar-H_2 RF Discharges, S. B. RADOVANOV, J. K. OLTHOFF, R. J. VAN BRUNT, and S. DJUROVIĆ*, *NIST* — Time-resolved optical emission, mass-selected ion energy distributions (IEDs) at the grounded electrode, and current and voltage waveforms were measured for radio-frequency (rf) discharges generated in a GEC rf Reference Cell at 13.56 MHz using Ar-H_2 gas mixtures. Measurements were performed for different mixture ratios, total gas pressures, and applied rf voltages. Structure in the ion energy distributions suggest that ArH^+ and H_3^+ are formed in the sheath by ion-molecule collisions at energies between 5 and 35 eV. Consistent with previous reports,[1] we have observed an increase in the H_α emission from discharges in hydrogen when argon was added. Possible correlations between the measured IEDs and Doppler broadening of H_α emission are examined.

*Permanent address: Institute of Physics, Novi Sad, Yugoslavia
[1]B. M. Jelenkovic, Z. Lj. Petrovic and A. V. Phelps, 1990 GEC Conference Abstracts, p. 170.

SESSION HB: ELECTRON-MOLECULE COLLISIONS
Wednesday afternoon, 20 October 1993
Grand Salon C, 13:30–15:30
M.A. Dillon, presiding

Invited Papers

HB-1 Electron Scattering Studies of Chlorine-bearing Hydrocarbons,* P.D. BURROW, U. of Nebraska, Lincoln, NE Halogenated hydrocarbon molecules appear in a number of applications of interest to Gaseous Electronics. Under low-energy electron impact many of these compounds readily fragment into free radicals and stable negative ions. Theoretical predictions of the cross sections and products of the dissociative attachment (DA) process in molecules with several halogens appear to be extremely difficult to carry out, although progress has been made on diatomics. This talk summarizes recent measurements and calculations on a much simpler family of molecules, namely those containing a single chlorine atom attached to a hydrocarbon frame. Even so, DA cross sections varying over 6 orders of magnitude can be illustrated. These results will be discussed in light of temporary negative ion energies, molecular structure and related measurements on vibrational excitation.[1]

*Work supported by NSF.

[1]Contributions from D. Pearl, G. Gallup, I. Fabrikant, K. Jordan and J. Nash are gratefully acknowledged.

HB-2 Studies of Electron-Molecule Collisions on Highly Parallel Computers,* V. McKOY and C. WINSTEAD, California Institute of Technology—We report on results of our studies of the cross sections for collisions of low-energy electrons with polyatomic molecules. These results are obtained using a multichannel extension of Schwinger's variational principle and an implementation of key steps of the associated computational procedure on distributed-memory parallel computers. After a brief discussion of some relevant aspects of the formulation[1,2] and of our parallel implementation,[3] we will present results from recent studies of electronic excitation by electron impact in several polyatomic molecules, including SiH_4, CF_3Cl, $(CH_3)_2CO$, p-$C_6H_4O_2$, and the C_5H_6 isomer [1.1.1]propellane.

*Supported by NSF and AFOSR.

[1]K. Takatsuka and V. McKoy, Phys. Rev. A **23**, 2352 (1981); **30**, 1734 (1984).
[2]C. Winstead and V. McKoy, Phys. Rev. A **47**, 1514 (1993).
[3]C. Winstead, P. G. Hipes, M. A. P. Lima, and V. McKoy, J. Chem. Phys. **94**, 5455 (1991).

Contributed Papers

HB-3 Isomer Effects in Low Energy Electron Scattering by C_3H_6 Molecules.* T. TAKAGI, L. BOESTEN, H. TANAKA, Sophia U., Tokyo, H. SATO, Ochanomizu U., Tokyo, and M. KIMURA, Argonne National Laboratory -- We recently measured differential elastic cross sections for electron scattering by the C_3H_6 isomers propylene and cyclopropane in the energy range 1.5-100 eV. We observed a strong isomer effect at small angles below 7 eV. In addition, the cross section for cyclopropane showed conspicuous structures at all angles. Both cross sections converged above 15 eV. Our continuum multiple scattering (CMS) calculations for the process reproduced the measured results reasonably well, and calculation provides an interpretation for the isomer effects, because of the presence of a weak dipole moment in propylene.

* Supported by the U.S. Department of Energy, Office of Energy Research, Office of Health and Environmental Research, under Contract W-31-109-ENG-38 (MK), and by a Grant in Aid from the Ministry of Education, Science, and Culture, Japan.

HB-4 Total Electron Scattering Cross-Sections and Negative Ion States of Halogenated Methanes.* T. UNDERWOOD-LEMONS, D. C. WINKLER, J. H. MOORE, and J. A. TOSSELL, U. of Maryland at College Park-The interaction of low energy electrons with halogenated methanes plays an important role in both their atmospheric and plasma processing chemistry. In this work, the total electron scattering cross-sections of mixed fluorohalomethanes (CF_nX_{4-n}) were measured for incident electrons in the energy range of 0.2-12 eV using electron transmission spectroscopy. Resonances in the scattering cross-sections may be interpreted as the capture of low energy electrons into unoccupied molecular orbitals. To aid in the assignments of the resulting negative ion states, we performed quantum mechanical calculations of the electron attachment energies and measured the dissociative attachment cross-sections. The effect of halogen substitution on the orbitals participating in electron capture are examined.

*Work supported by the National Science Foundation Grant No. CHE-91-20504.

HB-5 Low Energy Electron Collisions with SF_6*, S. K. Srivastava, Jet Propulsion Laboratory, Caltech - A survey on the electron collision cross sections for SF_6 will be presented for the following processes: eleastic and inelastic scattering, ionization, attachment, and inner shell excitation. The energy range covered will be from 0 eV to 1 KeV. This survey will include previously published results and our most recent measurements on ionization and attachment. Cross sections for the formation of SF_5^+, SF_2^+, SF_2^{++}, and SF_3^{++} have recently been measured in our laboratory. Cross sections for collisions leading to the formation of SF_6^-, SF_5^-, SF_4^-, SF_3^-, SF_2^-, F_2^-, and F^- have also measured and compared with previously published results.

*Work supported in part by the National Aeronautics and Space Administration and in part by the Airforce Office of Scientific Research.

HB-6 *Ab-initio* complex-Kohn calculations of dissociative excitation of the water molecule. TOMASZ J. GIL, THOMAS N. RESCIGNO, C. WILLIAM MCCURDY, AND BYRON H. LENGSFIELD, Lawrence Livermore National Laboratory.—We are reporting results of close-coupling complex-Kohn calculations of cross sections for electron-impact excitation of the water molecule into electronically dissociative states in the energy range from the threshold at 8 eV to 30 eV. We have coupled five channels including the $^1A_1$ ground state and excited singlet and triplet states formed by promoting the $3a_1$ and $1b_1$ electrons to the valence-Rydberg IVO $4a_1$ orbital. They have theoretical vertical energies in the range from 8 to 12 eV and are known to be dissociative. Our calculations have confirmed the existence of Feshbach resonances related to the A_1 and B_1 excited states which are responsible for dissociative attachment in water at rather high energies. We found that they indeed correspond to configurations $3a_1 4a_1^2$ and $1b_1 4a_1^2$. Our results include both total and differential cross sections. We discuss the comparisons between theory and relative experimental data. Work was supported by the U.S. Department of Energy.

SESSION J: POSTER SESSION
Wednesday afternoon, 20 October 1993
Grand Salon B, 15:45–17:30
M. Fréchette, presiding

JA: MODELING AND SIMULATION

JA-1 Gas Pumping Effect in Low Pressure Discharges*
H.-B. VALENTINI, D. WOLFF, IPHT inc. Jena, Germany - Using a steady-state gas dynamical three-fluid model the axial gas transport[1] in a positive column is calculated. The space charge density, the inertia of the particles, elastic and inelastic collisions and the viscosity of the neutral gas are taken into account across the

whole plasma. The equations of continuity and of momentum transfer for each species, the energy equation of the electrons as well as the Poisson equation for the electric field are used. Results for the radial profiles of the electric potential, the particle densities and the radial and, in particular, the axial drift velocities are given. In accordance with well-known experimental results it is shown that neutral gas flows to the anode if the degree of ionization is relatively high and to the cathode if the degree of ionization is very small. The change of the direction of the neutral gas flux is mainly caused by expansion of the space charge sheath with ion excess from wall into the plasma.

*Work supported by Deutsche Forschungsgemeinschaft

[1]C.C. Leiby,Jr. and H.J. Oskam, Phys. Fluids 10,1992 (1967)

JA-2 Influence of Background Gas Temperature on Electron transport coefficients and Propagation of Ionizing Wave in Flue Gas Discharges, A. POINSIGNON, H. HAMANI, M. YOUSFI, Univ. Paul Sabatier, CNRS, CPAT, Toulouse, FRANCE- The dependence of particularly electron attachment processes on temperature T_g of background electronegative gas is already known. Indeed, as T_g increases, due to the corresponding enhancement of the number density of vibrational excited molecules, the attachment processes become more efficient. Furthermore, it is known that temperature of flue gas from coal or oil fired power plants are generally higher than ambient gas temperature corresponding to usual conditions of measurements of electron transport coefficients. So, in typical flue gases (including mainly N_2, O_2, H_2O and CO_2), electron transport coefficients are calculated from numerical solution of Boltzmann equation taking into account the temperature effect on, more particularly, attachment coefficients. Then, from numerical solution of hydrodynamic conservation equations of electrons and ions coupled to Poisson equation, much emphazis is laid on the non-negligible consequences of such temperature effect on the anode directed ionizing wave characteristics (electron and ion densities and space charge electric field). Calculations are undertaken in flue gas discharge under overvoltage conditions and atmospheric pressure.

JA-3 Transition from a Townsend Discharge to a Normal Discharge via 2D-Modeling - V.I.Kolobov, A.Fiala, J.P.Boeuf, and L.C.Pitchford, CPAT, Université Paul Sabatier, Toulouse, France.- The constriction of a Townsend discharge on the right branch of the Pashen curve and an evolution of a subnormal discharge to a normal one has been investigated using a two-dimensional numerical modeling and an approximate analytical analysis. The calculations have been made for argon pd=1-10 Torr cm, gap length d=1 cm, electrode diameter 3 cm, a secondary emission coefficient γ=0.07, and the ionization source depending on the local electric field or provided by a Monte-Carlo simulation of the fast electrons. An analytical model provides an explanation of the mechanism of the constriction; field distortion is responsible for the constriction when the sign of the second derivative of the ionization coefficient with respect to the electric field strength is positive. A few calculations have been made to illustrate the influence of a possible E/N dependence of γ.

JA-4 Models for Plasma Etching, B. ABRAHAM-SHRAUNER, Washington University- Plasma etching surfaces are modeled analytically for isotropic and plasma assisted etching. In addition to exact evolution (surface) equations[1] in two cases and approximate superimposed isotropic and normal ion etching[2] solutions approximate analytical expressions for etch rates proportional to the ion energy flux[1] are used to calculate etching surfaces. Aspect ratio dependent etching is clearly seen. The simple etching expressions allow each user to plot etch rates and etching surfaces.

1. V. K. Singh et al, J. Vac. Tech. B 10, 1091 (1992).
2. D. J. Economou & R. C. Alkire, J. Electrochem. Soc. 135, 941 (1988).

JA-5 Vibrational Temperature Axial Profiles in Nitrogen Plasma Jet, S. ONO and S. TEII, Musashi Inst. of Tech. Tokyo, JAPAN-- Vibrational temperature axial profiles of the nitrogen electronic ground state has been calculated numerically in a reduced pressure N_2-Ar DC plasma jet. Results show that the vibrational temperature decreases along the axis and reach minimum value, then increase to Tv≈8000K and show almost constant temperature. The numerical calculation also shows that relatively high vibrational temperature in the down stream region is caused by the vibrational energy supply from highly vibrationally excited molecules that are produced by the recombination process. A comparative experiment has also been conducted by the spectroscopic measurement of the vibrational temperature[(1)]. The theoretical Tv profile agrees well with the experimental Tv qualitatively.

(1) S. Ono and S. Teii, J. Phys. D: Appl. Phys., 16, 163-170(1983)

JA-6 Applications of a 2D Simulation to Industrial Reactors, A. R. ELLINGBOE, H. Kim, B. D. Higgins, R. K. Porteous, and R. W. Boswell, Space Plasma and Plasma Processing Group, PRL, RSPhysSE, Australian National University - The HAMLET code is a 2D hybrid fluid/PIC plasma transport simulation. Atomic and ionic species are modeled using adaptively weighted particle-in-cell (PIC) techniques. The plasma potential and electron density and potential are solved using a fluid model. The HAMLET code has been used to model the transport in several inductively coupled systems of industrial relevance.

The transport of material from an evaporative source through a high density magnetized plasma has been studied. The material cools as it diffuses through the filling gas, until it is adsorbed on the chamber walls. Some proportion of the material is ionized during its transit of the plasma and is entrained, allowing it to be transported to a remote substrate.

A second simulation has been used to study an energy analyser immersed in the downstream plasma of a diffusion-type reactor. The ion energy distribution functions (IEDF's) measured by the analyser are examined for various analyser orientations, with and without magnetic fields, and in rapidly streaming plasmas. These IEDF's are compared to those obtained experimentally.

JA-7 Simulation of non-Maxwellian Electron Velocity Distributions in an Inhomogeneous Plasma Driven by Intense Microwaves*, J.P. Matte (1), T.W. Johnston (1), J.M. Liu (2), J.S. De Groot (2), and R.P. Drake (3); (1) INRS-Energie et Matériaux, Varennes, Québec; (2) UC Davis; (3) PPRI, LLNL and UC Davis. -- Flat-topped electron velocity distributions, of the type exp (-(v/u)**m), with m > 2, are observed in the UCD AURORA II device for inverse Bremsstrahlung heating with intense microwaves (V_{osc}**2/V_e**2 of order 1), in approximate agreement with electron kinetic simulations. Permanent magnets are arranged on the surface of the vacuum tank to confine the argon discharge plasma and to produce an axial density gradient. A microwave reflector limits the heating region to 0.7 N_c to avoid any collective heating at the critical surface. The ionization fraction (1%) is high enough that charged particle collisions dominate. A short microwave pulse (~ 0.2 to 2 μs) creates a very steep temperature gradient (LT/l_{ei} ~ 0.1 to 10). Langmuir probes are used to measure the electron distribution function in the plasma. Results will be compared to nonlocal heat transport theory and Fokker-Planck calculations.

* Work supported by NSERC (Canada) and U.S. DOE, PPRI, UCD and LLNL.

JA-8 Characteristic Energy and the Ratio of Longitudinal Diffusion Coefficients to Mobility for Electrons in NO at Moderate E/N, W. ROZNERSKI, J. MECHLIŃSKA-DREWKO and Z. LJ. PETROVIĆ*, Faculty of Applied Phys. and Math., Techn. Univ. Gdańsk, Poland - By means of a new version of a numerical procedure described earlier[1] the characteristic energy (D/μ) and the ratio of longitudinal diffusion coefficient to mobility (D_L/μ) have been determined over the reduced electric field E/N: $70 \le E/N \le 300$ Td and $70 \le E/N \le 400$ Td respectively. The present results of the D/μ are within the combined experimental errors of this work data and those reported previously[2]. As to the D_L/μ, the data-points of this work lie lower than those presented previously[2] and the difference between both data sets exceeds the combined experimental errors of both works.

*Inst. Phys., Belgrade, Yugoslavia.

[1]W. Roznerski, J. Mechlińska-Drewko and K. Leja, Joint Symposium (Gold Coast, 1991), p. 83.

[2]W. Roznerski, J. Mechlińska-Drewko and Z. LJ. Petrović, 45th GEC (Boston, Mass., 1992), p. 122.

JA-9 A Comprehensive Model for Radical Chemistry in Methane Discharges, J.R.DOYLE, D.J.DAGEL and C.Z.MALLOURIS, Macalester College, St Paul MN - We propose a quantitative model for the radical chemistry in methane glow discharges. A zero-dimensional (volume-averaged) rate equation approach is used, with additional terms to account for electrode and pumping losses. The model quantitatively predicts electrode radical fluxes as a function of pressure, electrode spacing, and methane dissociation rate, with other parameters provided by current literature values where available, and reasonable estimates otherwise. CH_3 is found to be the dominant mono-radical under all conditions, with CH_3-CH_3 recombination as the principal loss channel. Compared to previously proposed models, the present model utilizes a considerably simpler reaction scheme motivated by a careful evaluation of literature rate data. Under some conditions (e.g. at sufficiently low pressures) a reasonably accurate analytic model is in fact possible. A discussion of the uncertainties in the results based on the uncertainties in the literature rate constant data is presented. The validity of the zero-dimensional approach is also examined, using a linearized form of the one-dimensional diffusion-reaction equations. This procedure takes into account an approximate spatial radical source function S(x), and a generalized criteria for the validity of volume-averaged models is developed which can be applied to other plasma chemistry systems.

*Work supported in part by the donors of the Petroleum Research Fund, administered by the ACS.

JA-10 Nonlinear Gaseous Electric Discharge - Mathematical Modeling. M. KUMAN, Department of Electrical Engineering, University of Tennessee, Knoxville, TN 37996 --- A nonlinear equation is offered for description of the gaseous dynamic of a specific nonlinear electric discharge field. Sich nonlinear field could be used for separation of components in a gas mixture or enrichment of some of the components. The model leads to consequences that can be tested experimentally.

JA-11 Non-Equilibrium Vibrational Kinetics in N_2-H_2 Mixtures,* R. NAGPAL and A. GARSCADDEN, Plasma Research Group, WPAFB- Results from a detailed self-consistent collisional radiative model where the Boltzmann transport equation is coupled to the system of vibrational master equations in N_2-H_2 mixtures are presented. The results show that $N_2(X^1\Sigma_g^+, v \ge 30)$ are strongly quenched due to the V-T deactivation by H_2 even at a very low concentration (0.05 %) of H_2 in the gas mixture. This causes a severe depletion of N atom production by the vibrational mechanism which is the dominant dissociation channel at moderate E/N (30-60 Td)[1]. Above 0.2 % of H_2 in the mixture, the N atom number density is roughly constant and is due to direct electron impact dissociation. Implications of V-T quenching on the plasma chemistry and ionization balance in the gas mixtures will be presented.

* Work Supported by the Wright Laboratory.

[1] R. Nagpal and P. K. Ghosh, Chem. Phys. Lett. 183, 129 (1991).

JA-12 **Transport in Neutral Beam Assisted Etching,** M.D.KILGORE and D.B.GRAVES, U.of California-Berkeley - Etching systems which utilize directed beams of reactive neutrals have been explored recently as an alternative to conventional plasma etching.[1] Plasmas are employed to produce directed neutral beam species as well as background neutral radicals. These reactive species can etch the substrate with a minimum of charge-related device damage. However, neutral beam processing is inherently limited by pressure considerations. Very low pressures are desirable to maintain beam characteristics for anisotropic etching. Higher pressures are desirable to obtain high etch rates for reasonable process throughput. We apply the Direct Simulation Monte Carlo (DSMC) method to investigate this trade-off. We study reaction and transport effects for a simple model etching system consisting of beam and background reactants as well as etch products in a 2-D cylindrical chamber. Using model surface reaction probabilities, we look at the effect of gas-phase collisionality on the resulting etch rate. This enables the prediction of the optimum background gas pressure for neutral beam processing.

[1]T. Mizutani and T. Yunogami, *Jap. J. Appl. Phys.* **29**, 2220, (1990).

JA-13 A Nonlocal Model of Surface Wave Produced Plasmas, U. KORTSHAGEN, University Bochum, 44780 Bochum, Germany - A nonlocal kinetic model, which allows the approximate solution of the spatially inhomogeneous Boltzmann equation with the space charge electric field and the spatial diffusion taken into account,[1,2] is applied to a surface wave produced plasma. The results are compared to those of a local model, where the electron energy distribution function (EEDF) is calculated from the spatially homogeneous Boltzmann equation under the assumption that the EEDF is in equilibrium with the local electric field strength. In surface wave produced plasmas usually a pronounced radial inhomogeneity of the maintaining electric field is found. Thus the nonlocal and the local model yield considerably different predictions for the radial variation of the EEDFs and the radial distribution of spectral line intensities. The theoretically calculated EEDFs are compared to results of Langmuir probe measurements of the EEDF. Furthermore measured radial profiles of line intensities, obtained via Abel inversion, are compared to the theoretical predictions of both models.

[1]I.B. Bernstein and T. Holstein, Phys. Rev. **94**, 1475 (1954)
[2]L.D. Tsendin, Sov. Phys.-JETP **39**, 805 (1974)

JB: UNIQUE PLASMA SYSTEMS

JB-1 Pulsed e-beam generated in a dielectric limited discharge with proper preionization. M.GANCIU, G.MODREANU, A.M.POINTU, LPGP, Univ. Paris-Sud, Orsay, France and IFTAR, Magurele, Bucharest, Romania-A pulsed self collimated intense e-beam is produced on the axis of a discharge quartz tube, 2.8cm diameter, filled with oxygen at pressure, p, between 0.1 and 1mbar. It uses superposition of two discharges. The first one is created by two identical external electrodes adjacent to the tube (respectively cathode C and anode A, 8cm length, 2.5cm interelectrodes width) biased with symmetrical voltage steps, ± V, by means of a rotary atmospheric switch ensuring commutation time under 10ns. The second one is a negative glow- type DC discharge, current I, whose tip penetrates the inside part of C. Creation of the e-beam requires to adjust I for every set of p and V values. Then, intense light channel appears on the whole axis between C and A. Typical e-beam parameters, measured using Rogovsky coil and studying the emission of an excitation state of atomic oxygen ion, are: 50A, 50ns, 8keV, 3mm diameter, 100Hz.

JB-2 Spark Yields of S_2F_{10}, S_2OF_{10}, and $S_2O_2F_{10}$ in SF_6.* I. SAUERS, R. CACHEIRO,† and S. MAHAJAN,‡ ORNL - There has been recent interest in the production of S_2F_{10} by spark discharges in SF_6 due to the very high toxicity of this decomposition product. Improvements in detection sensitivity to below 10 parts-per-billion (1 in 10^8) using a cryogenic-enrichment gas chromatographic technique with an electron capture detector has permitted the detection of S_2F_{10} produced by a single spark discharge for energy deposited down to 10 J/ℓ. The S_2F_{10} yield (order of 10^{-10}mol/J) was found to depend on the presence of moisture and on electrode condition, with low moisture and conditioned electrode resulting in the highest yields. The formation of two other products S_2OF_{10} and $S_2O_2F_{10}$, both electronegative and possible interferents in S_2F_{10} detection were also investigated. Because of the lack of commercially available S_2F_{10}, production of S_2F_{10} by spark discharge under well defined conditions may be used in generating reference standards of this compound. Comparison of the yields of these disulfur compounds in spark to corona and arc discharges will be made.

*Work supported in part by OEM/DOE under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc., Bonneville Power Administration, Tennessee Valley Authority, EPRI, CEA and ESEERCO.

†U. of Tenn. ‡Tenn. Tech. Univ.

JB-3 Nonideality of Nuclear Plasmas, YOICHI WATANABE, Valley Research Corporation, Austin, TX - ^{3}He gas can be heated and ionized by the high energy protons and tritons generated from in-situ neutron induced nuclear reactions. Such plasmas (nuclear or fissioning plasmas) are weakly nonideal; that is, the ratio of the interaction energy between charged particles to the mean thermal energy, γ, is equal to or less than unity[1]. Using a two-temperature fluid model[2], we compute γ of a pure ^{3}He gas at various gas temperatures and pressures as a function of the thermal neutron flux. We find that γ exceeds 0.1 for neutron fluxes higher than 10^{16} cm^{-2}s^{-1} at 298 K and 10 atm. For example, $\gamma = 0.12$ (or $n_e=1.8\times10^{15}$ cm^{-3} and T_e=2600 K) for a neutron flux of 10^{18} cm^{-2}s^{-1}. The results indicate that weakly nonideal and nonequilibrium plasmas can be easily generated in a laboratory.

[1]V.E.Fortrov and I.T.Iakubov, Physics of Nonideal Plasma, Hemisphere Publishing Corporation, New York (1990).
[2]Y.Watanabe, J.Appelbaum, I.Maya, AIAA90-1613 (June 1990).

JB-4 Plasma Memory Devices,* P.J.DRALLOS, V.P. NAGORNY, and W.WILLIAMSON, JR., Dept. of Physics and Astronomy, Univ. of Toledo, Toledo, OH 43606 - The operation of certain gas discharge devices, such as AC-plasma display panels, depends on a 'memory' capability, which is accomplished through the interaction of the discharge and dielectric layers on the electrode surfaces. Typically, a single memory unit is comprised of a pair of parallel-plate electrodes, each coated with a thin insulating layer of dielectric. A source gas fills the remaining space between the electrodes. The electrodes are supplied with a square-wave, sustain potential. This potential is insufficient to produce a discharge when the dielectric is in an uncharged, or memory-off state. However, when the electrodes are charged (memory-on state,) the added potential due to the free charge, combines with the sustain potential, producing a brief discharge and leaving the dielectric in an equal but oppositely charged, memory-on state. 'Write' and 'erase' pulses control the dielectric surface charge, or memory state. These are accomplished by adjusting the magnitude and timing of the applied potential. Boltzmann computer simulations of the various duty cycles of these devices will be presented, and applications to AC-plasma display panels will be discussed.

* This work supported by the USDOE under contract No. DE-AC04-76DP00789.

JC: LASERS

JC-1 High Efficiency, High Power Output CO_2 Laser Operating at Unstable Glow Discharge Plasma Conditions*, C.E. FELLOWS and C.A. MASSONE, Laboratório de Espectroscopia e Laser, UFF, Brazil - A CO_2 DC laser without cooling set up and having high nitrogen parts in gas mixture, giving 30 W power output - 17% efficiency in 60 cm discharge tube length plasma, has been developed. It operates in an unstable glow discharge plasma regime which presents nonperiodic voltage spikes. This spikes depend on cathode surface and, if supressed, CO_2 power output and efficiency drastically diminish. The fact that a CO_2 laser without cooling is able to give those output power and efficiency values opens a field in plasma-gas laser emission interaction.

*Work supported by the Financiadora de Estudos e Projetos (FINEP) and the Conselho Nacional de Desenvolvimento Cientifico e Technológico (CNPq) of Brazil.

JC-2 Output Modifications in Pulsed Gas Lasers By Plasma Impedance Matching*, C.E. FELLOWS and C.A. MASSONE, Laboratório de Espectroscopia e Laser, UFF, Brazil - A theory that considers plasma impedances as an integral part of the electric circuit and explains the detected resonant narrowing of the laser pulse has been developed. From a normal and well-known excitation circuit having an spark-gap with capacitance and inductance plasma values, a charging capacitor, coupling inductance (Lext), parasitic inductance because of wires, transfer capacitor and plasma laser discharge tube capacitance and inductance (Lp), theory shows that, when Lp << Lext, excitation pulse period does not depend any more on Lext values. We then obtain, for example, pulse width values of 0.8 ns having Lext values as high as 16 μH.

*Work partially supported by the Financiadora de Estudos e Projetos (FINEP), the Conselho Nacional de Desenvolvimento Cientifico e Technológico (CNPq) and the Pró-Reitoría de Pesquisa e Pós-Graduação da Universidade Federal Fluminense (PROPP-UFF).

JC-3 Modeling of self-sustained discharge in an ArF excimer laser, H.Akashi, Y.Sakai and H.Tagashira, Department of Electrical Engineering, Hokkaido University, Sapporo 060 Japan
A self-sustained discharge development in an ArF excimer laser medium [$Ar/F_2/He$=7.89%/0.24%/91.87%(=1900Torr)] is simulated using continuity equations for charged particles, an energy conservation equation for electrons and a Poisson's equation. The results show that the cathode and anode sheaths are negligibly narrow but the space charge at the cathode brings tremendous magnitude of the field distortion. This distortion suggests to initiate a filamentation from a fine projection on the cathode surface, if there is, by the field emission, when the electron density grows up to $\sim 10^{14}$ cm^{-3}. The electron emission by energetic photons from the cathode is shown to be essential to moderate the field distortion at the cathode and to sustain the uniform glow discharge. Role of the preionization and the parameters of an external circuit for sustaining a uniform glow discharge are discussed.

JC-4 Temperature dependent gain of the atomic xenon laser,* Gregory A. Hebner, Sandia National Laboratories, Albuquerque New Mexico, Jong. W. Shon and Mark J. Kushner, University of Illinois, Department of Electrical and Computer Engineering, Urbana, Illinois - Measured and calculated gain of the 1.73 μm ($5d[3/2]_1$ - $6p[5/2]_2$) and 2.03 μm ($5d[3/2]_1$ - $6p[3/2]_1$) atomic xenon transitions for gas temperatures between 290 K and 590 K are presented. Fission-fragment excitation was used to characterize the gain in several Ar/Xe, He/Ar/Xe and Ne/Ar/Xe gas mixtures at a pump power of 8 W/cm^3. For a constant gas density, the gain exhibits an approximately T_{gas}^{-n} dependence with n between 2 and 3. The dominate reactions for controlling gas temperature dependencies have been identified as dimer formation, dissociative recombination and their effects on electron density. The implications of these measurements and calculations on scaling and high temperature operation will be discussed.

* This work was performed at Sandia National Laboratories and supported by the United States Department of Energy under contract DE-AC04-76PD00789.

JC-5 E-Beam Excitation of the He/Ne/Ar Laser,* L. M. LITTLE and J. T. VERDEYEN, Department of Electrical and Computer Engineering, U of Illinois - Lasing on the 703 and 725 nm Ne transitions was observed for Ne excited in a coaxial diode driven by a Febetron 706 pulse forming line. He, Ne, and Ar pressures were varied and the resulting spontaneous and stimulated emission output characteristics were examined for comparison with previously determined characteristics on the 585 nm transition.[1,2] These parametric studies showed a maximum peak power for a mix of approximately 6/14/1 at a total pressure of 1050 Torr. This was a higher Ne pressure and lower He pressure than that for the peak at 585 nm, which occurred at 26/6/1 with a total pressure of 1650 Torr. With a mix of 4/8/1 at 650 Torr, for which all three transitions will lase, the time to lasing onset and time to peak were compared. Results showed that each onset time and peak was separated by approximately 25 ns, with the 703 nm transition lasing and peaking first and the 585 nm transition lasing and reaching its peak last.

*Work supported by Sandia National Laboratory

[1]Jong W. Shon, et al, J. Appl. Phys., 73(12), 8059, (1993)

[2]Greg Hebner, J. Appl. Phys., to be published, 15 August, 1993

JD: MICROWAVE PLASMAS

JD-1 Self-Contained Modeling and Experimental Study of Surface Wave Argon Discharges in a Coaxial Structure, X. L. ZHANG, F. M. DIAS and C. M. FERREIRA, CEL-IST Lisbon Technic. U. - A self-contained model is presented for argon discharges sustained by an azimuthally symmetric surface wave propagating along a central metallic cylinder-plasma-glass tube-air-outer metallic cylinder, coaxial structure. For given operating parameters, the model provides a complete description of the spatial variation of the plasma density and of the field intensity, the wave dispersion relation and the power transfer from the wave to the plasma. Due to the presence of the central cylinder: *i)* the wave is guided both by this conductor and the plasma-glass interface; *ii)* the wave propagates beyond the end of the plasma column; and *iii)* absolute field measurements are possible. Probe measurements of the EEDF, the electron density and the plasma potential were performed. Experimental results for 360 MHz are presented and compared to calculations *vs.* the gas pressure.

JD-2 Linear slotted waveguide field applicator for sustaining microwave discharges, G. SAUVÉ, M. MOISAN and Z. ZAKRZEWSKI*, U. de Montréal - An elongated field applicator used to sustain long (with respect to the wavelength), uniform gaseous discharges is experimentally investigated. The power leaking aperture is a resonant array of centered inclined slots in the wide wall of a rectangular waveguide. The design, based on a WR-430 standard waveguide and operating at 2.45 GHz, was described earlier by Ji and Gerling[1] who tested its free-space performance. Our study focuses on experiments in an actual discharge setup. It shows the influence of both the plasma and the dielectric wall of the discharge chamber on the power match of the applicator. A properly designed simple structure with no adjustable elements can be made to assure an efficient power transfer to plasma and axial uniformity.

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[1] T.R. Ji and J. Gerling, J. Microwave Power and Electromagnetic Energy, 23, 3 (1988).

JD-3 Long microwave discharges sustained by leaky-wave structures, G. SAUVÉ, M. MOISAN and Z. ZAKRZEWSKI*, U. de Montréal - The characteristics of leaky-wave structures as field applicators in linear (extended in one direction), high throughput plasma sources has been investigated. The analysis of the general features of this class of discharges provides the base for an initial design of such applicators. We have tested experimentally (2.45 GHz up to 3 kW) a fast wave so-called troughguide structure, well known in antenna engineering. Long discharges of good axial uniformity were achieved using a periodically asymmetrical troughguide terminated with a matched load. To assure high power operation, we have devised and tested a new kind of ridge-waveguide mode transformers that allows to feed the microwave energy to the applicator directly from a standard waveguide. The main advantages of leaky-wave applicators are their simplicity of design and operation (no adjustable elements), a good power match at the input and good axial uniformity of the plasma. Their drawback is a lowered effiency due to the power loss in the terminating matched load.

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JD-4 A 2-D Model of a Microwave Plasma Ball Reactor, S.E. COE, D.S. BAILEY and A.D. BARNES, CRL, Hayes, U.K.- A 2-D axisymmetric model of a microwave plasma ball reactor, as used in Plasma Assisted Chemical Vapour Deposition systems, has been developed. The model can be broken down into two main parts. Firstly a model of the microwave coupling to the discharge and secondly a Collisional-Radiative-Diffusion model of the discharge plasma. Self-consistent solutions are obtained incorporating these two components of the model. The model is able to compute the position, size and shape of the plasma ball in the reactor in addition to the general discharge properties such as 2-D excited state density, electron density and electron temperature profiles. The model represents a valuable design tool for the optimisation of practical deposition systems. In addition to describing the key features of the model, results will be presented from initial calculations performed for an argon discharge plasma (for which the relevant cross-sections, diffusion coefficients etc.

are well known). The extension of the model to deal with methane/hydrogen mixtures, suitable for diamond coating applications, will also be discussed.

JD-5 Deposition of Thin Diamond Films in a Surface-wave Sustained Discharge (SWD), C. DE MELLO BORGES, M. MOISAN and L. ST-ONGE, U de Montréal - The deposition of thin diamond films with microwave plasmas at reduced gas pressure (torr range) is a current matter of investigation. One can classify these systems according to whether the plasma is in direct contact with the discharge wall (e.g. resonant cavity plasma and SWD) or not (e.g. bell jar system). This classification relates to the fact that hydrogen atoms, which play a key role in etching graphite and stabilizing the diamond phase, recombine on the discharge wall, the recombination rate increasing exponentially with the wall temperature. To reduce H atom recombination in SWD, a cooling jacket with an appropriate dielectric liquid is used around the tube and its efficiency controlled by actinometry measurements of the H-atom relative concentration and by assessing the deposition rate and quality of the diamond film. A second problem related to the use of SWD occurs when using large radius (R) discharge tubes such that fR > 2 GHz-cm (f is the operating frequency). The surface wave then propagates in high order modes which induce azimuthal non uniformity of the plasma, affecting the film quality and reproducibility. Ways of circumventing these problems are investigated.

JE: RF GLOW DISCHARGES

JE-1 GLOBAL MODEL OF ELECTROPOSITVE AND ELECTRONEGATIVE PLASMAS INVOLVING MOLECULAR GASES V. VAHEDI, C. LEE, K. NIAZI, AND M. A. LIEBERMAN EECS Department, UC Berkeley, Berkeley, CA 94720 - The global electropositive model [1] has been extended to include the presence of metastables and various ionic species (including negative ions for electronegative gases). Inelastic processes such as two-step ionization, dissociative attachment, mutual neutralization, and superelastic quenching of metastable species are included. Results of Lichtenberg et al. [2], giving the density profiles of positive and negative ions, are integrated to obtain the global particle balance for each species. In molecular gases, the global power balance equation becomes more complicated, as multiple ionic and neutral species interact through various inelastic processes. Thus, an expression for the generalized power balance is needed. Molecular gases such as chlorine, oxygen, and nitrogen will be used for case studies, and results will be presented over a wide range of neutral gas pressure and input power.

1. G. R. Misium, A. J. Lichtenberg, and M. A. Lieberman, *J. Vac. Sci. Technol.* **A 7**, 3 (1989).

2. A. J. Lichtenberg, V. Vahedi, M. A. Lieberman, and T. D. Rognlien, "Modeling Electronegative Plasma Discharges," submitted to *J. Appl. Phys.* for publication.

JE-2 2D SIMULATIONS OF DUAL RF EXCITED PLASMAS V. VAHEDI, C. K. BIRDSALL, M. A. LIEBERMAN EECS Department, UC Berkeley, Berkeley, CA 94720 - It has been observed experimentally by Goto *et al.* [1] that for a fixed power, the DC sheath voltage drop (ion bombarding energy) decreases as the RF drive frequency increases, causing less damage and sputtering at the target. Furthermore, it has been seen in simulations by Vahedi *et al.* [2] that for a fixed applied voltage, as the RF drive frequency is raised, the width of the capacitive-sheath decreases causing the ions to arrive more normally at the target. Simple scaling laws [2] also show that for a fixed applied voltage, the plasma density and power deposited into the system increase as the square of the RF drive frequency. Based on these results, we are studying a two-frequency capacitive RF discharge reactor with our two-dimensional simulation code, PDP2 [2]. One electrode is driven at 30-50 MHz to set up the plasma density while the target electrode is driven at 13.56 MHz with an adjustable voltage or current source to determine the ion bombarding energy. Plasma density and ion angular and energy fluxes will be shown over a range of operating frequencies.

1. Haruhiro H. Goto, Hans-Dirk Lowe, and Tadahiro Ohmi, *J. Vac. Sci. Technol. A* **10**, 3048 (1992).

2. V. Vahedi, G. DiPeso, T. D. Rognlien, and C. K. Birdsall "Verification of Frequency Scaling Laws for Capacitive RF Discharges Using Two-Dimensional Simulations," accepted by Phys. Fluids B for publication.

JE-3 MODELING ELECTRONEGATIVE PLASMA DISCHARGES A. J. LICHTENBERG. V. VAHEDI, and M. A. LIEBERMAN EECS Department, UC Berkeley. Berkeley, CA 94720 - A macroscopic analytic model for a three-component electronegative plasma has been developed [1]. Assuming the negative ions to be in Boltzmann equilibrium, a positive ion ambipolar diffusion equation is found. The electron density is nearly uniform, allowing a parabolic approximation to the plasma profile to be employed. The resulting equilibrium equations are solved analytically and matched to an electropositive edge plasma. The solutions are compared to a simulation of a parallel-plate RF driven oxygen discharge for several cases. In the simulation, α_0, the ratio of the negative ion to the electron density in the middle of the discharge, was found to be directly proportional to the pressure and inversely proportional to the discharge power. Using an electron energy distribution function that approximates the simulation distribution by a two-temperature Maxwellian, the analytic values of α_0 are found to close to but somewhat larger than the simulation values. The results indicate the need for determining a two-temperature electron distribution self-consistently within the model.

1. A. J. Lichtenberg, V. Vahedi, M. A. Lieberman, and T. D. Rognlien, "Modeling Electronegative Plasma Discharges," submitted to *J. Appl. Phys.* for publication.

JE-4 COMPARISION OF LABORATORY RESULTS FOR SPATIAL VARIATION OF AVERAGE ELECTRON ENERGY AND PIC SIMULATIONS V. VAHEDI. C. K. BIRDSALL and P. MIRRASHIDI EECS Department, UC Berkeley, Berkeley, CA 94720 - Spatially resolved probe measurements of the electron energy distribution function (EEDF) in capacitive RF discharges in argon showed that the effective electron temperature decreases with increasing plasma heating RF field [1]. This is being investigated with the Particle-In-Cell simulation code PDP1 [2]; similar results are obtained over the same range of neutral pressure in RF driven argon plasmas. Non-Maxwellian EEDFs and negative bulk heating rates are observed at low pressures, which are typical in low pressure capacitive RF discharges in a Ramsauer gas. We will present comparisons of laboratory measurements for spatial variation of average electron energy with those obtained from PDP1 over a range of neutral pressures and discharge powers.

1. V. A. Godyak, and R. B. Piejak, "A Paradoxical Spatial Distribution of the Electron Temperature in a Low Pressure RF Discharge," Presented at *IEEE ICOPS*, Vancouver, BC, June 1993.

2. V. Vahedi, C. K. Birdsall, M. A. Lieberman, G. DiPeso, and T. D. Rognlien, "Capacitive RF discharges modeled by Particle-In-Cell Monte-Carlo simulation. I. Analysis of numerical techniques," accepted by *Plasma Source Sci. Technol.* for publication.

JE-5 Measurements and Simulations of Plasma Densities in Capacitively Coupled RF Discharges, R. A. DOYLE, M. B. HOPKINS and M. M. TURNER, Dublin City University,Ireland; L. J. OVERZET, University of Texas at Dallas – We present intercomparisons of plasma density measurements obtained using microwave interferometry and various Langmuir probe techniques with densities calculated using a self-consistent kinetic simulation (PIC-MCC). All these approaches have their problems, and we discuss the systematic descrepancies that appear in terms of the known limitations of the techniques. We will present results for argon and nitrogen in the pressure range 20 to 200 mTorr, corresponding to plasma densities from $10^9 - 10^{10}$ cm^{-3}. Under these conditions electron temperatures varying from 1 to 4 eV are observed.

JE-6 Collisional Electron Heating in a RF–Discharge*
E. QUANDT, H.–M. KATSCH, P. MARK and K.G.MÜLLER
Universität Gesamthochschule Essen

In a parallel plate RF–discharge operating by a nonsinusoidal voltage with a steep rise and fall to a plateau the displacement and the convective current can be separated in time. By optical emission spectroscopy with time and spatial resolution the γ– and the α–mechanism of an Argon and Helium RF–discharge can be identified. Consequently the sheath oscillation heating, the Joule heating close to the sheaths, the energy deposition and the role of the secondary electrons from the cathodic sheaths are observed. The results are compared with model calculations on basis of the transport equations and with computer (PIC–MC) simulations. The fluid model roughly confirms with the experimental results. While taking into account a spatial distribution of Helium metastable atoms the computer simulation gives excellent confirmation.

*Work was supported by the DFG, SFB 191.

JE-7 Vector and Parallel Techniques for Simulations of Multi-Dimensional Nonequilibrium RF Glow Discharges,* Fongray Frank Young and Chwan-Hwa "John" Wu, Dept. of EE, Auburn University - Due to the advance of high performance computer systems, multi-dimensional simulations become possible in the past few years. However, the required computation time is still significant. The use of parallel systems can provide solutions within a reasonable turnaround time. Efficient numerical algorithms and techniques of vectorization and parallelization for rf glow discharge modeling are introduced. Performance measurements are investigated from Cray systems. Consequently, the simulation code is fully vectorized and the speedup ratio of the fully-vectorized code between the vector mode and the scalar mode approaches 12.20. Moreover, the parallel processing has a speedup ratio of 6.07 on a dedicated Cray Y-MP machine with eight processors versus a single processor. Therefore, mechanisms of rf discharge can be understood within a shorter turnaround time.

* This work is supported by NSF under ECS-9009395.

JE-8 Electrode geometry effects on local nonuniformities in rf discharges, M. SURENDRA, M. DALVIE, G. S. SELWYN, and C. R. GUARNIERI, IBM T. J. Watson Res. Ctr. – Discontinuities in bounding surfaces of rf discharges have important ramifications for discharge uniformity. These effects, which are predicted by 2-D fluid simulations of rf discharges, have been experimentally verified with spatial maps of optical emission. The model consists of charged species conservation equations, together with ion momentum and electron energy balances. Poisson's equation is solved for the self-consistent field. Domain boundaries can contain topological discontinuities and/or material changes. The perturbations in the boundaries give rise to local variations in electric field profiles and electron heating rates, and consequently nonuniform excitation and ionization rates. These variations can in turn lead to the formation of traps for contaminant particulates in the discharge. The presence of these traps and their relationship to local plasma nonuniformities is demonstrated experimentally.

JE-9 Using RF Transport Coefficients to Achieve a More Accurate Fluid Model For RF Glow Discharges,* Xing "Peter" Wu, Chwan-Hwa "John" Wu and Fongray Frank Young, Dept. of Electrical Engineering, Auburn University -- Transport coefficients are critical to the fluid models for rf glow discharge simulations. Transport coefficients used in traditional fluid simulation models were always obtained from a DC Monte Carlo simulation. For more accurate results, transport coefficients from a kinetic model under radio frequency field influence are applied. Results from this new fluid model are compared with those from a traditional fluid model, other benchmark simulation results collected by M. Surendra, and the experimental measurement in terms of plasma density, bulk energy, sheath width and other plasma properties. The comparison results show the new model has the high advantages of simulation accuracy and cost. The results display less than 5% error compared to the experimental measurements. This investigation provides a good chance for a more accurate fluid model for multi-dimensional simulations.

* This work is supported by NSF under ECS-9009395

JE-10 Ion Energy Distribution Functions in a Symmetrical RF-Discharge, U. KORTSHAGEN and M. ZETHOFF, University Bochum, 44780 Bochum, Germany - The ion energy distribution function at the electrode of a capacitively coupled RF-discharge in the collisional regime exhibits a structure of peaks and double peaks. This structure has been related to the temporal modulation of the electric field in the sheath in combination with the temporally constant creation of ions by symmetric charge exchange collisions.[1] This paper presents a theoretical and experimental investigation of the ion energy distribution functions at the grounded electrode of a symmetrical, capacitively coupled RF-discharge. The theoretical model is based on a self-consistent hydrodynamic sheath model coupled to a nonlocal kinetic model of the bulk plasma. The measurements are performed using an electrostatic energy analyzer. The parameters entering the model are determined via Langmuir probe measurements, evaluation of the ion energy analyzer characteristics and electrical measurements of the discharge current. Theoretical and experimental results are also compared to predictions of PIC simulations.

[1]C. Wild and P. Koidl, J. Appl. Phys. **69**, 2909 (1991)

JE-11 Modeling of a Plasma Display Cell- Ramana Veerasingam and Robert B. Campbell, Sandia Nat'l Lab Plasma display panels are actively researched as a possible choice for High Definition TV (HDTV) monitors. The physics is essentially a gas discharge phenomenon similar to RF discharges but operate on a much faster time scale and at higher pressures of the order of several 100's of Torr. Presently, a major effort is to improve the luminosity or brightness of a color display without compromising cost or power consumption. To better understand the operation of a display, we are developing multi-dimensional plasma models. We will present some results from a 1D model which is being developed as a first step in the project. The model will use a fluid description for the plasma using rates from a Boltzmann solver characterized as a function of E/N. We will include non-local effects using a model transfer function. A fully implicit Newton's method will be the numerical algorithm of choice.

JE-12 Comparison of Two-Dimensional Continuum Model Results to Measurements from a Simple Parallel-Plate Reactor, G.L. HUPPERT, V. MOHINDRA, R.A. BROWN and H.H. SAWIN, Massachusetts Institute of Technology - Continuum model results for a 13.56 MHz Argon plasma will be compared to measurements made on a cylindrically symmetric etching reactor. Comparison will be made for plasma induced emission, current-voltage characteristics, plasma potential, ion energy, ion flux, and electron energy.

JE-13 Particle Simulation of Low-Pressure Processing Plasmas, M. LAMPE, G. JOYCE and S.P. SLINKER, Naval Research Laboratory, Washington, DC 20375-5346 - In processing discharges with pressure < 1mtorr, both the ions and electrons have long mean free paths and nonthermal velocity distributions, and therefore should be modeled kinetically. Development of kinetic models has been hindered by the problem of resolving time scales ranging from 10^{-11}s (plasma oscillations) to > 10^{-5}s (ion residence times). We report on the development of a fast-running fully kinetic 2-D (r-z) simulation code for systems (such as ECR discharges) with well-magnetized electrons. Ions are treated by 2-D PIC simulation with MC collisions. Bulk electrostatic fields are calculated from quasineutrality, thereby avoiding the plasma frequency time scale. Between collisions and ion time steps, electrons are treated by guiding center dynamics with frozen electrostatic fields, which eliminates the gyrofrequency time scale. Microwave heating is included in a formulation which does not require resolution of the microwave period. Sheath potentials are calculated from reflection conditions. Ionization and plasma chemistry are included in a Monte Carlo formulation coupled to the electron distribution.

JE-14 Very High Frequency Capacitively Coupled Argon Discharges: Experiment and Simulation, M. J. COLGAN and D. E. MURNICK, Rutgers University, Newark, NJ and M. MEYYAPPAN, Scientific Research Associates, Glastonbury, CT—The effects of frequency (13.6-54.4 MHz) on 250 mTorr argon discharges were investigated. Scaling relations derived from spatially resolved optical emission data and fluid model simulations are reported. Voltage scaling at fixed frequencies is linear for many internal parameters, similar to the 13.56 MHz case. When frequency is increased at constant applied voltage, large increases in excitation and ionization rates at the sheath/glow interface and ion flux to the electrodes are accompanied by substantial increases in the average ion energy at the electrodes. At constant current, the plasma density, ion flux, and excitation and ionization rates are nearly independent of frequency, while total power dissipation and ion energy at the electrodes both decrease with increasing frequency. The results suggest that operation of diode reactors at very high frequencies can reduce damage to processed films and improve process efficiency.

JE-15 Sensitivity of Argon Plasmas to O_2, N_2 and H_2O Impurities, M. A. SOBOLEWSKI and J. K. OLTHOFF, N.I.S.T.
We have investigated rf discharges in mixtures of Ar gas with small quantities of O_2, N_2 and H_2O, using rf current-voltage measurements and mass-spectrometry. We have found that Ar discharges are very sensitive to small quantities of common impurity gases. This sensitivity must be considered if one is to obtain reproducible experimental data and valid comparisons of experiment with theory.

The current and voltage characteristics, especially the dc self-bias of the powered electrode, were sensitive to small quantities of all three gases. Concentrations as low as 20 ppm of O_2 in Ar had measurable effects on the dc self-bias. As N_2 is added to Ar plasmas the dc self-bias becomes less negative, with the change in bias proportional to the logarithm of the N_2 concentration. For O_2, the self-bias follows a more complicated, non-monotonic dependence. The effect of H_2O on self-bias is similar to that of O_2.

The changes in the electrical characteristics can be related to changes in charge density, sheath thickness, and sheath potential, which in turn influence the transport of ions across the sheaths. Indeed, changes in the electrical characteristics as the O_2 concentration is varied are correlated to changes in the ion energy distributions. This suggests that the electrical measurements could be used to monitor the reproducibility of ion energies, a critical factor in plasma processing applications.

JE-16 Time-resolved Laser Optogalvanic Spectroscopy of Bromine in a Radiofrequency Discharge, D. KUMAR and S. P. MCGLYNN, Department of Chemistry, LSU, Baton Rouge, LA - Pulsed laser optogalvanic (LOG) spectra of ~100 mTorr bromine in a ~ 32 MHz rf discharge are excited in the range 14,900 - 17,100 cm^{-1}. As with iodine[1], the transient LOG signal consists of a fast component synchronous with the laser pulse (width ~ 1 μs), followed by a delayed component (width 50-100 μs) whose delay accords with the acoustic wave propagation time to the nearer rf electrode. The fast component exhibits atomic transitions of bromine from plasma excited atoms, whereas the delayed component reproduces the photoacoustic spectra due to $\tilde{B} \leftarrow \tilde{X}$ and $\tilde{A} \leftarrow \tilde{X}$ excitations of molecular bromine. The origin and spectral characteristics of these two components will be discussed.

*Work supported by grants from U. S. Department of Energy and the LSU Center for Energy Studies.

[1]D. Kumar, P. L. Clancy, and S. P. McGlynn, J. Chem. Phys. 90, 4008(1989).

JE-17 Efficient Two-Dimensional Simulation of RF Glow Discharges, G.L. HUPPERT, R.A. BROWN and H.H. SAWIN, Massachusetts Institute of Technology - Efficient algorithms have been applied to the calculation of time periodic steady state solutions of the continuum model for an Argon discharge. Direct calculation of the time periodic steady state is coupled with iterative solution techniques to provide an efficient scheme. Spatial accuracy is obtained through use of a spectral-element discretization. Results for Argon discharges will be presented for simulations of a simple reactor for both equal and unequal electrode areas. Issues of numerical accuracy and computational efficiency will be addressed.

JE-18 Self-consistent particle-in-cell simulations of an rf sheath, M. SURENDRA, IBM T. J. Watson Res. Ctr. and D. VENDER, Dept. Phys., Eindhoven Univ. Tech. - The behavior of a collisionless rf sheath is studied in a PIC simulation. The 1-D simulation is bounded on one side by an electrode and a quasi-neutral plasma on the other side. The electrode is driven by an rf current. Particle fluxes are controlled at the plasma boundary to maintain a quasi-static source sheath. The plasma density at the sheath edge is 8×10^{15} m^{-3} and the maximum rf current is 50 Am^{-2}. Some characteristics of this system compare well with analytic models of rf sheaths. However, essentially no electron heating is observed under the conditions considered, with minimal distortion of forward and reverse electron velocity distributions. This contrasts with analytic models of collisionless rf sheath heating and non self-consistent simulations of electrons interacting with oscillating boundaries. The results indicate that collisionless rf sheath heating may be characteristic of a complete system. Alternatively, heating may be a threshold effect.

JE-19

WITHDRAWN

JF: POSITIVE COLUMNS

JF-1 On a simple method for ambipolar diffusion time calculation in non-circular cross-section low pressure discharges. N.BASHLOV, N. TIMOFEEV*, G. ZISSIS, LE VAN HIEU*, C.P.A.Toulouse.-- A method for the ambipolar diffusion time calculation in a non-circular cross-section discharge is proposed. Indeed, in the present work we deal with a trapezoidal cross-section discharge. The method is based on the following procedure. Ambipolar diffusion term in the electron density conservation equation can be presented as an electron density divided by the ambipolar diffusion time. This representation gives us the uniform Helmholtz equation for the electron density; the eigenvalue of this equation contains the ambipolar diffusion time. The Helmholtz equation with zero boundary conditions on the discharge wall has a nontrivial solution which, in the Cartesian coordinates, is a combination of the exponential functions. The form of the general solution depends on the shape of the tube's cross-section. In the case of the trapezoidal cross-section discharge the solution of the Helmholtz equation can be represented as the sum of the trigonometric and hyperbolic functions. Zero boundary conditions for the electron density leads to a homogeneous system of equations. Therefore this system has a nontrivial solution only when its determinant is equal to zero. Thus, our system is reduced only to the one equation whose solution gives the eigenvalue of the Helmholtz problem and therefore the ambipolar diffusion time in the discharge. The calculation were made for the different discharge tubes of the trapezoidal cross-section. According to our calculations the shape of trapezium has a strong influence on the ambipolar diffusion time. For each trapezium we determined effective radius (radius of the cylindrical tube with the same diffusion time). The contour of such a tube is about 10-20% less than having that of trapezium one.

*Laboratory of Plasma Physics, St Petersburg State University, Russia.
N. Bashlov is also with Lab. of Plasma Physics, St. Petersburg University.

THURSDAY MORNING

JF-2 The VUV Efficiency of Xenon/Rare-Gas Positive Column Discharges*, D.A. Doughty, General Electric Corporate Research and Development - Mercury-based fluorescent lamps provide high efficiency lighting in a broad range of commercial and residential applications. There is an increasing concern however, regarding the mercury from spent lamps entering the waste stream. To evaluate the possibility of a xenon-based system replacing mercury, the VUV efficiency of xenon/rare-gas discharges has been measured. The relative efficiency of the 147nm xenon resonance emission is measured as a function of xenon pressure, rare-gas buffer pressure, and discharge current. To calibrate these measurements an absolute determination of the 147nm emission must be made. Because these plasmas tend not to be diffuse radiators, it becomes very difficult to measure the radiant emittance at 147nm using direct calibrated detection. An alternate method is described, in which the density of the resonance level is measured via absorption. This density is combined with a calculation of the trapped decay rate of the resonance level and appropriate geometrical factors to yield the 147nm radiant emittance from the positive column.

* Work supported in part by the National Institute of Standards and Technology under the Advanced Technology Program.

JF-3 Measurement of Metastable Density in a Narrow Tube Noble Gas Glow Discharge Plasma, T. TOYOSHIMA, Y. OHSONE, T. KANEDA, Department of Electronics Engineering, Tokyo Denki University, J.S. CHANG, Department of Engineering Physics, McMaster University, Metastable density in a narrow tube (tube diameter d<10mm) helium an neon dc glow discharge positive column plasma is investigated both experimentally and numerically. The results show that: (1) He singlet density is observed to be nonmonotomically depend on the gas pressure, and no significant discharge current, hence plasma density, effects are observed; (2) He triplet density increases with increasing gas pressure and discharge current; (3) Ne metastable densities increase with increasing both gas pressure and discharge current; (4) Metastable densities predicted by the computer code (Chang et.al., 1992)agree qualitatively well with a present experiment.

JF-4 Further Study of Mercury Transport in Hg-Rare Gas D. C. Discharges. M. W. GROSSMAN, OSRAM SYLVANIA INC., DANVERS, MA. - Ion mobility and density gradient induced diffusion are the mechanisms usually discussed with respect to cataphoretic migration of mercury in Hg-rare gas d. c. discharges. In an earlier presentation[1], neutral gas entrainment was discussed as an additional mechanism of mercury transport. However, both transport mechanisms, that is, the neutral gas entrainment and gradient induced diffusion are dependent on the mercury density for the experimental conditions reported earlier[1]. The result was the folding together of the two transport mechanisms in the measurement of mercury transfer.

This presentation will discuss an experimental technique which permits unfolding of the neutral gas entrainment transport process from other mercury transport processes. A description of the experimental technique will be given. Also, data will be presented to indicate the magnitude of neutral gas entrainment for different tube and discharge configurations.

Related work[2] on cataphoresis will be discussed.

[1] M. W. Grossman 1992 Gaseous Electronics Conference
[2] C. Kenty, J. Appl. Phys., 38, 4517 (1967)

SESSION KA: INDUCTIVELY COUPLED PLASMAS I
Thursday morning, 21 October 1993
Grand Salon A, 8:00–10:00
T.J. Sommerer, presiding

KA-1 Characterization of Plasma in an Electrostatically Shielded Inductively Coupled Plasma Source, W.L. JOHNSON, Prototech Res. Arizona - The inductively coupled plasma source with electrostatic shielding ESRF has found application to semiconductor reactive ion etching. This source can operate at pressures between 10^{-5} torr and 10 torr. Measurements of the uniformity of plasma density both axially and radially are presented for the 12 inch bore plasma source. Radial uniformity depends upon the presence of both the susceptor and the susceptor bias. Measurements of the bias voltage and bias power are presented for the 8 inch air cooled source. Data is presented for the best etching to date on polysilicon and GaAs.

KA-2 Capacitive Coupling Effects in Inductively Coupled Plasmas for Etching. * Peter L. G. Ventzek, Robert J. Hoekstra, Joseph M. Barich, and Mark J. Kushner, Univ. of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - Inductively coupled plasmas (ICP) are being developed as high plasma density (10^{11}-10^{12} cm^{-3}), low pressure (a few - 10s mTorr) sources for semiconductor etching. In one configuration, the coil is a flat spiral placed at top of a squat cylinder generating an azimuthal electric field. An rf bias is separately applied to the substrate to control ion energies incident onto the wafer. The inductive voltage across the coil often capacitively couples to the discharge, thereby perturbing the plasma. We have developed a 2-d hybrid model for ICP reactors including both inductive and capacitive coupling. The model consists of electromagnetic, electron Monte Carlo and fluid modules which are iterated to convergence; and an off line plasma chemistry Monte Carlo simulation to obtain ion and hot atom energy distributions. Results from the model will be presented for plasma densities, plasma potentials and ion fluxes to the substrate while varying the inductive and capacitive coupling to the plasma.

* Work supported by SRC, NSF, IBM, LAM Research Inc., and U. of Wisc. ERC for Plasma Aided Manufacturing

KA-3 Operation of Remote Plasma Enhanced CVD Reactors with Unconfined Plasmas. * Irene Peres and Mark J. Kushner, University of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - In Remote Plasma Enhanced Chemical Vapor Deposition (RPECVD) the plasma is generated by inductively coupled electric fields in a narrow tube upstream of the deposition chamber. High selectivity of producing deposition precursors is made possible by isolating the plasma from injected gases. This is often compromised by penetration of the plasma into the downstream deposition chamber. The inability to confine the plasma results from fringing inductively coupled fields and undesireable capacitive coupling from the coils. We have developed a 2-dimensional hybrid model for RPECVD reactors which includes inductive and capactive coupling to investigate the unconfined mode of RPECVD. The hybrid model iterates between electromagnetic, electron Monte Carlo and fluid modules until convergence. The model properly accounts for dielectric walls with surface charging. We will discuss conditions for which the plasma remains confined or penetrates downstream for O_2, He and He/SiH_4 mixtures.

* Work supported by SRC, NSF, IBM and the University of Wisconsin ERC for Plasma Aided Manufacturing

KA-4
Spatial Density and Power Deposition of a Planar Inductively-Coupled Plasma (TCP) Studied Via Langmuir Probe Data and Induced Electric Field Simulation.
A.J.Lamm, N.M.P.Benjamin, T.Wicker, Lam Research Corp., Fremont, California 94538. -Planar inductively-coupled discharges are presently utilized to etch various types of thin films used in semiconductor applications. Of considerable

interest in the processing of thin films is the uniformity of etch. In order to achieve process uniformity, it is necessary to be able to control the uniformity of the plasma above the wafer. In the present experiment, the uniformity of the discharge is studied as a function of coil configuration in order to understand the influence of coil geometry on spatial power deposition. Langmuir probe data are presented for various coil configurations. These data are compared to a computer model of the time-dependent magnetic and electric fields induced in the presence of a plasma with a prescribed density and profile.

KA-5 High Power RF Monitoring of a Planar Inductively-Coupled Plasma, N.M.P. BENJAMIN, A.J. LAM and R.G. VELTROP, Lam Research Corp.,Fremont, Ca 94538. - Power and RF monitoring in plasma processing systems is usually confined to the 50 Ω side of the power transmission system between the generator and the matching network. Data that is more relevant to the process plasma can be obtained by measuring directly adjacent to the electrode in a capacitive discharge, or to the antenna in an inductive discharge. However, the voltages and currents at these points may be large, with substantial phase angles, when compared with the 50 Ω case, so considerable care must be taken in order to obtain valid data. High density processing plasmas are now often generated using inductive coupling techniques, but there is still a residual capacitive coupling fraction. In the present experiments RF monitoring is performed adjacent to the antenna in a planar induction system with a view to differentiating between the capacitive and inductive coupling components.

KA-6 **A 2-D Fluid Model of High Density Inductively Coupled Plasma Sources,** R. A. Stewart, P. Vitello*, and D. B. Graves, University of California-Berkeley- A 2-D (r,z) time-dependent fluid model is used to study plasma transport in inductively-coupled plasmas. A self-consistent calculation yields power delivered to the plasma electrons from both an external antenna coil and capacitive coupling to a biased substrate. We consider high aspect ratio reactor geometries and various antenna coil configurations. We have used our model to study the variation of the 2-D spatial profiles of plasma parameters including density, electron temperature and ion flux with both input power and gas pressures in Ar and Cl_2 discharges. Comparison is made with available experimental data.

*Lawrence Livermore National Laboratory

KA-7 **Spatiotemporal Characteristics of Collision Dominated-Inductively Coupled-Plasma,** K.KONDO*, H.KURODA and T.MAKABE, Keio Univ. Yokohama Japan — Plasma maintenance by rf currents applied to induction coils is one of the traditional and renewed methods, as is known as inductively coupled-plasma (ICP). This work describe time- and space-characteristics in a periodic steady state of a collision dominated-ICP with external coils and without static magnetic field. The governing equation system is one-dimensional relaxation continuum (RCT) model, developed by our previous work. RCT model is developed into the system including Maxwell's equations. Electron swarm parameters in $\boldsymbol{E} \times \boldsymbol{B}$ fields, $\boldsymbol{E}$- and $\boldsymbol{E} \times \boldsymbol{B}$-drift velocities and ionization rate constant et al, are calculated beforehand as functions of B/N and E/N using the Boltzmann equation. ICP for pressures of 0.1-5 Torr and 13.56 MHz in Ar is simulated as a function of dissipated power, and the spatiotemporal behavior is discussed. It will be stressed that the plasma is mainly sustained in the vicinity of wall sheath during the phase when the radial drift velocity is emphasized by $\boldsymbol{E} \times \boldsymbol{B}$-drift.
*Permanent address: Fuji Electric, Corporate Research & Development, Ltd.

KA-8 Acoustic Resonances in Inductively-Excited, Electrodeless High-Pressure Discharges, M. E. DUFFY and J. T. DAKIN, GE Lighting, Cleveland, OH 44112 – Electrodeless fused quartz arctubes, approximately cylindrical in shape, having external diameter and height of 20 and 17 mm respectively, were dosed with metal halide salts and filled with 250 Torr Kr at room temperature before sealing. Inductive excitation was provided by a seven turn coil, which was capacitively matched to the 50 ohm output of a 13.56 MHz (f_{rf}) power source. The power source was controlled by a signal generator whose dc output level established the time average rf power level in the range 250 to 500 W. The signal generator output had a sinusoidal ac component at 10 to 50 kHz (f_{am}), which caused the instaneous rf power level to modulate. Phenomena were observed at $f_{am} \approx 25$ kHz, the most obvious feature being a visible change in the shape and stability of the discharge. These phenomena were studied by varying the power level and the arctube height, and by sweeping the modulation frequency through 25 kHz at about 100 Hz (f_{fm}). A simple model identified the phenomena with the lowest acoustic resonance mode in the discharge gas.

SESSION KB: RECOMBINATION AND ION COLLISIONS
Thursday morning, 21 October 1993
Grand Salon C, 8:00–10:00
E. Mansky, presiding

KB-1 **Electron-Ion Dissociative Recombination***, M. R. Flannery *ITAMP, Harvard – Smithsonian and School of Physics, Georgia Tech.* Dissociative recombination in electron-diatomic molecular ion collisions has been described theoretically by a first-order treatment and by two *ab-initio* fully quantal treatments based on configuration mixing and on multichannel quantum defect theory, respectively. Agreement with experiment is limited to only ($e^- - H_2^+$) collisions and possibly to ($e^- - N_2^+$) collisions. In an effort (a) to gain further insight into the physics not included in the first-order treatment, and difficult to extract from the numerical quantal procedure; and (b) to see if simple analytical expressions for the recombination rate which are more accurate than the first-order expression can be derived without recourse to the full quantal treatments, a two-state semiclassical theory is presented here. Not only will it be invaluable for the simpler diatomic species, but the present theory can also be applied to cases where curves do not cross and to complex molecular systems.

* Work supported by AFOSR grant no. 89-0426 and partially supported by an NSF grant via ITAMP at Harvard.

KB-2 FALP-MS Measurements of Dissociative Recombination of Cyclic and Polycyclic Hydrocarbons*, B.R. ROWE, H. ABOUELAZIZ, J.C. GOMET, D. PASQUERAULT, A. CANOSA and J.B.A. MITCHELL, DPAM, Université de Rennes - Rate coefficients for the dissociative recombination of electrons with the ions $C_3H_3^+$, $C_6H_6^+$ and $C_{10}H_8^+$ have been measured using the Flowing Afterglow Langmuir Probe-Mass Spectrometer technique (FALP-MS).[1] Values of 0.7 x 10^{-6}, 1.0 x 10^{-6} and 0.3 x $10^{-3}cm^3s^{-1}$ have been obtained. Studies are continuing on anthracene, $C_{14}H_{10}^+$, and will be reported upon.

*Supported by CNRS

[1]H. Abouelaziz et al., J. Chem. Phys. 98, 12 (1993)

KB-3 Dissociative Recombination Studies by Time of Flight Spectroscopy. K.A. HARDY and J. SHELDON*, Physics Department, F.I.U. and J.R. PETERSON,** Molecular Physics Laboratory, SRI International.- The direct products of dissociative recombination (DR) of Ne_2^+, Ar_2^+, and Kr_2^+ ions have been observed and identified using time of flight (TOF) spectroscopy. The ions are formed and the DR reactions occur in an effusive source of metastable rare gas atoms, where an electric discharge is maintained by a hot filament source of electrons placed on the beam axis and held at potentials of -40 to -90 volts. The TOF spectra show a normal thermal distribution plus superthermal peaks that are ascribed to fast products of the DR of Ne_2^+, Ar_2^+ and Kr_2^+ ions. When an axial magnetic field is present in the discharge, the relative signal from DR increases relative to the thermal metastables which also increase absolutely. In addition to the major DR peaks, other small peaks appear in the distribution, which can be attributed to the DR reaction, including DR to the ground state.

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** JRP received support from NSF Grant PHY 911872

KB-4 Effect of Temperature on Electron Attachment and Detachment in SF_6 and c-C_4F_6#, P. G. DATSKOS, L. G. CHRISTOPHOROU, and J. G. CARTER, Oak Ridge National Laboratory and The University of Tennessee. - The total electron attachment rate constant for SF_6 and c-C_4F_6 was found to be virtually independent of T, for gas temperatures, T, in the range of 300 to 600 K and for mean electron energies below 1.0 eV. Under the same experimental conditions the stabilized SF_6^- does not undergo autodetachment but the stabilized c-$C_4F_6^-$ undergoes a profound increase in autodetachment (about four orders of magnitude). This difference between the SF_6^- and the c-$C_4F_6^-$ autodetachment can be attributed to the larger electron affinity of the SF_6 molecule compared to c-C_4F_6. The heat-activated autodetachment of c-$C_4F_6^-$ is related to the increase in the anion's internal energy with increasing T and is found to have an activation energy of 0.237 eV.

#Research sponsored by the Wright Laboratory, U.S. Department of the Air Force, under contract No. AF 33615-92-C-2221 with the University of Tennessee and the Office of Health and Environmental Research, U.S. Department of Energy under contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

KB-5 Neutral Dissociation Cross Sections for N_2 and CF_4*, M. R. Bruce, L. Mi, D. Soruco, and R. A. Bonham, Indiana U. - We have employed a method for absolute efficiency measurements of detectors suggested by Srivastava [1]. It consists of measuring the electron energy loss spectrum at a fixed scattering angle in coincidence with all ions produced by an incident electron pulse of fixed energy. The ratio of the number of *coincident* ions to the total number of electrons detected at the same energy loss is the ion detection efficiency of the apparatus if it is assumed that electrons losing more than the ionization potential only produce ions. Difficulties arise with atoms if resonance states in the continuum, which fluoresce to neutral states, occur with significant cross sections. For molecules an additional problem is neutral dissociation. We have used electron-ion coincidence measurements as a means of investigating neutral dissociation. The electron-ion coincidence spectra at 45° and 40 eV impact energy for He, Ar, Kr, N_2, and CF_4 will be reported. Absolute detector efficiencies of 0.46±0.03 for energy loss values above 25 eV were obtained in each case. Ratios of fluorescence to ionization for the rare gases and neutral dissociation to ionization for molecules will be reported.

[1] S. Srivastava, U. S. Pat. Appl.(NTIS Order No. PAT-APPL-7-358 027) * We acknowledge support from NSF grant PHY 9214126

KB-6 Spectroscopic study of nitrogen bombarded by MeV ions of hydrogen. JACINTHE PLANTE and ÉMILE J. KNYSTAUTAS, Dép. de physique, Université Laval, Québec G1K 7P4 - A nitrogen gas target (at various pressures) bombarded by 1 MeV H^+, 2 MeV H_2^+ and 3 MeV H_3^+ ions was studied spectroscopically in the vacuum UV (1200 Å to 2200 Å). Emission spectra were studied as a function of pressure (5 mT, 15 mT, 40 mT) and type of projectile (H^+, H_2^+, H_3^+). The spectra show the presence of atomic nitrogen N I and N II lines, molecular bands of N_2 (a $^1\Pi_g$ - X $^1\Sigma_g^+$) and of N_2^+ (C $^2\Sigma_u^+$ - X $^2\Sigma_g^+$). No emission of Lyman α at 1216 Å was observed in the collision of 1 MeV H^+ on nitrogen but the line was observed in the spectrum of H_2^+ at 5 mT. Other qualitative features in the spectra were noted and considered in terms of primary and secondary collisions.

KB-7 Ion Recombination Coefficients in Noble Gases: Pressure and Temperature Effects, R. COOPER and R.N. BHAVE, School of Chemistry, U. of Melbourne, Parkville 3052, Australia - Ion recombinaison kinetics have been observed by time resolved microwave absorption techniques on pulsed e-beam ionised rare gases. Conductivity decay in weakly ionised gases from 50 to 1500 torr was measured on time scales from 10 nanoseconds to 10 microseconds. Bulk gas pressure and ion densities ensured that recombination coefficients were for dimer cations with thermal electrons. Recombination coefficients have been measured for helium[1] from 50 to 1200 torr and at temperatures from -78 °C to +100 °C. At low temperatures, a distinct third body effect α_3 is observed as well as a two body rate α_2. A negative temperature coefficient for α_3 is observed of $T^{-2.9}$ for helium. For argon[2] no third body effect was observable over the temperature range studied. In neon a very weak third body effect is observed at 20 °C.

[1] R. van Sonsbeek, R. Cooper and R. Bhave, J. Chem. Phys. 97, 1800 1992.
[2] R. Cooper, R. von Sonsbeek and R. Bhave, J. Chem. Phys. 98, 383 1993.

SESSION L: POSTER SESSION

Thursday morning, 21 October 1993
Grand Salon B, 10:15–12:15
G. Sauvé, presiding

LA: SHEATHS AND BREAKDOWN

LA-1 2-D Model of Glow Discharges Including the Cathode Regions and the Positive Column, A.Fiala, L.C.Pitchford and J.P.Boeuf, CPAT, Université Paul Sabatier, Toulouse, France.- Results from a self-consistent 2-D hybrid fluid-particle model are presented to illustrate the electrical behaviour of DC low pressure discharges in the current range 10^{-7}-10^{-1}A in Argon for pd (product of the gas pressure and the gap spacing) from 1 to 3.3cmtorr. The principal results which will be presented include the 2-D distributions of the potential and the charged particle densities (1) during the transition from the Townsend to the normal and abnormal regimes and (2) in the positive column for discharges of 1 and 2cm diameters. The model consists of Poisson's equation coupled to the continuity equations for the electrons and ions with the important feature that the ionisation source term appearing in the continuity equations is determined from a Monte Carlo simulation. This treatement gives a correct physical picture of discharge behaviour over a wide range of conditions.

LA-2 Effects of the Operating Parameters on the Barium Emission and the Electrode Temperature of a Fluorescent Lamp, K. MISONO* and J. T. VERDEYEN, Dept. of Electrical and Computer Engineering, University of Illinois 61801 – The dependence of the neutral and ionized barium emission has been studied as a function of the operating parameters of the lamp such as current, heater power, and operating frequency (6–3000 Hz). Most of the observations utilized a square wave current source, but some comparison was made with the traditional 60 Hz inductive ballast operation. The barium emission intensity is proportional to I^{2-3} except at low current where it increases due to sputtering. When the anode oscillations disappear, the Ba* and (Ba+)* emissions increase rather significantly. These effects are very sensitive to the amount of seasoning of the lamp reaching more or less steady state after ~ 100 hours of operation. One of the major conclusions is that sputtering appears to be more significant for barium loss than is thermal evaporation.

*Visiting scholar from Toshiba.

LA-3 Sheath Models In Glow Discharges-: S. SHANKAR, Tech CAD, Intel Corporation, Santa Clara, California -

The intention of the paper is to compare and contrast between the various simple models that can be used to study the physics of plasma sheaths. These range from simple drift-diffusion models to higher moment models like second and third order moments. It will also be shown that various models can be arranged in a formal hierarchy based on these assumptions. Some of the cases that will be studied include DC discharges: mobility-limited regimes, diffusion-limited regimes, RF discharges: collisionless and collisional sheaths, and Magnetically-enhanced discharges. Validity of some of the existing models will be analyzed using Boltzmann equation simulations that have been done previously. Depending on the assumptions, the models will be used to study different parameter regimes and understand the physics in different regimes. Most of the models will have closed analytic forms for the solutions. Some numerical simulations using finite element techniques will be used to supplement the theoretical analysis. The paper will also examine critically the different models that are used in the continuum approximations to study weakly ionized plasmas.

LA-4 Time-resolved Avalanches in SF_6 under slightly Non-uniform Field, M.F. FRECHETTE, N. BOUCHELOUH, and R.Y. LAROCQUE, Câbles et Isolants, IREQ (HQ) and Ecole Polytechnique - Avalanches in low-pressure SF_6 were investigated in slightly perturbed uniform-field geometry. An avalanche was initiated by means of a short ultraviolet pulse. The UV pulse impinges on the plane cathode, resulting into the release of a large amount of photoelectrons. The plane anode hole by which the beam pervades, produces the geometrical field nonuniformity. The experiment was conducted under DC voltage. It was experimentally shown that the use of small ratios of the gap length over the hole diameter, which ranged from 0.3 to 0.8, perturbed the temporal growth of the avalanche. When compared with avalanches observed in a Pulsed Townsend experiment, the present rate of growth is typically slower. The present experimental conditions, namely large initial currents and slight geometrical field nonuniformity, tend to enlarge the duration of the avalanche while favoring delayed processes.

LA-5 Development of the Cathode Fall in Low Pressure Argon Discharges,* B.M. JELENKOVIĆ** and A.V. PHELPS, JILA, CU and NIST - The temporal and spatial development of the cathode fall of argon discharges was determined for a voltage pulse applied to a radially-uniform, low-current (100 μA) discharge. Typical final pulsed currents were 25 and 2 mA at 0.5 and 2 Torr. The parallel-plane electrodes were 80 mm dia. and separated by 11 mm. The 811 and 750 nm lines monitored the moderate and high energy electrons. The discharge voltage initially increases almost linearly, while the current increases as $I_0 \exp(at^2)$, where I_0 is the current between pulses. The collapse of the electric field and electron energy near the anode produce a drop in the emission from near the anode even though the current is increasing smoothly. The emission peak shifts towards and then away from the cathode as the current and emission increase further and then decrease to their final values. At 0.5 Torr cathode fall development starts at about 2 mA and requires about 2 μs. Spatial scans at 0.5 Torr show strong heavy particle excitation near the cathode once the high field region develops.

* Supported in part by US Air Force, Wright Laboratories.
** Permanent address: Institute of Physics, University of Belgrade.

LA-6 High Voltage Fast Discharge in Pure Mercury for Optimization of 254 nm Radiation, M. GANCIU and G. MUSA, IFTAR Plasma Dept. Bucharest Romania, O. MOTRET, A. KHACEF, C. CACHONCINLLE and J.M. POUVESLE GREMI CNRS/University of Orléans, France - In this work, we used a very compact Blumlein system with surface ferrite discharge preionization working with input voltage around 10 kV and allowing discharges of 25 ns duration with 0.2 J stored energy at 30 Hz. The mercury concentration inside the flash tube (dia : 0.8 cm, electrode separation : 2 cm) was controlled by heating. Despite a strong reabsorption, the total UV fluorescence at 254 nm increases with the concentration up to about 1.5×10^{19} cm^{-3} (maximum concentration for discharge stability in our system). Results were compared with 1 atm xenon discharge in the same experimental conditions. Results showed the possibility of improving the 254 nm UV emission yield in short high voltage thin surface discharge device in hot high pressure pure mercury.

LA-7 A Gas-Discharge Breakdown Model, M.AGACHE, S.LAUBE, M.FITAIRE, LPGP Orsay France - The breakdown of a DC electrical discharge between 2 parallel plates is investigated.The ions, because of their weak mobility, don't play an important role for the secondary emission at the cathode during the prebreakdown. We aim to show that the photoelectric effect may be responsible of the discharge prebreakdown. A numerical 1D simulation, taking in to account the differential cross sections, was used to analyse the electrons and U.V. photons productions (104.8, 106.7nm) in Ar. For values of the product pd > 2mmHg.cm and voltage V coresponding to a Paschen curve[1] for Ar with a Pt cathod the number of photons attending the cathode has been evaluated. Considering the efficiency of the photoelectric effect on Pt we can conclude that the second electron avalanche may be produced by a photo-electron. This leads to time lags of few μs to compare to a few tens of μs in the case of the secondary emission by ionic bombardement. The first Towsend coefficient calculated with this code is in good agreement with the values reported by von Engel[2] for E/p < 1000V/cm/mmHg.

[1]M.Druyvestein, M.Penning, Rev. Mod. Phys. 12, 87(1940)
[2]A.von Engel,Hndbuch der Phys. Springer Verlag,1956,Vol21,pg504.

LA-8 Formative Time Lag in Breakdown of Long Slender Discharge Tubes. JOHN F. WAYMOUTH, 16 Bennett Rd., Marblehead, MA. 01945. The breakdown of long slender discharge tubes takes place as an ionization front propagating from the high potential electrode toward the grounded electrode. This process is modeled as a non-linear RC transmission line in a manner similar to that of Horstman et al.[1] The capacitors consist of the wall capacitances to ground of 1-diameter long segments, while the resistors are the time-dependent resistances of 1-diameter long segments of the plasma column. Initial conditions are: segment resistances Ro very high (though not infinite), inner wall potentials zero (capacitances C uncharged). Breakdown occurs first at the high potential electrode, since E-field in the first resistor segment is high. Ionization frequency is very much greater than 1/RoC; thus, the first segment resistance decreases by factor ca 10,000 before C1 charges nearly to potential of the energized electrode. When C1 has charged, the rate of decrease of R1 slows drastically, while the high field region becomes the second segment and it breaks down in turn.. This mechanism is modeled as a set of difference equations with a spread-sheet program on a personal computer.. Results agree with experiments of Horstman, except that calculated propagation velocity appears to be too fast. I propose that this is caused by electron energy distribution not reaching equilibrium with local field; thus experimental ionization frequency is less than calculated.

[1]R. E. Horstman & F. M. Oude Lansink, J Phys D, **21** 1130 (1988)

LA-9 Suppression of Vacuum Breakdown Using Thin Film Coatings*, C. B. FLEDDERMANN, C. S. MAYBERRY, B. WROBLEWSKI, AND E. SCHAMILOGLU, Dept. of Electr. and Comp. Eng., Univ. of New Mexico- The use of thin film coatings for increasing the breakdown voltage in a parallel-plate high-voltage gap has been investigated. Both metallic and ceramic thin films were deposited at varying thicknesses and deposition conditions on a screen cathode using ion-beam sputtering. Improvements in breakdown voltage were observed for nearly any type of deposited film, with significant variations in breakdown voltage depending on film thickness and oxygen partial pressure during ceramic film deposition. For 500 nm thick metallic or oxide films, breakdown voltage was nearly doubled compared to the bare stainless steel screen, which is attributed to the burying of surface imperfections on the cathode. For 200 nm thick films, the covering of imperfections is less effective; however, high breakdown voltages can still be obtained by choosing an appropriate oxygen partial pressure during film deposition. Electric fields as high as 60 kV/mm were sustained across a 1 mm gap for 10 μsec pulses; lesser fields could be sustained for as long as 10 ms. These coatings alowed for the successful study of a planar liquid metal ion source.

*Supported by Sandia National Laboratories contract No. 69-5698, and partially supported by AFOSR grant F49620-92-J-0157P00001.

LA-10 Ignition Characteristics of the Thin-Wire Discharge,* A.KUTHI, J. R. BAYLESS and C. BURKHART, FPSI - In order to understand the functional dependence of ignition potential on gas pressure, electrode sizes, and geometry a simple phenomenological model for the cylindrical thin-wire discharge has been developed. The model is based on the concept of a voltage-dependent ionization volume. It correctly predicts the Paschen breakdown characteristics of thin-wire discharges in the low-pressure regime, i.e. below the Paschen minimum. The ignition voltage strongly depends on the diameters of both the anode wire and the cathode cylinder. The dependence of ignition voltage on cathode material is shown to be weak. Experimental data using 0.0125 cm diameter tungsten wire as the anode running along the center of a 5 cm x 2.5 cm cross-section, 20 cm long copper cathode box is in agreement with the model when the working gas is air. However, the measured thin-wire Paschen minimum for helium is 50% higher than the corresponding plane electrode Paschen minimum voltage required by the model.

*Work supported in part by NSF.

LA-11 Voltampere characteristics from SPEAR III.* J. BENSON, E. E. KUNNHARDT and S. POPOVIC, Polytechnic University and Stevens Institute of Technology- SPEAR III is rocket-based space experiment which includes a study of several different mechanisms for discharging a negative charged spacecraft to plasma potential i.e. "grounding". The vehicle body was driven to a high negative potential by biasing a separate conductive sphere positive. Four different grounding techniques were applied: hollow cathode discharge, neutral gas release, thermionic emission and field emission. We have performed the analysis of data collected during glow discharge enhancement by the neutral gas releases at various altitudes and attitudes with respect to the Earth's magnetic field. The results will be compared with the laboratory experiments and theoretical predictions.

* Work supported by SDIO/DNA

LA-12 Comparisons between 1.5D and 2D Simulations for Gas Pre-breakdown,* Jing-Ming Guo and Chwan-Hwa "John" Wu, Department of Electrical Engineering, Auburn University. The nitrogen gas pre-breakdown phenomena under homogenous external conditions has been respectively studied by the following four models: 1) 1.5D equilibrium fluid model; 2) 1.5D nonequilibrium fluid model; 3) 2D equilibrium fluid model; and 4) 2D nonequilibrium fluid model. In order to provide the solution with steep and varying gradients in large dynamic ranges, a More Accurate Flux-Corrected Transport (MAFCT) technique is adopted to solve the electron fluid equations[1]. The streamer speed in 1.5D simulations depends on the ionization channel radius and the streamer speed increases as the channel radius increases. The 2D models is used to assess the validity of 1.5D models. A more accurate way to decide the radius is adopted in this paper and it is compared with the 2D model. From the study, it is unrealistic to ignore the change of the electron density, the electric fields, the electron average velocity, and the electron mean energy along the radial axis, which play relatively important roles in streamer development.

*Work supported by NSF under ECS-9009395.
[1]E. E. Kunhardt and C. Wu, J. Comput. Phys. 68, 127 (1987).

LA-13 Discharge Pumped Resonant VUV Emission Sources Based on Rare Gas Mixtures, A.I. IVANOV , A.G. ZHIDKOV, Russian Academy of Sciences, General Physics Institute 117942 GSP-1 Moscow B-333, Vavilov Street, 38 - During a long time, rare gas mixtures have been used as active media for laser and gas discharge emission sources. From the viewpoint of VUV emission generation, resonant levels of rare gases are of special interest, because the essential power density of the emission can be achieved under relatively low pressure (0.01-1 atm) and pumping power (of the order of 1-10 W/cm^3). This allows one to use such VUV emission sources in both laser techniques and adjacent fields: pulse or, more importantly, continuous discharge devices. This work is devoted to the theoretical study of the kinetics of rare gas binary mixtures pumped by electric discharge at up to atmospheric pressure. Special attention is payed to He-Kr mixture, whose kinetics have been studied insufficiently.

LA-14 Streamer Formation in Coronal Discharges,* P.A. VITELLO, B.M. PENETRANTE and J.N. BARDSLEY, LLNL - Filamentary streamer discharges are of current interest due to their application to pollution control devices. Streamers produce non-thermal energetic electrons which, through dissociation and ionization processes, generate active radicals that in turn react with toxic molecules. For a given chemical gas mixture, the energy distribution of the electrons produced as the streamer bridges the gap between the electrodes is determined by the spatial and temporal evolution of the streamer. Streamers propagate due to a highly non-linear space charge driven ionization wave. We have developed a multi-dimensional coronal discharge model that can be applied to arbitrarily shaped electrode structures. We have applied this code to study some of the issues related to finding the optimum working conditions for streamers in corona discharges. We show for a point-to-plane electrode geometry in air how a coronal discharge evolves, as a function of gap voltage, from a diffuse to a filamentary streamer discharge.

*This work was performed at LLNL under the auspices of the U. S. DOE under Contract Number W-7405- ENG-48, with support from the Advanced Energy Projects Division of the Office of Energy Research.

LB: ION TRANSPORT AND ION-MOLECULE COLLISIONS

LB-1 Collision-Induced Dissociation and Charge Transfer Reactions of SiF_x^+($x = 1 - 4$). Thermochemistry of SiF_x and SiF_x^+. ELLEN R. FISHER, BERNICE L. KICKEL, AND P. B. ARMENTROUT, U. of Utah - Guided ion beam techniques are used to measure cross sections as a function of kinetic energy for interaction of Xe with SiF_x^+ ($x = 1 - 4$) ions. Energy dependences of the collision-induced dissociation cross sections are analyzed to yield the following 0 K bond dissociation energies (BDEs): $D(SiF_3^+\text{-}F) = 0.85 \pm 0.16$ eV, $D(SiF_2^+\text{-}F) = 6.29 \pm 0.10$ eV, $D(SiF^+\text{-}F) = 3.18 \pm 0.04$ eV, and $D(Si^+\text{-}F) = 7.04 \pm 0.06$ eV. The ionization energies, $IE(SiF_2) = 10.84 \pm 0.13$ eV and $IE(SiF_3) = 9.03 \pm 0.05$ eV, are also measured from analysis of endothermic charge transfer reactions. From these BDEs, measured IEs and previous results,[1,2] we derive heats of formation for the silicon fluoride cations and neutrals.

1. M. E. Weber and P.B. Armentrout, J. Chem. Phys. 88, 6898 (1988).
2. B. L. Kickel, E. R. Fisher and P. B. Armentrout, J. Phys. Chem., submitted.

LB-2 Electron Capture in Collisions of He^+ Ions with CO Molecules below 100 eV.* M. KIMURA, Argonne National Laboratory and Rice U., N. F. LANE, Rice U., and A. DALGARNO, Harvard U. -- Electron capture in He^+ + CO collisions is considered to be one of the dominant processes causing He^+ ion disappearance in the astrophysical environment [1]. We have investigated this process theoretically by using the diatomics-in-molecules (DIM) method for adiabatic potential surfaces and the quantum-mechanical close-coupling method for collision dynamics. Because of the strong dipole moment of CO, the adiabatic potential surfaces are strongly dependent on the molecular orientation of the CO molecule along the collision plane, and collinear formation of He^+-CO is most effective for electron capture.

* Supported by the U.S. Department of Energy, Office of Energy Research, Office of Health and Environmental Research, under Contract W-31-109-ENG-38 (MK), and Office of Basic Energy Sciences (NFL and AD).

1 S. Lepp, A. Dalgarno, and R. McCray, Ap. J. 358, 262 (1990).

LB-3 **The Modified Adiabatic Invariance Method for Thermal Ion-Dipole Molecule Reactions***, M. R. Flannery[†] and X. Qi[‡], *ITAMP, Harvard – Smithsonian[†] and School of Physics, Georgia Tech.*[††] A new modification to the semiclassical adiabatic invariance method (AIM) is presented to compute thermal energy rate coefficients for capture of various atomic and molecular ions by diatomic and triatomic molecules with permanent dipole moments. Results are presented for the following ion-molecule systems: He^+, C^+, and H_3^+ ions reacting with polar HCl molecules; and H^+, C^+, O^+, HCO^+, and H_3^+ ions with HCN molecules. The present modification of the AIM accounts for the coupling of the internal rotational angular momentum (j) of the target molecule to the orbital angular momentum (ℓ) of the projectile ion about the center of mass of the target molecule, and is most important in the limit of light ion mass or weak ion-molecule interactions.

* Work supported by AFOSR grant no. 89-0426 and partially supported by an NSF grant via ITAMP at Harvard.

LB-4 Ion-Molecule Reactions at High Temperatures. M. MENENDEZ-BARRETO, J. F. FRIEDMAN, T. M. MILLER, A. A. VIGGIANO, R. A. MORRIS, and J. F. PAULSON, USAF Phillips Laboratory, Geophysics Directorate - Reactions of O^- with H_2, D_2, and CH_4 have been studied in a flowing afterglow in the temperature range 300-1300 K. The reaction rate coefficients k measured for O^- + H_2 and D_2 versus temperature follow the trend observed[1] previously for the translational energy dependence of the reaction rates; apparently, rotational energy is unimportant in the reaction. The k values for O^- + CH_4 are found to decrease (by about 50%) between 300-1300 K. The translational energy and temperature dependences of k match up to 0.09 eV. It is not yet clear, within the scatter in the data at the highest temperatures, if the thermal rates show the beginning of a subsequent increase in k that was found with translational energy.[2] The problems associated with high temperature operation will be discussed.

[1]A. A. Viggiano, R. A. Morris, C. A. Deakyne, F. Dale, and J. F. Paulson, *J. Phys. Chem.* **94**, 8193 (1990) and **95**, 3644 (1991), and references therein.
[2]W. Lindinger, D. L. Albritton, F. C. Fehsenfeld, and E. E. Ferguson, *J. Chem. Phys.* **63**, 3238 (1975).

LB-5
Absolute Differential Cross Sections for keV-energy Collisions between Ions, Neutrals and Molecules, R. S. Gao, B. G. Lindsay, G. J.

Smith, K. A. Smith, and R. F. Stebbings, Rice University*. We have measured absolute angular scattering cross sections for collision processes including angular scattering, charge exchange, stripping, and electron capture in the energy range between 500 and 5000 eV. Projectile species include H, H^+, O, O^+, He and He^+. Targets include H_2, N_2, O_2, and rare gases. In many instances these data are the only absolute angular scattering data available. We will review these measurements in the light of their application to discharge phenomena.

*Supported by the Robert A. Welch Foundation, NASA, and the NSF Atmospheric Sciences Section.

LB-6 Heavy Ion Beam Induced Charge Transfer in Ar-Cs Mixtures,* D. E. MURNICK, Rutgers U., Newark, NJ 07102, R. GERNHÄUSER, A. ULRICH, W. KRÖTZ, J. WIESER, Tech. U. München, Germany - In situ production of target ions in cold, dense matter by heavy ion collisions and subsequent selective charge transfer may provide an effective pumping scheme for heavy ion beam pumped lasers. Charge transfer from cesium atoms to doubly charged argon ions was used for selective population of 4d-levels in Ar II. The argon ions were produced in an argon-cesium gas target by a pulsed beam of 100 MeV $^{32}S^{8+}$ ions from the Munich Tandem van de Graaff accelerator. The ion beam of 12×10^6 ions/pulse had a pulse width of 2 ns and a repetition rate of 32 kHz. The argon pressure was typically 250 mbar. The cesium partial pressure was adjusted by heating the gas target, including a cesium reservoir, to temperatures between 250 and 500^{0}C. Time resolved wavelength spectra showed large intensity increases corresponding to 4d ^4D and 4d ^4F to 4p transitions in Ar II in the ultraviolet wavelength region between 300 and 400 nm. This is interpreted as a resonant charge transfer of outer electrons of cesium to 4d levels in Ar II in Cs^0+ Ar^{2+} collisions.

*Work supported in part by the German Ministry of Research and Technology (BMFT).

LB-7 Hydrogen Atom and Ion Source, R.J. SEVERENS, M.J. DE GRAAF, Z. QING, D.K. OTORBAEV, R.P. DAHIYA, J. WEVERS, R.F.G. MEULENBROEKS, M.C.M. VAN DE SANDEN, and D.C. SCHRAM, Eindhoven Univ. Techn. - High intensity hydrogen atom and ion beams can be obtained by expansion of a cascade arc plasma in a low pressure vessel. At intermediate ambient pressure, anomalous recombination results from charge exchange of H^+ with H_2^v to H_2^+, conversion to H_3^+ and subsequent dissociative recombination. The required H_2^v reenters the atomic plasma beam from wall association and recirculation. At lower pressure (10 Pa) in a confining magnetic field this recombination is much less effective and a highly ionized plasma beam results; then the ro-vibrational excitation of the residual $H_2^{v,r}$ molecules favour negative ion formation. Applications in ion sources and archaeological artefact restauration are discussed.

LB-8 Effect of Excitation Energy Loss on the Transport Property of Ions in Gas N.Ikuta and S.OKUDA Tokushima Univ.Jpn.--- Ion transport properties in model gases having a constant total collision cross section (CCS) are analysed replacing a part of CCS to excitation cross sections by using the FTI method[1]. Isotropic scattering only in the center of mass frame is assumed for both the elastic and inelastic collisions but excluding superelastic collisions. In the thermal region, the mean energy is lowered from the thermal energy due to excitation energy loss, but mobilities naturally have high values to recover the mean energy. The mean energy completely recovers to a value of only elastic collision in a high E/N value. Such variations with the recovering effect is given with the balance of gain and loss rates in the momentum and energy through a loop of flight and collisions. Wannier's energy[2] will largely depart from the true value of mean energy in such situations of "low energy and high drift velocity". However, note that the recovering effect works well in conditions "$d\nu/\varepsilon > 0$" with highly anisotropic velocity distributions. Superelastic collisions with the principle "detailed balance" may markedly reduce the recovering effect.

1) N.Ikuta, E.Nishi and S.Nakajima: J.Phys.Soc.Jpn. 61(1992)4425.
2) G.H.Wannier: Bell System Tech.J.,Jan.(1953)170.

LB-9 Dependences of Ion mobility on Masses of Ion and and Gas. N.IKUTA and T.KAWABATA, Tokushima Univ.Jpn. ----- Transport properties of ions in model gases are analysed using the flight time integral (FTI) method[1] taking into account the mass ratio between an ion and a gas atom, R:1/1, S:4/1 and T:1/4, referred to He atom. Here, S and T have the same reduced mass 4/5. A constant collision cross section is assumed throughout this work. Isotropic scattering in the center of mass frame (ISCM) which demands anisotropic scattering in the Labo frame is assumed, and anlysis is executed with an extended FTI procedure. Ion mobility curves are commonly dependent on (a): the mean collision frequency propor-tional to the mean relative speed, (b): mean accelera-tion in a flight which is dependent on ion mass, and (c): residual forward velocity moment after scattering in ISCM which is dependent on the mass ratio. The ion transport properties in various mass ratios vary as complex functions of E/N and conditions above descrived, and the data in R, S and T draw independent mobility curves in several view points. Nevertheless, the outline of them obeys the basic transport property in a constant collision cross section. Details will be shown at the conference.

1) N.Ikuta, E.Nishi and S.Nakajima: J.Phys.Soc.Jpn. 61(1992)4425.

LB-10 Relations between Interaction Potentials and Ion mobility Curves N.IKUTA, Tokushima Univ.Japan----- Reduced mobility curves of ions in gases have been analysed theoretically estimating the interaction potential in such forms as $V(r) = C_1r^{-12} - C_2r^{-4}$. The long range interaction potential due to induced dipole $-C_2r^{-4}$ gives the momentum transfer and integral cross sections both inversely proportional to relative velocity v_r in a low range. Accordingly, ions must have a constant mobility independent of ion and gas temperatures. However, it is well known that the Langevin limit given by the polarizability of gas is valid only in very low E/N and in very low gas temperature. Furthermore, the zero-field mobility reported often do not agree with the Langevin limit[1]. On the other hand, the constant mobility in the low E/N thermal region[2] are proved to be given by the thermal motion of gas atoms with positive and negative dependencies on gas temperature. We consider, therefore, that the dipole potentials might not work effectively on the ion transport property even in a thermal region but also in a high E/N region as are observed in mobility curves forming a hump or a fall without a hump.

1) H.Tanuma et al.:Sect.Meeting,Phys.Soc.Jpn.27aZK11(92).
2) N.Ikuta,E.Nishi and S.Nakajima: J.Phys.Soc.Jpn.61 (1992)4425.

LB-11 Ion Transport Properties under Constant Collision Frequency E.HOLCOMB, S.OKUDA and N.IKUTA Tokushima Univ.Japan ----- Recently, transport properties of ions have been analysed by using the Flight Time Integral

(FTI) method assuming isotropic scattering in both the CM and Labo frames[1] (ISCL). Transport properties of ions in gas of the same mass as He with a Maxwellian distribution at 300K have been analysed accurately using the assumption of a constant collision frequency (CCF) with an extended FTI method adequate for isotropic scattering in the CM, consequently anisotropic in the Labo frame. Starting velocity distributions with anisotropic components have been obtained from the velocity dispersion functions and the relative velocity v_r with respect to gas atoms. The drift velocities obtained are prortional to E/N with values twice those of the previous data (ISCL) due to the forward components of the starting velocities used in this analysis for the first time. Wannier's energy accurately agrees with the mean energy in flight, and quite clear relations among the various quantities and the drift velocity are obtained. Detailed comparisons with those under constant collision cross section (CCS) are also performed.

1) N.Ikuta,E.Nishi and S.Nakajima: J.Phys.Soc.Jpn.61 (1992)4425.

LB-12 Ion Swarm Analysis in Dynamic Equilibrium, K. IINUMA, N. SASAKI, and M. TAKEBE, Tohoku U., Yamagata U., JAPAN - A mathematical analysis of dynamic equilibrium for an arbitrary number of ion swarms drifting, diffusing, and inter-reacting in a neutral gas has been developed for the first time. An asymptotic solution derived from a general solution of a coupled transport equations[1] describes a set of similar Gaussian profiles with two common "equilibrium" transport coefficients which are functions of the drift velocities, diffusion coefficients, and reaction-frequency determinants. Although all the arrival time spectra apparently aggregate to the same location, there exists a slight peak difference between arbitrary two spectra. The difference holds even in the equilibrium. The discrepancy between thermal equilibrium and dynamic equilibrium is ascribed phenomenologically to the appearance of the peak difference. A generalized equilibrium constant for ion-molecule reactions is defined by a quotient of two reaction-frequency determinants. Those four kinetic constants can uniquely be determined by the transport coefficients and reaction frequencies of all ion species without any influence of the initial conditions.

1. K. Iinuma, Can. J. Chem. 69, 1090 (1991).

LB-13 Fast Beam Photofragmentation Dynamics of $H_2(i\ ^3\Pi_g\ v=4)$, B.R. CHALAMALA*, E.R. WOUTERS and W.J. VAN DER ZANDE, FOM Inst. Atomic Molecular Phys., Amsterdam - The decay of several quasibound rotational levels of $H_2(i\ ^3\Pi_g\ v=4)$ is investigated experimentally using fast neutral beam photofragmentation spectroscopy.[1] A fast 4-6 keV beam of metastable H_2 is formed by the charge transfer of H_2^+ on cesium. An intracavity CW dye laser excites the $H_2(c\ ^3\Pi_u^-, v=4)$ molecules to the i $^3\Pi_g$ electronic state. The excited i $^3\Pi_g$ decay by photon emission to the repulsive b $^3\Sigma_u^+$ state or by barrier tunnelling. Upon dissociation, the fragments scatter out of the beam and are detected on a two-particle time and position sensitive detector. From these coincidence measurements, we determine the positions of the fragments (R1, Φ1, R2, Φ2) with respect to the center of the detector and their fligth time difference (τ). These observables then yield the kinetic energy of the hydrogen fragments (ε) and the angle of dissociation with respect to the fast beam (Θ). From the kinetic energy release spectra, we determine the branching between fluorescence before and after barrier tunnelling.

* Permanent address: Dept. Phys., U. N. Texas, Denton, TX 76203.

[1] H. Helm, D.P. de Bruijn, J. Los, Phys. Rev. Lett. 53, 1642 (1984).

LB-14 Toward Detailed Correct Kinetics of Rare Gas Halide Active Media: Accurate Analytical Potentials and Related Properties of R'RX Molecules with Application to RXeF* (R=Ne, Ar, Kr), F.Y. NAUMKIN, V.G. PEVGOV, General Phys. Inst., Moscow - Accurate analytical potentials have been derived for arbitrary R'RX systems with spin-orbit coupling included. Three combinations of 3 potentials arise from interaction of ground state rare gas R' atom with rare gas halide RX molecule in $^2\Sigma_{1/2}^+$, $^2\Pi_{3/2}$ and $^2\Pi_{1/2}$ states. For ArXeF* molecule, emphasis has been placed on respective B, C, D states of XeF* interacting with Ar. Polarization bond of Ar in field of Xe^+ - F^- dipole reaches 0.1 eV maximum value on normal to Xe-F axis at re=3A of Ar-XeF separation, all equilibrium distances (re's) being almost unperturbed from those of isolated diatomics. To consider temporal dynamics of excited states in terms of their diabatic potentials, a simple perturbation theory treatment is proposed. Corresponding effects on radiative lifetimes are evaluated. All above properties are considered also for NeXeF* and KrXeF*.

LB-15 Electron Detachment and Charge Transfer in Low Energy Collisions of Na^- with Atomic Hydrogen, J.A. FEDCHAK, R.L. CHAMPION and L.D. DOVERSPIKE, College of William & Mary, and Y. WANG, University of Notre Dame Radiation Lab - Cross sections for electron detachment and charge transfer have been measured for the system Na^- + H in the relative energy range 3 < E_{cm} < 20 eV. The electron detachment cross section decreases from about 30 Å^2 at E_{cm}=8 eV to 20 Å^2 at 18 eV. An absolute scale could not be experimentally determined for the charge transfer channel, but the cross section is seen to increase by a factor of five between E_{cm}=5 and 15 eV. In order to establish a scale for the charge transfer channel, a perturbed stationary state (PSS) calculation was performed and predicts the cross section to be less than 0.02 Å^2 over the energy range investigated.

LC: ELECTRON TRANSPORT AND COLLISIONS

LC-1 Absolute and Relative Optical Oscillator Strength Determinations for the Group IV Tetrafluorides with Zero Angle Electron Energy Loss Spectroscopy,* M. DILLON, D. SPENCE and K. KUROKI, Argonne National Laboratory, Argonne, IL - Energy loss spectra using incident electrons of 200 eV and recorded at zero scattering angle have been determined for CF_4, SiF_4, and GeF_4. The range of energy losses (∼ 20 eV) includes all transitions out of the upper valence shells. The upper valence shells of each of the tetrafluorides has an electronic configuration and ordering { $(a_1)^2\ (t_2)^6\ (e)^4\ (t_2)^6\ (t_1)^6$ } consisting of predominantly lone-pair electrons. The zero-angle spectra were first transformed to relative optical absorption spectra by employing an electron optical conversion function valid for circular orifices. Where possible these were normalized to a previous measurement and compared with determinations found in the literature. Orbital assignments and ionization potentials are also included. The former were determined from a combination of *electron energy loss* and *vacuum ultraviolet* spectroscopies.

* Work supported in part by the U.S. Department of Energy, Office of Environmental Research under contract w-31-109-Eng-38

LC-2 Lifetime of $A^3\Sigma_u^+$ State of N_2 in the Afterglow of Nitrogen Pulsed Discharge, * E.AUGUSTYNIAK and J.BORYSOW, Physics Department, Michigan Tech. University – The absorption time transients and populations of $N_2(A^3\Sigma_u^+)$ were measured, using a high resolution laser absorption technique ($B^3\Pi_g(v'=2) \leftarrow A^3\Sigma_u^+(v''=0)$) in a pure nitrogen pulsed discharge. The experiment was performed at various pressures (0.25 - 1.25 Torr), discharge currents (0.4 - 1.3 Amp), pulse durations (5 - 40 μs) and repetition rates (5 - 500 Hz). The lifetimes and populations are in the range 100 - 470 μs and $(0.5 - 4.7) \times 10^{12}$cm^{-3}, respectively. The postulated, parameter free, model describes the measured lifetimes within an experimental error. The model takes into consideration the loss of $N_2(A)$ metastables due to energy pooling, quenching by nitrogen atoms and diffusion. At high excitation (0.5 Torr, 1 Amp, 30 μs pulse, 24 Hz) quenching of $N_2(A)$ is caused mostly by atoms (50%) and diffusion (40%).

* Supported by The National Science Foundation and State of Michigan Research Excellence Fund.

LC-3 Electron Transport in Hydrocarbon - Rare Gas Mixtures * A. A SEBASTIAN and J. M. WADEHRA, Wayne State University. --- We have recently applied an extended version of our novel algorithm[1] for exactly solving the Boltzmann equation to the problem of electron transport in mixtures of simple hydrocarbon gases with argon, neon and krypton subjected to externally applied electric fields. It is observed that the values of the electron swarm parameters for these mixtures exhibit a great deal of sensitivity to the relative concentration of the hydrocarbon component. For the case of ethane gas, when mixed with these rare gases, we have calculated the drift velocity, average energy and the ratio of the longitudinal diffusion coefficient to the mobility (characteristic energy). In the collision term to the Boltzmann equation we have included the contributions of momentum transfer, vibrational excitation, ionization and dissociation cross sections. It also is of interest to note that both the rare gases and the hydrocarbon gases we have investigated possess a Ramsauer minimum in their elastic cross sections. The sensitive nature of the swarm parameters to relative concentration is due in part to the overlap of vibrational cross sections with these R/T minima.

*Support of the AFOSR (F49620-92-J-0027) is gratefully acknowledged.

1. Drallos P.J. and Wadehra J.M.,*Phys.Rev.A.* 40, 1967 (1989)

LC-4 **Drift Velocities of Gas Mixtures from Electrical Insulation Used in Low Pressure Environments**, D. L. SCHWEICKART and A. GARSCADDEN, Wright Laboratory, W.P.A.F.B., OH - Several practical issues must be considered when solid electrical insulation is used in a low pressure environment. The physical basis for charge transport in the gaseous medium, which inevitably accompanies the solid insulation, is important from a reliability viewpoint. A methodology was established to enable the measurement of drift velocities and an original version of a pulsed-Townsend drift tube was designed, constructed and instrumented. The gases investigated were not specific to any one polymeric insulation, but instead covered a range of typical polymers. Drift velocities were measured in a broad range of synthesized binary mixtures chosen from the three molecular gases (CO_2, CO, N_2O) and Ar. In general, the measurements were made within the E/n range from 0.5 to 500 townsends. In most instances the drift velocities of the molecular binary mixtures are shown to scale linearly with the ratio of partial pressures in the mixture. However, certain mixtures (CO_2/CO, Ar/CO) exhibited a synergistic drift velocity enhancement which is believed to be attributable to the interaction between the respective elastic and inelastic collision processes.

LC-5 Electron collision cross sections for H_2 II, H. ITOH, H. WADA# and N. IKUTA*, Chiba Inst. of Tech., Furukawa Electric Co.Ltd. #, Tokushima U. *, Japan---It is now an open but serious problem that the vibrational excitation cross sections of H_2 molecule theoretically obtained by Morrison[1] and that deduced by England[2] from the swarm data disagree to each other. The results of beam experiment, on the other hand, agree with the theoretical cross section[3]. Examinations in order to find the cause of these discrepancies have been carried out using the FTI method[4]. We obtained the cross sections which fit to the drift velocity data and the D_T/μ data independently, but it has been impossible to obtain a cross section that fits to both of them. Theoretically derived cross section for vibrational excitation by Morrison can not give swarm parameters that agree with the data of swarm experiments. These facts show that there may be a fault in the present swarm theory. A possible cause of errors is the anisotropy in scatterings[5] which has not been strictly included to the analyses.

[1]M. A. Morrison et al:Aust. J. Phys., 40(1987)239.
[2]J. P. England et al:Aust. J. Phys., 41(1988)573.
[3]H. Ehrhardt et al:Phys. Rev., 173(1968)220.
[4]N. Ikuta and Y. Murakami:J. Phys. Soc. Jpn., 56(1987)115.
[5]N. Ikuta and H. Gotoda:8th Swarm Seminar, (1993).

LC-6 Measurement of Electron Impact ionization and attachment coefficients in NO_2/He Mixtures and derived electron collision cross sections for NO_2, Y.Sakai, Y.Okumura, S.Sawada and H.Tagashira, Department of Electrical Engineering, Hokkaido University, Sapporo 060 Japan

The electron impact ionization α/p_{20} and attachment coefficients η/p_{20} in NO_2/He mixtures with various fractional partial pressure K of NO_2 are measured by a steady-state Townsend method for E/p_{20} up to 500 V/cm/Torr. The α/p_{20} depends significantly on K, since α/p_{20} in NO_2 is smaller than that in He for $E/p_{20} < 200$ V/cm/Torr, but the former > the latter for $E/p_{20} > 200$ V/cm/Torr. The η/p_{20} in NO_2 decreases strongly with increasing E/p_{20}, on the contrary the η/p_{20} for K < 0.8, the decreasing tendency of α/p_{20} against E/p_{20} is very small. It and decreases with decreasing K. From these data we derived a set of the electron collision cross sections for NO_2 using a Boltzmann equation so as to obtaine good agreement between the calculated α/p_{20} and the measured ones. The cross section are fundamentally modified from available data for N_2O.

LC-7 Validity of Cross Sections Derived from D_T/μ Data under Anisotropic Scattering Conditions, K.YAMAMOTO and N.IKUTA*, Shikoku Univ. and Tokushima Univ*. Japan ----A series of calculations to test the validity of the Boltzmann equation analysis with momentum transfer cross section q_m is performed by FFT Monte-Carlo simulation[1)]. Differential model cross sections of Reid[2)] and of Haddad et al.[3)] with pronounced backward and the inverted forward dominated scatterings are used under constant q_m in both the elastic and inelastic collisions. The results are discussed here. While the mean energy and the drift velocity vary slightly with the change of anisotropy in scattering, the transverse diffusion coefficient D_T significantly varies with the change of integral cross section in relation with the change of anisotropy. This fact shows that the usual analyses of the Boltzmann equation are invalid in D_T if anisotropic scatterings exist. ND_T cannot be determined solely by the reduced field E/N but varies with the anisotropy in scaterings. Therefore, the collision cross sections so far derived from D_T/μ data may have to be reanalysed.

1) N.Ikuta,K.Yamamoto et al.:J.Phys.Soc.Jpn.54(1985)2485
2) Ivan D.Reid: Aust.J.Phys.32(1979)231.
3) G.N.Haddad,S.L.Lin and R.E.Robson: Aust.J.Phys.34 (1981)243.

LC-8 Experimental determination of cross sections for emission of H_γ and CH(A-X) lines in e + C_3H_8 collisions in a plasma carburizing furnace,* G. SULTAN and G. BARAVIAN, LPGP CNRS, U. of Paris-Sud, Orsay France, - Optical emission spectroscopy which was used as diagnostic, characterization and control technique of the H_2-C_3H_8 plasma in a BMI reactor for carburization of metallic parts allowed the determination of some cross sections of interest in the formation of radiative species created from discharge dissociation of C_3H_8. The discharge conditions were varied with the respective concentrations of the mixture propane-hydrogen. The current density was equal to about 1 mA/cm^2 , the total pressure 1 Torr, and the flow rate 5 l/mn. The study of the relative intensities of the CH line at 431.4 nm and the H_γ line at 434 nm versus the concentration of propane leads to the cross sections for emission of H_γ and CH($A^2\Delta - X^2\Pi$) in e + C_3H_8 collisions. These values are respectively included in the range 2.2 10^{-21} - 1.1 10^{-20} cm^2 for H and 1.3 10^{-21}- 6.5 10^{-21} cm^2 for CH. This method also applies to the determination of cross sections by electron impact creation of excited C, CH and H species.

* Work supported in part by EDF.

LC-9 Dissociative Attachment to Vibrationally Excited H_2 Molecules as the Principal Mechanism for H^- Formation in Hydrogen Discharges,* J.R. Hiskes, LLNL, Univ. of CA, Livermore, CA–Several mechanisms have been proposed for H^- formation in a hydrogen discharge. The lack of essential theor. and exp. data has made a specific identification difficult since both vibrational distributions and negative ion densities must be known for a modelling comparison with experiment. Eenshuistra et al.[1] report both $H_2(v)$ and H^- concentration observed in a medium density discharge. Principal excitation processes included in this analysis are thermal resonant and fast electron excitation throughout the full vibrational matrix and molecular-ion surface recombination. Principal de-excitation include $b^3\Sigma_u(v)$ and fast-electron excitation and ionization, $H_2(v)$ surface and V-T relaxation. H^- equilibrium forms via DA, detachment and recomb. processes. Variations in modelling results are expressed in terms of both rate processes and exp. density uncertainties. The solutions presented here represent the first successful comparison of both $H_2(v)$ and H^- concentrations with exp. and confirm the $H_2(v)$ - DA process as the principal mechanism.

*Work performed at LLNL, under the auspices of the U.S. DOE under contract W-7405-ENG.

[1]P.J. Eenshuistra, R.M.A. Herren, A.W. Kleyn, and H.J. Hopman, Phys. Rev. A40, 3613 (1989).

LC-10 **Covariant Matrix Mass Spectra of CF_4*, M.R. Bruce, L. Mi, and R.A.Bonham, Indiana U.** -.We report a covariant matrix mass spectroscopic study of CF_4 using pulsed electron beam time-of-flight mass spectroscopy. The frequency of detecting two ions in the same experiment is plotted with the flight time of the fastest ion on the horizontal axis and the flight time of the second ion on the vertical axis. Correlated events (two ions from the same parent) show up as elliptically shaped objects while uncorrelated events (different parents) are circular. Contour maps of frequency vs. flight times with 3 % statistical accuracy will be shown for the reactions $CF_4^{2+} \rightarrow CF_3^+ + F^+$; $CF_2^+ + F^+ + F$; $CF^+ + F^+ + (F_2$ or 2F); and $C^+ + F^+ + (F_2 + F$ or 3F). Because of the increased sensitivity of the method, a number of new break up processes have been identified and their appearance potentials have been observed. A vertical exponentially decreasing tail extending to higher mass, was observed on the $CF_3^+ - CF_3^+$ accidental coincidence peak. A fast CF_3^+ ion is followed by a slower CF_3^+ ion, probably from the break up of a long lived CF_4^+ ion. The appearance potential is close to 15 eV and its lifetime is less than 1 μsec compared to 15±3 μsec reported by Schmidt et al [1].

[1] M. Schmidt, R. Seefeldt, and H. Deutsch, Int. J. Mass Spec. Ion Proc. 93, 141 (1989). * We acknowledge support from NSF grant PHY 9214126.

LC-11 **Appearance Potentials of Positive Ions Produced by Electron-Impact Dissociative Ionization of SF_6, SF_5Cl, S_2F_{10}, and SOF_2**, K. L. STRICKLETT, J. M. KASSOFF, J. K. OLTHOFF, and R. J. VAN BRUNT, *NIST* — Appearance potentials (APs) of positive ions produced in the ion source of a quadrupole mass spectrometer by electron collision with the molecules SF_6, SF_5Cl, S_2F_{10}, and SOF_2 are measured. The electron-energy scale is calibrated by comparing the ion onset energies with the observed onset of Ar^+ from argon mixed with the sample gases. The APs of the fragment ions from SF_6 are in agreement with previous results.[1] In the case of S_2F_{10}, which has a mass spectrum at 70 eV nearly identical to that of SF_6, the APs of the predominant fragment ions are found to be significantly lower than the corresponding ions from SF_6, e.g., SF_5^+ and SF_3^+ appear respectively at 13.2 and 13.3 eV from S_2F_{10} and at 15.7 and 19.7 eV from SF_6. The relevance of these results to the use of mass spectrometry for detection of discharge by-products in SF_6 is discussed.

[1]B. P. Pullen and J. A. D. Stockdale, *Int. J. Mass Spectrom. Ion Phys.*, **19**, 35 (1976).

LD: INDUCTIVELY COUPLED PLASMAS II

LD-1 ANALYTIC MODELING OF RF INDUCTIVE SOURCES V. VAHEDI, G. J. DIPESO, T. D. ROGNLIEN and D. W. HEWETT Lawrence Livermore National Laboratory, Livermore, CA 94550 - We have developed a two-dimensional ($R - Z$) analytic model of an RF inductive source based on magnetized diffusion theory. For a given profile of B_r, the radial component of the magnetic field, all the other electromagnetic field components are calculated. A diffusion equation is then solved to obtain the two-dimensional profiles of the ion density and power density deposited into the electrons. To determine the electron temperature, T_e, and plasma density, n_0, we also solve particle and power balance equations. We will show a comparison between the analytic results and self-consistent simulation results from the code ZMR [1, 2].

This work performed by LLNL under DoE contract No. W-7405-ENG-48.

1. D. W. Hewett, *J. Comp. Phys.* **38**, 378 (1980).
2. D. W. Hewett, G. J. DiPeso, V. Vahedi, and T. D. Rognlien, "Self-Consistent Fluid Simulation of RF Inductive Sources," to be presented at this conference.

LD-2 A 1-D Fluid Model of a High Density, Low Pressure Chlorine Discharge, J. D. Bukowski and D. B. Graves, Dept. of Chemical Engineering, U.C. Berkeley -
We present a 1-D fluid model of a high density, low pressure chlorine plasma. We have investigated issues such as degree of dissociation, electron attachment, and ion-ion recombination at these low pressures, and their effects on plasma properties. The advantages of analytic sheath models over numerical resolution of the sheath are explored. Electrons are treated with the drift-diffusion approximation and the electron temperature is obtained from an electron energy balance. The ion momentum balance and ion energy balance are spatially resolved. Atomic and molecular neutral species densities are also spatially resolved.

LD-3 A One Dimensional Inductively Coupled Plasma Experiment, B. P. COONAN, M. B. HOPKINS and M. M. TURNER, Dublin City University, Ireland – We describe an inductively coupled plasma (ICP) with cylindrical symmetry. This one-dimensional system is a more appropriate platform for basic investigations than geometrically more elaborate ICPs designed for particular applications, since many of the theoretical complications associated with helical coils are removed. We will discuss the design of the system and present a preliminary characterization in terms of currents, voltages and Langmuir probe measurements.

LD-4 The Response of an Inductively Coupled Plasma to the Power Interruption, D.C. SCHRAM, F.H.A.G. FEY, J.A.M. VAN DER MULLEN and J.M. DE REGT, Eindhoven Univ. Techn. - The study of the response of the emission to the power interruption gives insight in the fundamental processes in the ICP. It is found e.g. that levels of elements (analytes) introduced via water droplets respond essentially different from those of the main gas argon. Due to evaporation the Saha balance of analytes will be distorted. It is essentially this deviation from LTE which, manifested in the response of analyte levels to the interruption of the power, makes it possible to probe the overpopulation of ground levels of various analytes as a function of position, central flow and power. The response of argon levels gives information on the transport phenomena of electrons and the temperature inequality $T_e \neq T_a$. By studying the response of the continuum it is possible to unravel the contribution of the free-bound and free-free interactions from each other. This provides insight in radiative recombination processes and in the electron-atom momentum transfer collision.

LD-5 Electrical Characterization of a High Density Inductively Coupled RF Plasma Etching System
R. PATRICK, LSI Logic Corp. and F. BOSE, ETH Hoenggerberg -
An inductively coupled RF (13.56 MHz) system consisting of a flat powered coil situated above a dielectric window at the top of a plasma reaction chamber has been characterized using single and double Langmuir probes. The system is found to be capable of generating a high density plasma ($N_i > 10^{11}$ cm^{-3}) at pressures of < 5 mTorr. By making measurements as a function of probe position, it is found that both the density of the plasma and its uniformity are strong functions of the applied power. Correlations have been made with etch rate, etch uniformity and Si lattice damage measurements using Thermawave techniques. It is found that these quanitities are dependent on the power deposited in the wafer and reflect non-uniformities seen in the discharge.

LD-6 Density Profile of Inductively Coupled Argon Plasma Sphere
M. HASEGAWA and M. KAWAGUCHI, Mie University, Japan
Profiles of plasma density and electron temperature have been measured for an ICP argon sphere (pressure of 1 Torr and 130 mm in diameter) excited by a circular rf coil (13.56 MHz) wound around the sphere. The profiles were measured by using a movable electrostatic double probe. The rf output of an oscillator was below 40 W. The profile of plasma density showed significant nonuniformity. For example, on the coil surface, it had a peak between the center and the wall, which made the plasma like a luminous ring. On the other hand, plasma density on the axis perpendicular to the coil surface decreased gradually from the center toward the wall. The inhomogeneity in electron temperature was much smaller than in the plasma density. Typical values of plasma density and electron temperature were 6×10^{16} m^{-3} and 5eV, respectively. By using those profiles, the flow pattern of plasma particles was illustrated under the assumption that dc transport of charges obeys an ambipolar diffusion.

LD-7 A 1-D Model of an Inductively Coupled Fluorescent Lamp Discharge, S.E. COE and G.G. LISTER, CRL, Hayes, U.K.- A comprehensive 1-D model of an inductively coupled fluorescent lamp discharge has been developed. The model treats the discharge as an infinitely long annulus with the coil represented by an annular current sheet inside the internal re-entrant. The model includes treatment of the radiation transport of the two main U.V. lines based upon the Biberman-Holstein theory, solution of the mercury excited state and electron ambipolar diffusion equations to determine the density profiles of all the discharge species, solution of Maxwell's equations to determine the electric and magnetic field profiles and also a full power balance calculation. In addition the model solves the local electron energy balance equation to determine the spatial variation of the electron temperature, which occurs in these lamps, due to the non-uniform power deposition. Key outputs from the model include the overall lamp efficiency, the electrical properties of the discharge and the thermal loading on the lamp walls. Results from the model have been very promising and have semi-quantitatively reproduced experimental results. In addition to a detailed description of the model, example results will be presented along with comparisons with experiment.

LD-8 2D FLUID SIMULATION OF RF INDUCTIVE SOURCES
D. W. HEWETT, G. J. DIPESO, V. VAHEDI, and T. D. ROGNLIEN
Lawrence Livermore National Laboratory, Livermore, CA 94550 - Inductive and other high density sources are of great interest to industry and are promised to be the next generation of plasma processing reactors. The two-dimensional ($R - Z$) electromagnetic code ZMR [1] is being modified to include interactions between charged-particles and neutral species for modeling inductive sources self-consistently. Presently, the code models an argon plasma with momentum-transfer, excitation and ionization as electron-neutral reactions and scattering and charge-exchange for the ion-neutral reactions. The electrons and ions are treated as Maxwellian fluid species. In the zero electron inertia limit, the electron momentum equation is combined with a modified set of Maxwell's equations to do the field advance. The numerical techniques used in ZMR relax the typical temporal and spatial constraints (e.g. $\omega_{pe}\Delta t < O(1)$, $\lambda_{De}/\Delta x < O(1)$, and $c\Delta t/\Delta x < 1$) allowing one to choose appropriate time-step to resolve only the frequencies of interest (e.g. $\omega_{RF}\Delta t < O(0.1)$). Analytic boundary conditions are used to resolve the proper density profile without resolving the Debye sheaths. Density and power profiles will be shown over a wide range of neutral pressures and input powers.

This work performed by LLNL under DoE contract No. W-7405-ENG-48.

1. D. W. Hewett, *J. Comp. Phys.* **38**, 378 (1980).

LD-9 Inductive Plasma Source for Thin Film Growth*, J.T. SCHEUER, M. TUSZEWSKI, M.R. DAW, I. CAMPBELL, B.K. LAURICH, Los Alamos National Lab-We are developing a tool for semiconductor thin film growth based on the plasma immersion ion implantation technique. This compact, inexpensive, high throughput implanter will allow separate control of dose rate, ion energy and substrate temperature while mitigating charging effects. The present system employs a cylindrical inductive plasma source (35 cm diameter, 400 kHz, 500 W) which has been characterized using Langmuir and magnetic probes. Radial and axial profiles of plasma density and electron temperature along with measurements of induced plasma current will be presented for a range of neutral pressure and rf power. Comparisons will be made to a model of inductive source operation. Initial results of oxide growth on silicon and III-V materials will be presented.

*This work performed under the auspices of the US Department of Energy.

SESSION MA: RF GLOW DISCHARGES
Thursday afternoon, 21 October 1993
Grand Salon A, 13:30–15:30
J. Ingold, presiding

MA-1 GEC rf discharge benchmark model, M. SURENDRA, IBM T. J. Watson Res. Ctr. – A basis of comparison for self-consistent simulations of rf discharges was introduced at the 1992 GEC. 12 modeling efforts have produced results from 1-D simulations using identical cross sections or swarm parameters under specified conditions. The agreement between groups using the particle-in-cell - Monte Carlo collisions technique is good. Differences between PIC-MCC and convective scheme solutions to the Boltzmann equation exist primarily in the electron number density, and not energy density. Fluid simulations, which range from drift-diffusion for charged species transport with an electron energy balance to two ion-moment, three electron-moment equation solvers, generally show variation in the electrode rf voltage. The differences are most significant at the lowest pressure. These results demonstrate the effect of neglecting or approximating various terms in the moment equations, such as ion inertia, electron pressure and heat conduction gradients, and also different boundary conditions.

MA-2 Numerical Simulation and Acceleration Method for Electronegative Plasmas, Merle E. Riley, Sandia National Laboratories, Albuquerque, NM 87185 USA - An rf-driven, low-temperature, capacitively-coupled, chemically-reacting plasma is a fiendish combination of physical time scales resulting in mathematical stiffness. Previously we developed a combination of electron Boltzmann equation, ion fluid equation, and time-cycle average equation descriptions which enabled a reasonable numerical solution for the one-dimensional electropositive plasma.[1] Those solutions are reasonably independent of the numerical approximations. The electronegative plasma (Cl_2 in particular) adds a new measure of difficulty to the acceleration schemes when the plasma charge balance is dominantly between positive and negative heavy ions. Results will be discussed on the Cl_2 discharge.

[1]M.E.Riley, K.E.Greenberg, G.A.Hebner, and P.Drallos, submitted to J.Appl.Phys., July, 1993.

MA-3 Localized and Distributed Discharges in Helical Resonators P.Bletzinger, Aero Propulsion and Power Directorate, WPAFB, Ohio Analog to inductive discharges, helical resonators can also operate in inductive and capacitive modes. A medium sized helical resonator using argon could be switched between the two modes solely by changing the operating frequency, depositing similar rf powers into either a well confined annular, or a diffuse, widely distributed plasma. No matching network was used. Maximum rf power was 200W. In the inductive mode power deposition improved with rf power, pressure and transformer ratio increasing. In both modes the resonances were broadened with increasing pressure and shifted by increasing electron density. The resonances were broadened much further using SF_6. Power also could be deposited into higher order modes, but with higher SWR. The voltage at the end of the coil had resonance peaks only in the capacitive modes, similar to operation without plasma. Especially at pressures below 0.1 Torr the discharge was no longer purely inductive in the inductive mode. The operat ing modes were also checked measuring the electron density outside the resonator with a microwave interferometer.

MA-4 RF Power Dependence of Transient Laser Optogalvanic Signals in a Capacitively-Coupled Neon Discharge*, D. KUMAR, R. R. ZINN, and S. P. MCGLYNN, Department of Chemistry, LSU, Baton Rouge, LA - Temporal characteristics of pulsed-laser induced optogalvanic signals in some $1s_j \rightarrow 2p_k$ (Paschen notation) excitations in ~ 5 torr neon have been investigated in rf discharges at rf powers ranging from 0.05 to 5.0 watts. A gradual transition to a drastically different temporal profile is observed as the rf power is decreased in steps from maximum to minimum. These changes may be studied using a recently developed method which permits distinction between the two components of an optogalvanic signal, one generated by ionization rate changes and the other by photoacoustic effects.[1]

*Work supported by grants from U. S. Department of Energy and the LSU Center for Energy Studies.

[1]D. Kumar and S. P. McGlynn, J. Chem. Phys. 93, 3899 (1990); Chem. Phys. Lett. 176, 536(1991).

MA-5 Measurements and Simulations of Electronegative RF Plasmas, D. VENDER, E. STOFFELS, W. W. STOFFELS, G. M. W. KROESEN and F. J. DE HOOG, TUE - The presence of negative ions in rf processing plasmas strongly influences discharge maintenance and behaviour. Measurements in low pressure, negative ion dominated plasmas prepared by adding small amounts of halocarbon (CF_4 or CF_2Cl_2) to an Ar plasma give negative ion densities of 10^{17} m^{-3} at 25 mTorr neutral pressure and a power of 50 W at 13.56 MHz in a parallel plate reactor with 5 cm electrode separation. The dominant negative ions are F^- for CF_4 (with $n_-/n_e \sim 10$) and Cl^- for CF_2Cl_2 ($n_-/n_e \sim 100$). Ar^+ is the dominant positive ion for halocarbon concentrations of up to 30%. The measurements are used to guide the development of kinetic simulations of the electronegative plasma. In order to adequately resolve the electron distribution and attain tolerable run times, species dependent scaling is used in the simulation which uses the PIC/MCC algorithm. Measurements of the spatial negative ion distributions and energy resolved Ar^+ fluxes are compared with the simulation results.

MA-6 **Time Dependence of the EEDF and the $3p^54s$ Populations in HF Argon Discharges**, C. M. FERREIRA, P. A. SÁ and J. LOUREIRO, CEL-IST, Lisbon Tech. U. - We present a systematic investigation of the time dependence of the electron energy distribution function (EEDF) and the populations in the $3p^54s$ levels of argon in a low pressure argon discharge sustained by a harmonic electric field for a wide range of the angular frequency, ω, from microwaves to a few kHz. The analysis is based on the time-dependent coupled solutions to the Boltzmann equation and the system of rate balance equations for the populations of the $3p^54s$ levels of argon. From the present formulation, the time behavior of both the EEDF and the populations $n_j(t)$ may be explained as follows: (i) For frequencies $\omega >> \nu_e$, ν_e denoting the characteristic frequency for electron energy transfer, the EEDF has practically no time-modulation and it follows the applied field with a large time-delay; (ii) For $\nu_j^e << \omega << \nu_e$, where ν_j^e denotes an effective frequency for relaxation of the j-th level of the $3p^54s$ configuration (due to diffusion of metastables, radiative decay of resonance levels and quenching by electronic and atomic collisions), the EEDF and the electron rate coefficients for excitation of the $3p^54s$ levels are strongly time-modulated, while the populations of the levels are practically constant; (iii) Finally, when $\omega \leq \nu_j^e$, there is an increasingly large modulation in the populations as ω decreases.

MA-7 Low Temperature Plasma Simulations Using Direct Application of Electron Energy Distribution Functions. * Kazutaka Kitamori, Hokkaido Institute of Technology, Department of Industrial Engineering, Sapporo, 006 Japan and P.L.G. Ventzek, University of Illinois, Department of Electrical and Computer Engr., Urbana, IL 61801 - A short-coming of fluid simulations is that the macro-parameters used at low pressures near boundaries may not be accurate. We present an extension of a PIC model in which electron and ion velocity distribution functions generated by an electron and ion Monte Carlo simulation (MCS) are imported into a module that uses an analytic solution of the Boltzmann equation to solve for steady state reactor charged species densities. In this scheme, Boltzmann's equation contains only ionization rate terms and is field-free. The solution for the species densities begins from an initial guess on a spatial mesh and is allowed to relax without using macroparameters. Electron and ion dynamics are determined only by their velocity distribution functions. Poisson's equation is semi-implicitly solved at each time-step and the fields are used in the MCS. The model will be applied to an inductively coupled plasma (ICP) reactor.

* Work supported by the National Science Foundation

MA-8 A Dynamic Stochastic Simulation of the Boltzmann Equation, D.P. LYMBEROPOULOS, J.D. SCHIEBER and D.J. ECONOMOU, University of Houston.-A stochastic simulation method is proposed which allows the efficient treatment of the Boltzmann equation. The stochastic process is described by a master equation. Interesting quantities, e.g. the time evolution of mean electron energy, and the electron velocity distribution function, are evaluated not by solving the master equation as an ordinary differential equation but with the help of a stochastic simulation, which generates realizations of the underlying stochastic process, referred to as the Dynamic Monte-Carlo Simulation, DMCS, method. Both the direct simulation Monte-Carlo, DSMC, as well as the "null collision" Monte-Carlo, NCMC, treatment of the electron-collisions require as input the mean-free path distribution, MFPD. However in DMCS the MFPD is actually an output. Applications of the DMCS method to electron motion in He and Cl_2 in time-dependent uniform and space-varying fields will be presented.

SESSION MB: ELECTRON COLLISIONS

Thursday afternoon, 21 October 1993
Grand Salon C, 13:30–15:30
R.A. Bonham, presiding

MB-1 Free-free Transitions of Electrons Colliding with Oxygen Atoms,* S. CHUNG and CHUN C. LIN, U. of Wisconsin and E. T. P. LEE, Phillips Laboratory (Air Force Systems Command) - The cross sections for electron free-free transitions in the presence of neutral oxygen atoms are calculated at about 100 incident-electron energies for a given photon wavelength. From these cross sections the Maxwellian-averaged continuous absorption and emission coefficients are obtained for the wavelength range of 1 to 30μ and for the electron-temperature range of $5x10^3$ to $5x10^4$ K. The continuum wave functions are computed by the Hartree-Fock method. The electron exchange and the orthogonality conditions are included in the integro-differential equations which are solved non-iteratively without ancillary approximations. The effects of the polarization of the oxygen atoms are taken into account by means of the method of polarized orbitals. A significant difference is found between the present work and previous calculations which treated the polarization empirically.

*Work supported by Phillips Laboratory (Air Force Systems Command).

MB-2 Autoionization States in CO_2 and CS_2 Studied by Electron Impact.* A.T. Wen, D. Tremblay, B. Tremblay, C. Gourier and D. Roy, LPAM, Dépt. de Physique, U. Laval, Québec, Qc. G1K 7P4. A multi-angle-detector electron scattering spectrometer has been adapted to electron ejection measurements. A study of autoionization from Rydberg states has been carried out for CO_2 in the continuum region 15 - 19 eV by low-energy electron impact. Observations have been made of structure due to excitation of these states by slow electron scattering and their decay by ejection of electrons. A multi-angle parallel detection technique has been used and this has enabled some CO_2 autoionizing states resulting from non-dipole transitions to be observed clearly. The major features appearing in the ejected electron spectra of CO_2 have tentatively been classified and/or assigned, and the spectral behaviour (intensity, width, and shape) of these features has been addressed as a function of incident energy and angle of ejection. In addition to the features already known, new features have been observed, and they seem to be rather sensitive to electron impact energies employed. Studies of autoionizing states in CS_2 in the energy region 11 - 14 eV are also presented.

* Work supported financially in part by NSERC/CRSNG, Fonds FCAR du Québec and NCE Programme.

MB-3 Electron-Molecule Collisions using the R-Matrix Method, Jonathan Tennyson, University College London - The R-matrix method has been used for low energy (<20eV) electron collision from diatomic molecules. Targets studied include homonuclear systems such as H_2, N_2 and O_2, polar molecules such as NO, CO and HF, and ions including H_2^+ and HeH^+. Processes studied include elastic scattering, vibrational excitation, electronic excitation and dissociative attachment or recombination. Nuclear motion can be included in these calculations either within the adiabatic approximation or using a generalised non-adiabatic approach. The R-matrix method is particularly good for studying systems for which resonant processes are important. Recent work has focussed on improved treatments of target wavefunctions which means that many electronic states can accurately be treated at the same time, and on studying dissociative recombination in cases where there are no curve crossings. A survey of latest results will be presented at the conference.

MB-4 Revised Electron Collision Cross Sections for Silane Derived from Swarm Data,* R. NAGPAL and A. GARSCADDEN, Plasma Research Group, WPAFB- The two-term Boltzmann analysis of the swarm data breaks down completely in pure SiH_4 and SiH_4-Ramsauer rare gas mixtures. Large discrepancy between the two-term and Monte-Carlo calculated drift velocities in the above systems indicates inconsistency in the existing[1] two-term derived SiH_4 cross sections. We have removed this inconsistency by using Monte-Carlo calculations to unfold the cross sections in SiH_4 and in SiH_4-Ar,-Kr mixtures. It is shown that swarm data in SiH_4-He mixtures[2] is a valuable alternative where the two-term and Monte-Carlo results agree very well and hence two-term analysis can be accurately used to derive the cross sections in these mixtures. Significantly improved momentum transfer and the first vibrational excitation cross sections for 0-5 eV are presented.

* Work Supported by the Wright Laboratory.

1 M. Kurachi and Y. Nakamura, IEEE Trans. Plasma. Sc. 19, 262 (1991).
2 M. L. Andrews, K. A. Kirkendall and A. Garscadden, 36th GEC SUNY New York (1983).

MB-5 Electron-Impact Ionization of NF_3, NF_2 and NF.* A LEVIN, V. TARNOVSKY, K. BECKER, City College of C.U.N.Y., R. BASNER, M. SCHMIDT, INP Greifswald, Germany and H. DEUTSCH, Universität Greifswald, Germany - The electron-impact ionization of NF_3 has been studied using two different experimental methods, the fast-beam technique at City College and a high-resolution double-focusing mass spectrometer at Greifswald. Absolute parent ionization cross sections were measured independently by both groups and the results were found to agree to within 20% (at 70 eV). We also report measurements of the partial cross sections for dissociative ionization of NF_3 carried out in both apparati. Ionization and dissociative ionization cross sections for the NF_2 and NF free radicals could only be measured using the fast-beam technique by the City College group. The measured cross sections will also be compared to calculated total single ionization cross sections for NF_3, NF_2 and NF using a new additivity rule.

*Work supported by the National Science Foundation (NSF), the American Chemical Society-Petroleum Research Fund (ACS-PRF), AT&T Bell Laboratories, and by a NATO Collaborative Research Grant

MB-6 Elastic and Vibrationally Inelastic Cross Sections and Energy Loss Spectra for Electron Collisions with Propane,* M.A. DILLON, L. BOESTEN,† H. TANAKA,† M. KIMURA, and H. SATO,& Argonne National Laboratory, Argonne, IL - Absolute elastic cross sections for electron-propane (C_3H_8) collisions have been measured using incident kinetic energies of 2, 3, 4, 5, 6, 7.5, 8.5, 10, 15, 20, 40, and 100 eV and recorded over scattering angular range of 10° to 130°. These cross-sections have been integrated by employing a nonlinear phase shift fitting procedure. Angular distributions have been found to correspond at least qualitatively to a scattering formulation using only local potentials and also to a multi channel Schwinger variational calculation.

Experiments on vibrationally inelastic scattering reveal the existence of a shape resonance with a peak at 7.5 eV characteristic of trapping by C-H antibonding valence orbitals.

† Sophia University, Tokyo, Japan

& Kochanomizu University, Tokyo, Japan

* Work supported in part by the U.S. Department of Energy, Office of Environmental Research under contract w-31-109-Eng-38

MB-7 Electron-H_2^+ Scattering Using the Finite-Element Method With Iterative-Variational Solution of the Algebraic Problem. C.A. WEATHERFORD,[a] Florida A & M University – Coulomb Sturmians are used to calculate the ground state of H_2^+. The required multicenter integrals are calculated to very high accuracy in momentum space. Differential cross sections describing electron scattering from the ground state of H_2^+ are then calculated using the finite element method.[1] The solution of the resulting linear algebraic problem is accomplished using the iterative-variational method.[2]

[a]Supported by FAMU-NASA CeNNAs 30-1704-019 and by Air Force contract FY33615-90-C-2032.

1. C.A. Weatherford, W.M. Huo, and J. Shertzer, Bull. Am. Phys. Soc. **37**, 1108 (1992).
2. B.I. Schneider and L. Collins, Comp. Phys. Comm. **53**, 381 (1989).

SESSION NA: INDUCTIVELY COUPLED PLASMAS III
Thursday afternoon, 21 October 1993
Grand Salon A, 15:45–17:45
D.A. Doughty, presiding

Invited Paper

NA-1 An Enclosed Inductively Coupled Plasma for Spectrochemical Analysis of Semiconductor Gases, RAMON M. BARNES, TRACEY JACKSIER*, and ANA GAILLAT, DEPT. of Chemistry, Univ. of Massachusetts - An enclosed inductively coupled plasma discharge operated at atmospheric pressure and 40.68 MHz at modest power (<1.6 kW) has been developed for the analysis of gases used in the semiconductor industry (*e.g.*, arsine, boron trichloride, chlorine, hydrogen chloride, silane).[1] Discharge container geometry, inlet and outlet configuration, and chemical admixtures are critical in the design and operation of stable discharges under low-flow (100 mL/min) and non-flow conditions. Computer simulations for noble (Ar, Ne, Kr, Xe) and reactive (chlorine, HCl) gases support experimental observations. Qualitative identification and quantitative calibration procedures for ultratrace concentrations of metallic impurities have been demonstrated based on atomic emission spectrometry. Each of these aspects will be described and illustrated.

*American Air Liquide, Chicago Research Center, Countryside, IL 60525.

[1]M.J. Jahl, T. Jacksier, and R.M. Barnes, J. Anal. At. Spectrom. 7, 653 (1992).

Contributed Papers

NA-2 A Molecular Flow-Hydrodynamic Model for Hot Atom and Ion Fluxes in Inductively Coupled Plasmas for Etching. * Robert J. Hoekstra, Peter L. G. Ventzek and Mark J. Kushner, University of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - Inductively coupled low pressure (2-20 mTorr) reactors are being developed as high plasma density sources for etching and deposition. ICP reactors operate in the quasi-continuum flow regime. To address these conditions, we have developed a hybrid molecular flow-hydrodynamic (MFH) transport model. The model uses as input electron impact sources for ionization and excitation, and electric fields produced by a companion plasma model of ICP reactors. The MFH model then follows the trajectories of pseudo-particles for ions and radicals while including all pertinent charge exchange and neutral chemical reactions using iterative particle-mesh algorithms. Momentum transfer with an advecting fluid flow field, produced by an off line model, is included. We will discuss the effects of geometry (flow inlets/outlets) and gas pressure on the uniformity of the hot atom, radical, and ion energy fluxes in ICP and RIE reactors. The gas mixtures will include Ar, $Ar/CF_4/O_2$ and He/CF_4.

* Work supported by SRC, LAM Research Inc., NSF, and U. of Wisc. ERC for Plasma Aided Manufacturing

NA-3 Off-Resonance Raman Scattering Experiments in a Hg-Kr Inductively Coupled Discharge, D. MICHAEL, GE Lighting. An Off-Resonance Raman Scattering technique is used to measure the absolute number density of excited Hg ($6\ ^3P_1$) state in a Hg-Kr Inductively Couped Discharge [1]. The discharge is created within a cylindrical quartz container with a coaxial inner wall (76mm OD, 23mm ID and 103mm length). Axial and Radial scans were obtained at various input power levels (10-30W). Variation of this excited Hg state and the 253.7nm UV Hg line were obtained as a function of Hg vapor pressure.Detection of collisionally induced LIF at detuned pump beam settings may explain discrepancies between estimates and measured Hg ($6\ ^3P_1$) densities. An absorption experiment was also performed to check the validity of the Raman Scattering technique. Another cell that contained Hg-He was constructed to look for possible interference effects from Krypton with the Raman signal.

[1]L.Bigio and D.Johnson,"Near-Resonance Electronic Raman-Scattering Measurements of Hg ($6\ ^3P_1$) in a low pressure Hg-Ar discharg", J. of Opt. Soc. Am. B, Vol.8 No.3, 525-530 (1991)

NA-4 Modelling of Mixed E and H Regimes in an Inductively Coupled Plasma. F. A. HAAS, S. YANG and N. St. J. BRAITHWAITE, Oxford Research Unit, Open University, Oxford, UK - Low power inductively coupled discharges show faint light emission (E regime), but as the power is raised, a much brighter annular ring (H regime) is formed. A two-dimensional (r,z) theoretical model of the diffusion processes involved, shows a saddle structure for the electron density as well as determining the ionization rates through eigenvalue conditions. Consideration of the electron pressure balance reveals the importance of line averaged inertial terms arising from the electron motion induced by the imposed fields. Experiments have been performed with a 500 kHz radio frequency source coupled to a low pressure argon plasma via a thirty turn coil wound on a containing glass vessel (diameter 15cm, height 50cm). Probe measurements reveal that the electron density has a saddle structure about the mid-plane of the containing vessel.

NA-5 Collisionless Electron Heating in Inductively Coupled Discharges, M. M. TURNER, Dublin City University,Ireland – An electromagnetic particle in cell simulation, with Monte Carlo collisions, is used to show that there is a collisionless electron heating mechanism of importance in inductively coupled discharges. The process is a warm plasma effect and can be understood in terms of linearizations of the Vlasov-Maxwell equations. Results for various gases show that collisionless heating dominates when the pressure is less than $\sim$ 10 mTorr, provided that the plasma density is greater than $\sim 10^{11}$ cm^{-3}.

NA-6 Electrical Characteristics and Electron Heating Mechanism of an Inductively Coupled Argon Discharge V.A. GODYAK, R.B. PIEJAK and B.M. ALEXANDROVICH, Osram Sylvania Inc. The external electrical characteristics of inductively coupled argon rf discharges at 13.56 MHz have been measured over a wide range of power at gas pressures ranging from 3 mTorr to 3 Torr. External parameters, such as, coil voltage, current and phase shift between the two were measured. From these measurements the equivalent discharge resistance and reactance, the power transfer efficiency and the coupling coefficient between the primary coil and the plasma were determined as a function of discharge power and gas pressure. The efficient rf power transfer and the large value of the effective electron collision frequency found here at low gas pressure suggest some collisionless electron heating mechanism. This mechanism is identified as non-local electron heating in the inhomogeneous rf field due to spatial dispersion of the plasma conductivity, a phenomenon which underlies anomalous skin-effect.

NA-7 Spectroscopic Measurements of Species Concentration for Oxide Etching Chemistry in Inductively Coupled Plasma Reactors, E. A. WHITTAKER, H. C. SUN, V. PATEL, B. SINGH, H. LEE, B. BRYCKI, New Jersey Sematech Center of Excellence in Plasma Etch.--- The development of a fundamental understanding of semiconductor plasma etching chemistry is a long sought goal of the processing community. We have recently developed a tunable diode laser absorption spectrometer capable of sensitive, chemically selective detection of a wide range of chemical species found in etching plasmas. The method may be used *in-situ* and in real time and thus can provide a wealth of data for use in chemical models of etching. Using this method we have measured the concentration of various species that occur in fluorocarbon based discharges in different inductively coupled plasma reactor configurations. The species yields have been measured for a range of reactor and process conditions. For comparison, the oxide etch rate was monitored using *in-situ* laser interferometry and plasma characteristics of the reactor were determined using radial and vertical scanning tuned Langmuir probes. A factor of three to five improvement in oxide etch-rate was observed with inductively coupled schemes as compared to parallel plate tools.

Preliminary chemical modeling efforts will also be presented.

Social Hour/Cocktail
18:30–19:30
Salon Alfred Rouleau C

Conference Dinner/Banquet
19:30–23:00
Salon Alfred Rouleau A
Speaker/Conférencier: S. Leney, Hydro-Québec

SESSION NB: LOW-ENERGY ION-MOLECULE COLLISIONS

Thursday afternoon, 21 October 1993
Grand Salon C, 15:45–17:45
A.V. Phelps, presiding

Invited Paper

NB-1 Internal Energy Effects on Ion Molecule Reactivity. ALBERT VIGGIANO, Phillips Laboratory, Geophysics Directorate, Hanscom AFB MA -- The variable temperature - selected ion flow drift tube has proven to be a valuable tool for deriving internal energy dependences of a variety of ion molecule reactions. The technique will be described and compared to other techniques for obtaining information on internal energy dependences. Rotational energy has been found to effect reactivity in number of ways such as adding energy and preventing dipole locking, but frequently has been found to have only a minor effect on reactivity. Vibrational excitation often has a more pronounced effect on reactivity, both positive and negative. A number of examples showing the versatility of this technique will be given including the effect of N_2 rotations and vibrations on the charge transfer between Ar^+ and N_2.

Contributed Papers

NB-2
Product State Distributions in Low-Energy Ion-Molecule Reactions,* P. C. COSBY, J. R. PETERSON, AND B. VAN DER KAMP, SRI International--Charge transfer neutralization of molecular ions in cesium vapor produces Rydberg states of the neutral molecule built on the reactant ion core that generally lie above one or more dissociation limits of the molecule and predissociate. The translational energy release spectrum of these dissociative charge transfer products provides a rapid and complete measurement of the vibrational and electronic population distributions in the molecular ion.[1] Changes produced in these populations by low energy (eV) ion-molecule reactions can thus be monitored with the dissociative charge transfer reaction at keV energies. This technique has been applied to the vibrational quenching of O_2^+, CO^+, and NO^+ by their parent gases in a Nier-type electron impact ion source. The influence of extraction voltage on the state composition of ions produced by a hollow cathode discharge is also examined.

*Research supported by the NSF Grant PHY-91-11872.

[1]C. W. Walter, P. C. Cosby, and J. R. Peterson, J. Chem. Phys. **98**, 2860 (1993) and references therein.

NB-3 Exciton and ion reactions within van der Waals clusters*, M. FOLTIN and T.D. MÄRK, Inst. Ionenphysik, Univ. Innsbruck, Austria
Electron impact ionization of rare gas clusters R_n has been found to result[1] via multiple collisions of the incoming electron in the production of cluster ions R_n^{+*} containing-besides an ionic chromophore (e.g. R_2^+)- an excimer R_2^*. Radiative decay of this excimer (trapped exciton) in the ns and μs time regime leads to violent fragmentation of the respective cluster ions. However, this fragmentation may be quenched in the presence of a dopant molecule reacting with the excimer and the ionic chromophore by charge and excitation transfer. Energetics, kinetics and dynamics of these reactions (including also mixed cluster systems[2] such as Ar/O_2) have been studied by mass spectrometric methods and by

molecular dynamics calculations thereby given a vivid picture of the rather complex reaction sequence involved.

*Work supported in part by the Österr. Fonds zur Förderung der Wissenschaftlichen Forschung and the BMWF, Wien.

1 M. Foltin and T.D. Märk, Chem. Phys. Lett., 180 (1991) 317
2 M. Foltin, V. Grill and T.D. Märk, Chem. Phys. Lett., 188 (1992) 427

NB-4 Proton Transfer and Drift of Positive Ions in Methane,* J.de URQUIJO, C. CISNEROS, H. MARTINEZ and I. ALVAREZ, Instituto de Física, UNAM, México - The mobility of CH_5^+, H_3O^+, $C_2H_5^+$ and $C_3H_5^+$ has been measured with a drift tube-mass spectrometer for 15<E/N<500 Td (1 Td $=10^{-17}$ V cm^2), and low gas pressures in the range 3-16 Pa. All ion mobilites are about 15% lower than those calculated from the polarisation-limit theory, but they do scale according to it. Over the range 100<E/N<240 Td, the mobilities of CH_5^+ and H_3O^+ are lower than those of $C_2H_5^+$. This behaviour is thought to be due to proton transfer reactions of CH_5^+ and H_3O^+ with CH_4 and H_2O[1]. At low E/N the present mobilities of CH_5^+ and $C_2H_5^+$ are in good agreement with those of Ridge and Beauchamp[2].

* Work supported by DGAPA and CONACYT.

1 J. D. Betowski et al, Chem. Phys. Lett. 31, 321(1975)
2 D.P. Ridge and J.L. Beauchamp, J. Chem. Phys. 64, 2735 (1976)

NB-5 Single- and Double-Electron Capture in Collisions of Multiply Charged He^{2+}, C^{q+} (q = 4, 5), and Ar^{q+} (q = 6, 8) Ions with H_2 Molecules at eV Collision Energies,* M. KIMURA, Argonne National Laboratory, Argonne, IL 60439 and Rice U., Houston, TX 77251, N. SHIMAKURA, N. F. LANE Rice U., S. KRAVIS, I. SHIMAMURA, Y. AWAYA, RIKEN, Tokyo, Japan, and K. OKUNO, Tokyo Metropolitan U.--Recent experiments [1] suggest that double-electron capture dominates, single-electron capture in $He^{2+} + H_2$ collisions below 1 keV while single electron-capture becomes dominant above this energy. Another experiment [2] suggests that double-electron capture is always the dominant process in $Ar^{q+} + H_2$ collisions in the energy region from 0.1 eV to a few keV. Our theoretical results obtained by using a molecular orbital expansion method clearly confirm these experimental findings and provide a theoretical rationale based on adiabatic potentials and dynamic analysis.

* Work supported in part by the U.S. Department of Energy, Office of Energy Research, Office of Health and Environmental Research, under Contract W-31-109-Eng-38 (MK), and by the Office of Basic Energy Sciences (NFL, NS).

1 K. Okuno, K. Soejima, and Y. Kaneko, J. Phys. B 25, L105 (1991).
2 S. Kravis, M. Kimura, K. Shimamura, Y. Awaya, N. Shimakura, and K. Okuno, Phys. Rev. A XX, XXX (1993).

NB-6 Reactivity of Atmospheric Ions with Fully Fluorinated Compounds, R. A. MORRIS, A. A. VIGGIANO, and J. F. PAULSON, Air Force Phillips Laboratory, Geophysics Directorate- The ions O^-, O_2^-, O^+, O_2^+, CO_3^-, NO_3^-, NO^+, and H_3O^+ have been studied in the gas phase for reactivity toward the fully fluorinated compounds CF_4, C_2F_6, c-C_4F_8, C_6F_{14}, and SF_6. Rate constants and reaction product branching fractions were measured at 300 K by using a selected ion flow tube (SIFT) apparatus. Recently, the atmospheric lifetimes of the reactant neutrals in the study have been predicted[1] to be extremely long, some greater than 2000 years. Some of the reactions reported here are rapid, a result which leads to decreased atmospheric lifetimes for these compounds compared with the earlier predictions. Many of the reactions feature dissociative charge transfer pathways leading to multiple ionic products. The chemistry and atmospheric implications will be discussed.

1A. R. Ravishankara, et al., Science, 259, 194 (1993).

NB-7 Guided Ion Beam Studies of the Reactions of Group 3 Metal Ions (Sc^+, Y^+, La^+, and Lu^+) with Silane. Metal Silicon Bond Energies.* BERNICE L. KICKEL and P. B. ARMENTROUT, Univ. of Utah - Guided ion beam techniques are used to measure cross sections as a function of kinetic energy for the reactions of the group 3 metal ions, Sc^+, Y^+, La^+ and Lu^+ with silane. In all four systems, products include the metal hydride and dihydride cations, as well as metal silicon species, $MSiH_x^+$ (x = 0 - 3). The general mechanistic details of these reactions may be understood in terms of an insertion of the metal center into the Si-H bond of silane. The subsequently formed intermediate then decomposes to yield the observed products. The energy dependences of the cross sections are analyzed to yield 0 K bond dissociation energies of the various metal silicon species. The present results are compared to those previously reported by Sunderlin and Armentrout for reactions of the group 3 metal ions with methane.

*Work supported by the National Science Foundation.

1L. Sunderlin and P. B. Armentrout, J. Am. Chem. Soc. 111, 3845 (1989).

SESSION PA: THERMAL PLASMAS AND PLASMA TORCHES I

Friday morning, 22 October 1993
Grand Salon A, 8:00–10:00
M. Boulos, presiding

Invited Papers

PA-1 Non-equilibrium Mechanisms in (sub)Atmospheric Plasmas and in their Expansion, D.C. SCHRAM, J.A.M. VAN DER MULLEN and M.C.M. VAN DER SANDEN, Eindhoven Univ. Techn. - Stationary or flowing (sub)atmospheric plasmas can be characterized by two non-equilibrium parameters: the ground state deviation from Saha δb_1 and the heavy particle to electron temperature ratio T_h/T_e. The state is then defined by p, n_e, δb_1 and T_h/T_e, with T_e as a dependent parameter. This description allows for a simplification of the plasma transport equations in e.g. a 2 D-code and easier comparison with measurable quantities (as n_e) as illustrated from recent work on ion current from a flowing cascade arc plasma source. The expansion of such a plasma in a low-p vessel leads to a flowing high density recombining plasma with underpopulated excited states as manifest from a.o. absorption spectroscopy. Additional reactions as asymmetric charge exchange and dissociative recombination of molecular ions with injected molecules as H_2, N_2, C_nH_m and SiH_4 (for surface modification and plasma deposition) are summarized. The importance of recirculation flows and ro-vibrational excitation is indicated.

PA-2 Advances in Induction Plasma Modeling and Diagnostics, M.I. BOULOS, Plasma Technology Research Center, U. of Sherbrooke (Qué.) - Induction plasmas are characterized by the simultaneous presence of both laminar and turbulent flow regimes in the discharge. These can have a major influence on the flow pattern temperature and concentration fields. Results obtained based on mathematical modelling and diagnostics studies provide an insight in the basic phenomena involved and an estimate of the effective turbulent diffusivity under such conditions. Examples are given for the synthesis of ultrafine ceramic powders and the plasma spraying of protectives coating and free-standing bodies under atmospheric and low pressure conditions.

Contributed Papers

PA-3 A Model for Diamond Film Growth in a Thermal Plasma Reactor,* B. W. YU and S. L. GIRSHICK. A numerical model was developed for diamond film CVD in an atmospheric-pressure rf plasma reactor. The main components of the model are submodels for the plasma, the fluid boundary layer above the deposition surface, and the growing diamond film. The plasma model predicts two-dimensional temperature and velocity profiles. The boundary layer model covers the region between the substrate and the 4000 K isotherm, and treats the chemical kinetics of the C-H-Ar system. This is coupled to any of several proposed surface growth mechanisms. The numerical calculations are compared to experimental data obtained in our laboratory. Good agreement is found regarding predicted growth rates based on methyl radicals or monatomic carbon as growth monomers.

*Work supported in part by NSF, the Engineering Research Center on Plasma-Aided Manufacturing, and the Minnesota Supercomputer Institute.

PA-4 Atmospheric pressure waveguide-fed plasma torch, M. MOISAN, G. SAUVÉ and Z. ZAKRZEWSKI*, U. de Montréal - Theoretical and experimental investigations of the electrodynamic properties of a waveguide-based microwave sustained plasma torch, operating at 2.45 GHz with input power up to 3 kW, are reported. The plasma is sustained at the end of a coaxial shaped section: the working gas (argon and helium in the present case) flows in a channel within the inner conductor and exits into the discharge through a nozzle at the conductor tip. The system comprises coaxial and waveguide elements that serve the purpose of wave mode conversion and impedance matching. Its description in terms of an equivalent circuit yields the full electrodynamic characteristics of the torch, which is verified experimentally. From the outcome of this model, new features are introduced in the torch structure, allowing us to optimize its performance and simplify its design.

*Permanent address: Polish Academy of Sciences, IMP-PAN, 80-952 Gdansk, Poland.

PA-5 Non-equilibrium Effects in Thermal Plasma Systems, D.V. GRAVELLE and S. VACQUIE*, CRTP, U de Sherbrooke - The state of equilibrium of different plasma sources is examined using experimental results obtained at CRTP and CPA. Parameters such as the temperature and the electron density distribution, using emission spectroscopy, are analyzed in terms of power levels, chamber pressure and plasma gas composition. Four basic concepts for generating thermal plasmas are used in data collection, namely: high power transferred arc plasma reactor, wall-stabilized transferred arc column, non-transferred arc plasma torch and high frequency induction plasma reactor. Determination of the temperature, from N_e data, using Saha equation and from a Boltzmann plot show important deviations from equilibrium for certain experimental conditions and regions of the plasma. Departures from LTE are evaluated using electron density measured from the Stark broadening of hydrogen lines and from the recombination continuum which do not rely on LTE assumptions. The mutual correlation between non-LTE behaviour and some coating properties obtained under low pressure plasma spraying operations is shown. The importance of establishing the limits of validity of LTE in thermal plasma modeling is pointed out.

*Centre de Physique Atomique, Université Paul Sabatier, Toulouse

PA-6 Destruction of Acetone Using a DC Plasma Torch, C. B. FLEDDERMANN, K. WROBLEWSKI, B. WROBLEWSKI, W. WILBANKS, D. ADAMS, L. ENRIQUEZ, AND J. M. GAHL, Deptartment of Electrical and Computer Engineering, Univiversity of New Mexico- Plasma torches are a viable technology for the destruction of hazardous industrial chemicals. In this work, a dc plasma torch is used to destroy acetone, a common industrial solvent. The plasma torch is of cylindrical geometry with a tapered inner bore and is excited using a tungsten electrode located along the axis of the cylinder. The torch is powered by a welding power supply operating at 25 V with currents between 20 and 100 mA. The acetone vapor is generated by bubbling argon through heated liquid acetone. The destruction of the acetone vapor is monitored using optical absorption spectroscopy. The absorption edge of acetone is at approximately 330 nm: for shorter wavelengths, acetone is highly absorbing. A copper hollow cathode lamp producing line radiation at 324.7 or 327.4 nm, just below the absorption edge, and a monochromator/PMT combination located downstream from the torch, are used to monitor the effluent from the gun. Results will be presented for the acetone destruction efficiency as a function of the operating parameters of the torch. This type of system will be readily applicable to the destruction of other industrial wastes.

SESSION PB: MODELING AND SIMULATION

Friday morning, 22 October 1993
Grand Salon C, 8:00–10:00

T.W. Johnston, presiding

PB-1 **Tonks-Langmuir Problem for a Bi-Maxwellian Plasma** V. A. GODYAK, Osram Sylvania Inc., V. P. MEYTLIS, Courant Inst., NYU. Non-equilibrium electron energy distribution functions (EEDF) are typically observed in low pressure gas discharge plasmas. Numerous experiments and electron kinetic modeling of various low pressure (mTorr range) discharges have demonstrated EEDF's which may be represented by a sum of two Maxwellian distributions with essentially different temperatures. In this work we give an analytical solution for the ionization balance in an ion inertia controlled plasma slab (Tonks-Langmuire problem) with a bi-Maxwellian EEDF. The solution shows that the ambipolar potential, the plasma density distribution and the ion flux to the wall are governed by the cold electrons, while ionization rate and voltage drop across the wall sheath are governed by the hot electrons.The ionization rate is found to be spatially uniform contrary to the T-L solution where it is proportional to the plasma density distribution. The temperature of hot electrons is found to be close to that of the T-L solution and in good agreement with experiments[1] carried out in a capacitive rf discharge. The energy balance for cold electrons shows that their heating by hot electrons, if accounted for only by recoil on atoms and ions, does not agree with experiment[1] unless an electron cooling effect involving electron acoustic waves[2] are taken into account.

References:

1.V.A.Godyak et. al., Plasma Sources Sci.& Technol., 1, 36 (1992).
2.M.Surendra & D. Graves, Phys. Rev. Lett., 66, 11, 1469 (1991).

PB-2 Radiation Trapping Simulations Using the Propagator Function Method with Complete Frequency Redistribution, J. E. LAWLER, G. J. PARKER, and W. N. G. HITCHON, Univ. of Wisconsin-Madison–An integral method of solving the Holstein-Biberman equation based on a propagator function is described.[1] This method is used to solve the equation with a Lorentz lineshape and complete frequency redistribution in an infinite plane parallel geometry, a (hollow) spherical geometry, and an infinite cylindrical geometry. The method is ideal for solving for both the time dependent and the steady state density of resonance atoms which results from a production rate per unit volume with arbitrary spatial and temporal dependence. Resonance atoms are important in the power balance and ionization balance of many glow discharge plasmas. The propagator function method is 100 times faster than the Monte Carlo method. The greater speed of the propagator function method makes it well suited for fully self-consistent kinetic simulations of glow discharge plasmas.

[1]J. E. Lawler, G. J. Parker, and W. N. G. Hitchon, J. Quant. Spectrosc. and Radiat. Transfer, 49, 627 (1993).

PB-3 Radiation Trapping Simulations Using the Propagator Function Method with Partial Frequency Redistribution, G. J. PARKER, W. N. G. HITCHON, and J. E. LAWLER, Univ. of Wisconsin-Madison–An integral method of solving the modified Holstein-Biberman equation based on propagator functions is further developed. This method is used with a Voigt lineshape and partial frequency redistribution in an infinite plane parallel, a spherical geometry, and an infinite cylindrical geometry. An emission spectrum is also generated in these simulations. Simple analytic expressions are derived for the propagator matrix elements in the standard high symmetry geometries, and a Monte Carlo method is used to evaluate the propagator matrix elements in more complex cases. Time dependent spatial maps of the resonance atom density and emission spectrum are computed from production rates per unit volume with arbitrary spatial and temporal dependences. The huge speed advantage of a propagator function simulation over a pure Monte Carlo simulation makes the propagator function method ideal for simulations of glow discharges in which resonance atoms dominate the ionization and/or power balance.

PB-4 Simulation of Electron Density Increase during the After-Glow of an RF Discharge,* P.J.DRALLOS, Dept. of Phys and Astron, Univ. of Toledo, Toledo, OH 43606 and M.E.RILEY, Sandia National Labs, Albuquerque, NM 87185 - Numerical simulations of the after-glow of capacitively-coupled, radio-frequency-driven He discharges have been performed. The solutions incorporate a self-consistent, fully kinetic solution of the time-dependent Boltzmann equation coupled with a novel time-cycle-average equation method[1]. Our results indicate that, during the after-glow, the electrons and ions can undergo nearly a four-fold increase in density. We have determined that the increase in density is due to the large metastable populations. During the early stages of the after-glow, metastable-metastable collisions continue to produce electrons and ions. However, unlike the the mobility-dominated transport during the rf-driven discharge, the after-glow transport is controlled by the much slower ambipolar diffusion. When the metastable densities are much larger than the plasma density, the ion production rate may exceed the diffusion loss rate, allowing the plasma density to increase. These results are in good agreement with experimental observations[2].

* This work supported in part by Sandia Natioinal Laboratories and the USDOE under contract No. DE-AC04-76DP00789.

[1] P.J.Drallos and M.E.Riley, submitted to J. Comp. Phys., June 1993.

[2]K.E.Greenberg, and G.A.Hebner, J. Appl. Phys., June 15 (1993).

PB-5 **Modeling the positive column of a fluorescent lamp without mercury*** TIMOTHY J. SOMMERER *Corporate Research and Development, General Electric Company, P. O. Box 8, Schenectady, New York 12301*—We are investigating various discharge/phosphor systems with the goal of developing a mercury-free replacement for existing fluorescent lamps. The initial work centers on an Ar/Xe positive column discharge combined with a quantum splitting phosphor. This talk will outline the modeling issues and report results from from fluid and kinetic/fluid hybrid models of the Ar/Xe positive column. The fluid model is based on a "two-temperature" electron model of the Ar/Hg positive column [1], which includes all pertinent gas phase reaction and radiation transport mechanisms. Replacement of the "two-temperature" electron model with a kinetic description of the electrons allows one to accurately include important processes such as the excitation of high-lying Xe levels and Ar metastable levels.

*Work partially supported under the NIST Advanced Technology Program, Cooperative Agreement 70NANB3H1372.

1. J. T. Dakin and L. Bigio, J. Appl. Phys., **63** 5270 (1988).

PB-6 CRITICAL DRIFT VELOCITY FOR STABLE POSITIVE COLUMN OF A LOW PRESSURE DISCHARGE, H.S. Maciel and G. Petraconi, ITA/CTA, 12228-900, São José dos Campos-Brazil - Plasma parameters including electron drift velocity (V_{de}) have been measured by means of electrostatic probes in a positive column of a mercury discharge operating with vapour pressure in the range of 10^{-4} - 10^{-3} torr and current in the range of 2.0 - 4.0 A.The plasma column is considered as a three-component, low pressure fluid, in which ionization and colisions play a significant role.The application of the generalized Hurwitz Criterion for stability is found to predict an electrostatic instability when the electron drift velocity exceeds 0.82 of the electron thermal velocity (V_{te}). Measurements of (V_{de}) were made by using the directional probe method of Maciel and Allen[1] and by means of a double probe technique suggested by Ariga[2]. The results confirm that above this critical value of V_{de}, strong oscillations set in and double layers are shown to form in the plasma column.

[1]-Maciel and Allen, Journal of Plasmas Phys.42, 321 (1989).

[2]-Seiichi Ariga, Journal Phys. Society of Japan, 31, 4 (1971).

PB-7 The Effect of Elastic and Inelastic Angular Distributions on Discharge Simulations, W. N. G. HITCHON, G. J. PARKER, and J. E. LAWLER, Univ. of Wisconsin-Madison –A very detailed, self-consistent kinetic discharge model is used to examine the effect of various representations of collisional processes in determining the discharge model behavior. The effects of allowing anisotropy in elastic collisions instead of using the momentum transfer cross-section, the effects of allowing partial momentum conservation in inelastic collisions, and the effects of including a Coulomb collision operator are all described. Both dc and rf discharges are considered. It is shown that all of the approximations described above can make a profound difference to model predictions. This confirms that many discharge simulations have great sensitivity to the physical and numerical approximations. Our results reinforce the importance of using kinetic theory models with highly realistic approximations of various collisional processes.

PB-8 Excitation Processes in the Particle Beam Pumped Atomic Ar Laser Using He/Ar Mixtures. * Jong W. Shon John M. Lape and Mark J. Kushner, Univ. of Illinois, Dept. of Elect. and Comp. Engr., Urbana, IL 61801 - The particle beam excited high pressure atomic Ar laser (3d → 3s) using He/Ar gas mixtures operates on at least three infrared transitions (1.27 μm, 1.79 μm, and 2.4 μm) with efficiencies > 1%. The upper laser level of the 1.79 μm transition may be populated by three body recombination of Ar^+ and Ar_2^+, radiative decay, quenching of higher lying excited states, and dissociative recombination of $HeAr^+$. The branching ratios for these processes in large part determine the dependence of laser performance on gas mixture and pressure. A computer model of the Ar laser using He/Ar mixtures has been developed to investigate excitation mechanisms and methods to optimize the laser's performance. The model contains 18 atomic levels in Ar to resolve gain on the cited transitions, and uses a Monte Carlo simulation to obtain excitation rates. Results from the model and comparisons to experiment for gain and laser oscillation in fission fragment and e-beam pumped plasmas will be discussed as a function of gas mixture, power and pressure.

* Work supported by Sandia National Laboratory.

SESSION QA: THERMAL PLASMAS AND PLASMA TORCHES II

Friday morning, 22 October 1993
Grand Salon A, 10:15–11:45
D.C. Schram, presiding

Invited Papers

QA-1 Characterization of Thermal Plasma Jets,*
E. PFENDER, Dept. of Mechanical Eng. and ERC for Plasma-Aided Manufacturing, U. of Minnesota -
In the first part of this overview, the behavior of a typical plasma jet as used, for example, for plasma spraying will be reviewed, including the effects of arc behavior on the jet structure, transition to turbulence, gas entrainment, demixing effects, and the associated problems of measuring temperature and velocity fields using spectroscopy and enthalpy (pitot) probes. - In the second part, modeling attempts of plasma jets will be reported with emphasis on argon plasma jets in ambient argon.

* Work supported in part by NSF, ECD-87-21545

QA-2 Recovery of Aluminium from Dross in a Rotary arc furnace, M.G. DROUET, M.D. HANDFIELD, J. MEUNIER and C. LAFLAMME - An innovative technology for the treatment of aluminium dross is being implemented in industry. The technology is based on a rotary arc furnace using two graphite electrodes. A 650 kW pilot plant is made available for industrial customers to test their particular dross. A first unit of 1.5 MW is being installed to replace a gas-fired furnace. The new technology avoids massive additions of fluxing salts, it decreases the dusts entrained and the thermal losses due to the off-gas. As compared with the Alcan process which uses a 1.5 MW plasma torch, the proposed technology presents higher energy efficiency, better metal recovery and no explosion risk associated with water leakage from the plasma torch. Moreover, the investment and operating costs are substantially lower. The results from the 650 kW pilot plant tests and the commissioning of the industrial unit will be presented.

Contributed Paper

QA-3 Mechanisms of Electron re-Heating in Nitrogen Plasma Jet, Y. TAKAKURA, S. ONO and S. TEII, Musashi Inst. of Tech. Tokyo, JAPAN -- Results are reported for the heating of electrons in the down stream region of DC plasma jet. The electron temperature and electron density axial profiles have been measured by the electrostatic double probe method. The electron temperature ($\simeq$1.5 $\sim$0.5eV) once decreases along the gas flow axis but increases again at downstream region. This re-heating phenomena has been explained by the super-elastic collision between the electron and the vibrationally excited nitrogen molecules. The mechanism of the vibrational temperature re-heating has been confirmed by the spectroscopic measurement of the vibrational temperature of the nitrogen molecules exist in the plasma jet as well as the theoretical calculation. All data will be presented and discussed.

SESSION QB: SHEATHS AND BREAKDOWN

Friday morning, 22 October 1993
Grand Salon C, 10:15–12:15
J.F. Waymouth, presiding

QB-1 Two Different Types of Boundary Sheaths in Low Pressure Plasmas*
H.-B. VALENTINI, IPHT inc. Jena -
Using a steady-state two-fluid model and simple geometries it is shown that two types of boundary sheaths can exist in low pressure plasmas. Additionally to the well-known positively charged boundary layer where the electron drift nearly attains the sound speed, under certain conditions, e.g., by laser light produced plasmas[1,2], around a slightly positive plasma core a very weakly negative or quasi-neutral boundary region of large dimension can occur where the electron drift velocity remains small. The transition between both the types of mathematical solutions of the basic equations takes place relatively suddenly. Related phenomena as plasma expansion into vacuum and the contracted column are discussed. Various parameters as various Knudsen numbers and various charge to mass ratios are included.

*Work supported by Deutsche Forschungsgemeinschaft

[1]I.M. Cohen, Phys. Fluids 8, 2097 (1965)
[2]K.-U. Riemann, Phys. Fluids B3, 3331 (1991)

QB-2 A Kinetic Study of Sheath Propagation in Two Dimensions,* E.R. KEITER and W.N.G. HITCHON, Engineering Research Center for Plasma-Aided Manufacturing, University of Wisconsin-Madison - Sheath propagation in Plasma Source Ion Implantation(PSII) is modeled using a two dimensional kinetic description, originally described in one dimension by Hitchon, et. al.[1] The ion distribution function f_i is calculated as a function of time, self-consistently with the electrostatic potential Φ in two spatial coordinates. The instantaneous and integrated fluxes of ions as functions of energy at the surface of the target and the sheath propagation rate are the main quantities of interest. Comparisons with the measured propagation rate are made, in the real geometry for different neutral pressures and electron temperatures. The variation in the ion fluxes with position on the target and with process parameters such as the applied voltage is also presented.

* Work supported by NSF grant #ECD-8721545.

[1] W.N.G.Hitchon, D.J. Koch, and J.B. Adams, J. Comp Phys., 83, 79 (1989)

QB-3 Measurements and calculations of the sheath length in low pressure discharge. K. B. Liland, L. C. Pitchford (CNRS, CPAT, Toulouse), A. M. Pointu (LPGP Orsay) and M. Ganciu (IFTAR, Margurele, Bucharest, Romania). An experimental method has been developed to estimate the sheath length in a glow discharge at low pressure [1]. We present here results from a 1-D fluid model with non local ionisation (Monte Carlo simulations). By smoothly increasing the voltage from a steady state to a higher voltage during some ns the responding current is calculated. The time integrated current is used in the calculation of the sheath length. The ratio between the transient capacitive voltage (voltage increase) divided by the integral of the current is equal to the capacitance between the ions at the sheath edge and the cathode. We find excellent agreement between the sheath length calculated from this method and that determined directly from the calculation of the electric field (5%).

1. Application to the sheath width measurement. M. Ganciu and A. M. Pointu, XXI ICPIG, 1993.

QB-4 Model Prediction of the Arc-Cathode Interaction of Free-Burning Arcs,* X. ZHOU, J. HEBERLEIN, and E. PFENDER, U. of Minnesota- A theoretical model has been formulated describing the influence of the arc condition and the cathode material on arc cathode erosion. A realistic, one-dimensional sheath model has been used supplemented by an integral energy balance of the ionization zone between the sheath and the arc, and by a differential energy balance of the cathode. The results of the calculations show that for high current applications the thermionic emission dominates in the removing of the energy flux from the cathode spot, and for these conditions the thermal design of the cathode plays a secondary role. In contrast, for low currents, the cooling of the cathode spot will be dominated by the thermal characteristics of the cathode material in the case of nitrogen and argon plasmas, but the cooling of the cathode spot will be affected by both the thermionic emission and the thermal design of the cathode or will even be dominated by the thermionic emission for hydrogen plasmas. The results are in reasonably good agreement with the experimental results.

*Work supported in part by NASA Lewis Research Center through grant No. NASA/NAG3-1332.

QB-5 Theory of the cathode spot in a vacuum arc, K.-U. RIEMANN, Inst. für Theoretische Physik, Ruhr-Universität Bochum, D-44780 Bochum, Germany. We consider the sheath region in front of the cathode of an vacuum arc. A previos theory of the boundary layer of a plasma in Saha ionization equlibrium is applied to the plasma ball in front of the cathode spot [1,2]. It results in a strong density decrease from the plasma ball to the sheath edge. This density decrease and an improved plasma energy balance is accounted for in a unified theory of the arc cathode starting from Ecker's existence diagram methode [3] and indicating possible areas of arc spot operation in the T_c–j–plane, where T_c is temperature and j the current density of the cathode spot. Evaluating the analysis for the case of a copper metal vapor arc, we find an existence area which is essentially increased in comparision to Ecker's results. Due to this increased existence area, Ecker's 0- and 1-mode grow together for high very current densities.

[1] K.-U. Riemann, J. Phys. D: Appl. Phys. **25**, 1432 (1992)
[2] K.-U. Riemann, IEEE Trans. Plasma Sci. **17**, 641 (1989)
[3] G. Ecker in: *J.M. Lafferty (ed.) Vacuuum Arcs — Theory and Application*, Wiley, New York 1980

QB-6 Dynamics of the Barium Emissions and the Electrode Temperature of a Fluorescent Lamp, K. MISONO* and J. T. VERDEYEN, Dept. of Electrical and Computer Engineering, University of Illinois 61801 – The time dependence of the emissions from neutral (5535Å) and ionized (4554Å) barium and the electrode temperature have been investigated using a square wave current source of variable frequency (6–3000 Hz). Although the hot spot temperature decreased during the anode cycle at low frequency, the emission from both species was virtually undetectable during that phase of the operation. Both Ba and Ba^+ emissions were detected during the cathode cycle and increased with time. At higher frequencies (~600 Hz), most of the electrode heating occurs during the cathode cycle because of the disappearance of anode fall. The time averaged absolute temperature decreases during high frequency operation. A mathematical model based upon the continuity equations for Ba, Ba*, Ba^+ and Ba^{++} will be discussed and correlated with the experimental results.

*Visiting scholar from Toshiba.

QB-7
Application of Paschen's Law in HID Lamp Design,
H. Gu and N. Brates, Osram Sylvania, Inc.
The implication of Paschen's law as it affects the design and operation metal halide discharge lamps is presented. Breakdown voltages, V_b, were measured for arc tubes with fixed electrode to starting probe distance "d" and various argon gas fill pressures "p". No conclusion could be drawn from the measurements carried out at room temperature due to small amount of mercury residue inside the arc tubes introduced by exhausting process. A correlation between V_b and product of pd is obtained for the lamps started in a cold box at temperature of -22°C (V_b = 241 + 11.8 pd, R=0.88, with pd range of 8-20 torr-cm). Because of different work function of the electrodes, the slope of the curve for these lamps is slightly smaller than that of classical curve for argon[1]. Secondary ionization coefficient for thoriated tungsten electrode was computed and equals to 0.050±0.022. Optimum gas fill pressure is experimentally determined with consideration of minimum breakdown voltage and desired lamp performance.

[1] M. J. Druyvesteyn and F. M. Penning, Review of Modern Physics 12, 114 (1940)

QB-8 Gas Discharge Triggered by Cold Electron Sources, S. LAUBE, M. FITAIRE, *A. TALSKY, P. GARCIA, M. AGACHE, E. LEDUC, LPGP, Univ. Paris-Sud, France, *Univ. Masaryk, Brno, CS -
Presence of electrons is a necessary condition for electrical breakdown in a gas-filled gap. We report here experimental results on the influence of electron emitters on the breakdown voltage.
Two types of emitting systems have been used by applying high electric fields on an insulator: (a) a pseudo-cathode (PC) where a dielectric sheet (thickness≈100 μm, diameter=35 mm) is sandwiched between a conducting plate and a grounded grid, (b) a MIM (Metal-Isolator-Metal) system where an oxide layer (thickness≈10 nm) is sandwiched between two thin deposited layers of metal.
These two systems have been used to help to trigger gas discharges. The measurements show similar results: the breakdown voltage may be reduced to a limiting value near the extinction voltage; this behaviour is explained with the help of a probabilistic model.

SESSION RA: PLASMA-SURFACE INTERACTIONS
Friday afternoon, 22 October 1993
Grand Salon A, 13:30–15:45
D.B. Graves, presiding

RA-1 Interactions of Hyperthermal Fluorine Atoms with a Silicon Surface K. P. GIAPIS and T. A. MOORE, Division of Chemistry and Chemical Engineering, and T. K. MINTON Jet Propulsion Laboratory, California Institute of Technology - The precise profile evolution in the etching of features on semiconductors depends critically on the detailed interaction mechanisms of the etching species with the bombarded surfaces. While the reactions of directly impinging ions and atoms may dominate etching, the majority of these will scatter inelastically, and their second impingement on the sidewalls may affect anisotropy. We have undertaken the study of the inelastic and reactive scattering of energetic fluorine atoms with a silicon surface. A molecular beam of fluorine atoms, with energies between 2.5-6.0 eV, is produced by laser induced breakdown of a controlled amount of SF_6. The beam is directed at a Si target, which is placed at the center of rotation of a rotatable mass spectrometer detector. Both surface and detector rotate about the same axis, so scattered products and their flux can be determined as a function of the incident and final angles, θ_i and θ_f. New data show that inelastically scattered fluorine atoms lose >50% of their incident energy at the surface and that they scatter over a wide angular range. The fraction of incident energy lost increases when the incident energy is decreased. In addition, impulsive energy transfer is the same for the same included angle (θ_i and θ_f). The implications of these observations in the reduction of anisotropy during plasma etching of semiconductors will be discussed.

RA-2 Role of Low Energy Ion Bombardment in Plasma-Surface Chemistry: Molecular Dynamics Simulations of Silicon Etching M.E. BARONE, and D. B. GRAVES Department of

Chemical Engineering, University of California - We explore the role of low energy (<100 eV) ion bombardment in enhancing fluorine etching of silicon using molecular dynamics (MD) simulations. MD simulations are an ideal tool to understand the complex dynamics of surface and near-surface processes during the brief but intense collision cascade caused by the impact of a fast ion or neutral at a surface undergoing plasma processing. It is known that substantial etch rates of Si can be obtained using ion energies near threshold. Since the collision cascade is complete within a fraction of a picosecond, the role of the energetic species in enhancing etch rates has been difficult to determine. We examine the role of enhanced spontaneous etching, in which energetic species serve the purpose of creating partially fluorinated silicon, during the collision cascade, which later react with thermal F atoms, creating the etch product that desorbs spontaneously. Accuracy in simulating details of energy deposition and dissipation during the collision cascade is essential to capture the true chemistry and physics of this process. We examine the processes by which mass, momentum and energy are transported during the collision cascade. Video illustrations of events occurring during ion-assisted etching will be presented.

RA-3 Reactive Ion Etching of Silicon in $CBrF_3$ Plasma: Pressure and Power Effects on the Etching Characteristics, H. S. MACIEL and R. K. YAMAMOTO, ITA/CTA and LSI/PEE/EPUSP - The characteristics of the reactive ion etching of silicon have been investigated as a function of pressure and power in $CBrF_3$ plasma. The characterization was performed in a home-made RIE reactor using a 13.56 MHz RF generator. The pressure and power were varied between 50 and 300 mTorr, and 50 and 200 W, respectively, with gas flow rate fixed at 20 sccm. The silicon etch rate was 60 to 190 nm/min and the silicon to silicon oxide selectivity varied between 1:1 and 4:1. The silicon etch rate was observed to increase with pressure and power. The silicon etch profile degradation was observed under high pressure (because of a decrease of the mean free path of the impinging ions) and under high power (because of an increase of the ion bombardment energy). The silicon to silicon oxide selectivity increased with pressure and decreased with power. Best silicon etch profiles were obtained under the conditions of 50 mTorr and 50 W, and 100 mTorr and 100 W.

RA-4 Spatially Resolved Plasma and Wafer Surface Potential Measurements*, T.J. Dalton and H.H. Sawin, Massachusetts Institute of Technology - Variations in both plasma and wafer surface potential have been measured on an Applied Materials Precision 5000 plasma etcher using a tuned langmuir probe. Surface potential variation caused by nonuniform plasma is an important cause of gate oxide breakdown during plasma etching of polysilicon gates. Surface potential variation is negligible in the absence of a magnetic field. The presence of a 100 Gauss field can induce surface potential variations of 15 volts or larger. The observed surface potential variations correlate with both magnetic field direction and plasma potential variations. A neural network analysis has been done to characterize the effect of process variables (rf power, pressure, magnetic field strength) on wafer surface potential variations for Ar and Cl_2 chemistries.

*Work supported by SEMATECH under contract 91-MC-503.

RA-5 Threshold Ion Energies in the Film Growth by Dual-Frequency Plasmas, L. MARTINU, J.E. KLEMBERG-SAPIEHA, O.M. KÜTTEL, A. RAVEH and M.R. WERTHEIMER, École Polytechnique, Montreal, Quebec, Canada - Ion bombardment which occurs concurrently with plasma-assisted film growth can greatly enhance the resulting film properties, even when deposition occurs at low substrate temperature T_s. In the present work we use a dual-mode microwave/radio frequency (2.45 GHz/13.56 MHz) plasma to independently control the energy and flux of ions impinging upon a growing film surface. We have determined values of the threshold ion energy, $E_{i,c}$, and of the threshold ion/neutral flux ratios, $(\phi_i/\phi_N)_C$, which we identify by transition in the films' structure-related characteristics, such as density, microhardness, internal stress and electrical resistivity. Different $[E_{i,c}; (\phi_i/\phi_N)_C]$ values have been found for various amorphous materials investigated, namely SiO_2:H [70eV, 0.26], SiN:H [170eV, 0.60] and a-C:H [80eV, 0.28]. We interpret these results in terms of various phenomena occurring during the growth process, namely surface mobility of precursor species, subplantation in hydrogen-rich surfaces, and of phenomena in the plasma sheath region.

RA-6 Nonmetallic Magnetic Hard Disks Using Plasma Source Oxygen-Implanted Iron-Doped Glass,* J.H. BOOSKE, F.S.B. ANDERSON, E. WICKESBERG, R.F. COOPER,** J. JACOBS J.L. SHOHET, L. ZHANG, and B. RATCHEV, Engineering Research Center for Plasma-Aided Manufacturing, University of Wisconsin-Madison--We describe a novel process to fabricate a thin non metallic magneticmedium with isolated, 10 nm-scale magnetic grains. The concept's objective is to fabricate magnetic hard disk substrates with high read-write spatial resolution with practical process timescales (hours). The technique involves oxidation of a ferrous-iron-doped magnesium-alumino-silicate glass, causing nucleation of $MgFe_2O_4$ ferrite spinel crystallites.[1] The oxidation reaction is driven by Plasma Source Ion Implantation (PSII) of oxygen into the iron-doped glass substrates. The work will determine whether PSII can repeat previous furnace-driven-surface-diffusion results[1] with faster process times, as well as whether one can regulate the size and spacing of the ferrite precipitate grains by controlling the oxygen ion fluence, dosage, and implant energy.

*Work Supported by the National Science Foundation under Grant ECD-8721545
** Dept. of Material Sciences & Engineering-Univ. of Wisconsin-Madison

1 G.B. Cook, R.F. Cooper, and T. Wu, "Chemical Diffusion and Crystalline Nucleation During Oxidation of Ferrous Iron-Bearing Magnesium Aluminosilicate Glass," J. Non-Crystalline Solids 120, 207-222 (1990).

RA-7 VUV-induced Oxidation of Polyethylene. A. Holländer, J. Klemberg-Sapieha, M. R. Wertheimer, Dept. Engineering Physics, École Polytechnique Montréal, Canada.
Short wavelength radiation can play an important role during the surface treatment of polymers by low pressure plasma, but this fact is frequently overlooked. We have investigated the effect of vuv radiation (112 nm < λ < 180 nm) on polyethylene (PE) films as follows: The polymer, placed in an atmosphere of low pressure oxygen gas, was exposed to radiation from hydrogen-based plasmas. PE has a strong absorption below 160 nm with a maximum at 90 nm; Oxygen molecules absorb between 135 and 170 nmwhich results in the dissociation to ground state and excited atomic oxygen (AO). VUV emission of H_2/O_2 and He/H_2 plasmas lead almost exclusively to AO formation and PE excitation, respectively, while pure H_2 plasma results in both. It was found that VUV excitation of PE contributes greatly to the rate of oxidation, contrary to the reaction of the polymer with AO.

RA-8 Fast Expanding Plasma Beam Deposition of C and Si-Thin Layers, D.C. SCHRAM, J.W.A.M. GIELEN, A.J.M. BUURON, G.J. MEEUSEN, S.N. DOUMTCHENKO, P.D.

HAALAND and M.C.M. VAN DE SANDEN, Eindhoven Univ. Techn. - In the expanding plasma beam deposition method fast deposition (up to 100 nm/s) is achieved by effective transfer of ionization and dissociation to the injected monomers as C_nH_m, CO_2, and SiH_4 from the high intensity Ar, or Ar/H thermal plasma source. The binding energy in the expanding argon, or argon/hydrogen plasma beam is transferred to the monomers by asymmetric charge exchange and dissociative recombination. Several deposition results on amorphous (a:C-H and a:Si-H) and crystalline (diamond) layers are presented. The role of radicals and ions and the influence of flow and recirculation patterns are discussed.

RA-9

Spectral Emission from Substrate Species in a Surface Discharge*

R. Schaefer, W.J. Schafer Associates, Inc. - The surface discharge (SD) is a versatile plasma light source which has been used for many applications, ranging from pumping lasers to treating contaminated water. Spectra from SD light sources can differ from standard flashlamps due to the spectral contribution from the substrate material. In this paper spectral data is presented showing the variation of substrate spectral contributions from a SD on fused silica in argon and krypton at different electrical power densities. Emission lines over 200-400 NM associated with silicon and the rare gases are identified. As the power density is increased, the relative strength of the spectral contribution from the substrate increases relative to the contribution from the rare gas. It is shown using a simple model that the initial appearance of substrate spectral output correlates with the vaporization of substrate material.

*Work supported in part by the U.S. Dept. of Energy

SESSION RB: DIAGNOSTICS
Friday afternoon, 22 October 1993
Grand Salon C, 13:30–15:45
G.S. Selwyn, presiding

RB-1 Absolute hydrocarbon densities in a diamond growth DC discharge,* K. L. MENNINGEN, M. A. CHILDS, H. TOYODA, L. W. ANDERSON, AND J. E. LAWLER, University of Wisconsin. - A highly sensitive multi-element optical absorption technique is used to measure the absolute column density of methyl radicals and CH in a dc hollow cathode plasma-assisted diamond chemical vapor deposition (CVD) system with CH_4 and H_2 used as the input gases. The plasma gas temperature is determined at different spatial points using the H_2 emission spectrum. The temperature and radical density spatial maps provide clues to the chemical processes taking place in the discharge. Comparison with measurements made in a hot filament CVD system reveals some of the similarities and differences between the two deposition methods.

*Work supported by the Army Research Office.

RB-2 Electric Field Measurements by Laser Spectroscopy of H atoms: Time-resolved results in 30kHz discharges, J.P.BOOTH, M.FADLALLAH, J.DEROUARD and N.SADEGHI Lab. de Spectrométrie Physique, Univ. Grenoble 1, France- A new method for non-perturbative in-situ determination of electric fields in discharges has been develloped, based on laser induced fluorescence of Rydberg state H atoms. The atoms are excited to the n=2 state by two photons at 243nm, then further excited to n=6 by one photon at 410nm, with detection of the Hα emission, produced by radiative and collisional cascading. Analysis of the Stark splitting of the n=6 state, observed from the structure of the 2-6 excitation profile, allows the electric field to be determined. Results are presented for 30kHz, 1Torr H_2 discharges, with temporal (30ns) and spatial (0.5mm) resolution and detection of fields as low as 20V/cm. As well as the previously observed temporal asymmetry of the cathode sheath[1], we have measured fields of up to 100V/cm close to the electrode in the anodic half-cycle.

[1]J.P.Booth, J.Derouard, M.Fadlallah, and N.Sadeghi, J.Appl.Phys. (to be published, 1993)

RB-3 Electric-Field Measurements in 13.56-MHz Helium Discharges, K. E. GREENBERG and G. A. HEBNER, Sandia National Labs - In previous studies,[1,2] Rydberg atom spectroscopy was used to measure electric fields in DC and 15-kHz helium discharges. Those studies utilized the optogalvanic effect to detect excitation of the Rydberg states. We have developed a variation of this technique that allows the measurement of electric fields in high-frequency (13.56 MHz) discharges and has much greater spatial resolution. These improvements arise from the detection of the Rydberg Stark manifolds by laser-induced fluorescence rather than by the optogalvanic effect. When helium Rydberg levels are excited by a laser, many other excited states are populated by collisional transfer and subsequent cascading processes; fluorescence from these other excited states can be used to monitor the excitation and structure of the Rydberg Stark manifolds. As an example, electric fields were measured in 0.5-Torr parallel-plate discharges by exciting the n=11 singlet manifold and monitoring fluorescence from the 1s2p←1s3d triplet transition.

[1]D. K. Doughty and J. E. Lawler, Appl. Phys. Lett. 45, 611(1984).

[2]B. L. Preppernau and B. N. Ganguly, Rev. Sci. Instrum. 64, 1414(1993).

RB-4 Analysis of Transient Laser Optogalvanic Signals in a Capacitively Coupled Neon RF Discharge,* R. R. ZINN, D. KUMAR, and S. P. MCGLYNN, Department of Chemistry, LSU, Baton Rouge, LA - Temporal profiles of pulsed-laser induced transient optogalvanic signals in several $1s_j$ -> $2p_k$ (Paschen notation) excitations in a 0.5 W, ~ 30 MHz rf discharge in ~ 5 torr neon have been analyzed. A recently developed method permits separation of two distinct components in the optogalvanic signals, one generated by laser-induced changes in the equilibrium ionization rates, and the other generated by a photoacoustic effect.[1] Curve-fitting software is used to deconvolute the two components into their various subcomponents. Significance of these components will be discussed. This analysis may enable us to predict temporal profile for other transitions in the same $1s_j$ -> $2p_k$ group.

*Work supported by grants from U. S. Department of Energy and the LSU Center for Energy Studies.

[1]D. Kumar and S. P. McGlynn, J. Chem. Phys. 93, 3899 (1990); Chem. Phys. Lett. 176, 536(1991).

RB-5 Probes as Internal Surfaces in Bounded Plasmas*
H.-B. VALENTINI, E. GLAUCHE, D. WOLFF, D. KAISER**, M. HERMANN**, IPHT inc. Jena, **University Jena, Germany - Using a steady-state two-fluid model[1,2] and coaxial and concentric geometries, single and double probes are treated as internal boundaries in bounded plasmas. Generation of charge carriers, elastic and charge exchange collisions and various charge to mass ratios are included. Boundary conditions are studied for various physical conditions[2]. Results are given for number densities, drift velocities, the electric potential and the characteristics of probes. In particular, the dimensions of the regions of particle collections are exactly calculated for electrons and ions. An electromotive force can arise between walls of different curvature[2]. Additionally, a mathematical description of the origin of the anode fall is elaborated.

*Work supported by Deutsche Forschungsgemeinschaft

[1]R.N. Franklin, Plasma Phenomena in Gas Discharges (Oxford: Clarendon 1976).
[2]H.-B. Valentini, J. Phys. D:Appl.Phys. (1993) (is printing)

RB-6 Langmuir-Probe Measurements in Flowing Afterglow Plasmas. R. JOHNSEN and E. V. SHUN'KO, UNIVERSITY OF PITTSBURGH--Langmuir probes are used extensively to measure electron and ion densities in flowing afterglow experiments. Our recent experiments in flowing afterglows (electron densities from 10^8 to 10^{10} cm^{-3}, helium pressure of 1.6 Torr) with cylindrical Langmuir probes of different sizes (diameters of 10 and 25 μm) show, however, that the inference of ion densities from the observed ion-current vs. voltage characteristics is seriously flawed. The orbital-limited probe theory yields ion densities that are larger by factors of 10 to 20 than the electron densities! Furthermore, the collected ion currents do not scale linearly with probe area, as predicted by theory, but they are nearly independent of it! We conclude that the orbital-limited theory fails for ion collection because it ignores ion-atom collision in the probe vicinity. However, the collisionless theory seems to work fairly well for electrons. The measured discrepancies between the ion and electron collecting modes are far worse than indicated by early work in afterglow plasmas[1] at low pressures and confirm recent work in discharge plasmas by Sudit and Woods[2].

1 D. Smith and I.C. Plumb, J. Phys. D 6, 196 (1973)
2. D. Sudit and R.C. Woods, Paper given at the 45th Gaseous Electronics Conference, and private communication
*This work was, in part, supported by NASA

RB-7 Quantitative Studies of Probe Surface Contamination in Reactive Gaseous Plasmas, S.TEII, S.ONO, Musashi Institute of Technology,Tokyo Japan and K.SHINOHARA Nihon Koushuha Co. Ltd. Yokohama, Japan. Probe surface contamination and its influences on the probe measurement in reactive gaseous plasmas have been quantatively studied by using the parameter C which is defined as the ratio of electron current to ion current of a probe. When the probe is contaminated, the parameter C, that is, the degree of probe cleanliness decreases and the probe curve becomes distorted. Experimental results show that for the case of Ar+SiH_4 (0.04%) gas mixture discharge, the parameter C decreases to 80 % within 30 seconds after starting the measurement and the determined Te and Ne under this condition include error of approximately 27 % and 40 %, respectively. The recovery of parameter C can be achieved both by the method of ion bombardment and the current heating. The decreasing rate and recovering rate of parameter C depend on the kinds of gases as well as the applied bomberment voltage and heating current. Data will be presented and discussed.

RB-8 Measurement of Acoustic Spectrum in Electrodeless Microwave Powered Arcs, W. P. LAPATOVICH and S. J. BUTLER, OSRAM SYLVANIA INC., Salem, MA - Acoustic effects in lighting related discharges have been studied as both desirable[1] and undesirable[2] phenomena. We describe a non-invasive technique for mapping the acoustic spectrum of small electrodeless microwave driven arcs. The acoustic resonances are excited by amplitude modulation of the microwave drive signal and are detected by both optical and electronic means. Optical detection consists of monitoring the displacement of the arc channel. Small modulation depths (≈10%) are required to achieve macroscopic arc deflections. Electronic detection is more sensitive and can detect resonances at lower modulation depths which do not cause macroscopic arc deflection. This is accomplished by a sweeping the modulation frequency while monitoring the amplitude and phase of the envelope of the reflected microwave energy, using a phase locked tuned receiver. Resonant frequencies in the range of 15- to 500 kHz corresponding to longitudinal, azimuthal and radial modes were measured. Agreement of the observed spectra with theoretical predictions is good. The average speed of sound in the discharge vessel based on the spectra is approximately 430 ± 35 m/s.

[1]V. D. Roberts, U. S. Patent 4,983,889 (1991)
[2]H. L. Witting, J. Appl. Physics. 49(5), 2680. (1978)

RB-9 Phase Resolved Two-Dimensional Emission Profile of a LF Helium Discharge, B. N. GANGULY and A. GARSCADDEN, Wright Laboratory, WPAFB OH- Time resolved two-dimensional plasma induced emission intensity of a low frequency (30-100 KHz), low pressure (1-3 torr) symmetric helium glow discharge has been measured using a phase locked gated (≈ 100 nsec) intensified CCD detector and a narrow band 587.5 nm interference filter. The entire interelectrode gap is imaged on the 18 mm photocathode; 512 × 512 pixels image resolution permits spatially and temporally resolved emission intensity profile measurement of the entire discharge volume. The emission intensity profiles under the measured conditions do not exhibit spatially asymmetric behavior[1,2] during increasing and decreasing discharge current, although the emission intensities are not temporally symmetric about the voltage zero crossing. The conditions for spatial asymmetry have also been investigated.

[1] M. P. Alberta, H. Debontride, J. Derouard and N. Sadehi, J. Phys. III France 3, 105 (1993).
[2] J. P. Boeuf and P. Belenguer, NATO Advanced Study Institute Series B 220, 155, (Plenum, New York, 1990).

Postdeadline Papers—Program of the 46th Annual Gaseous Electronics Conference Montréal, Québec; 19–22 October 1993

SESSION D: POSTER SESSION
Tuesday afternoon, 19 October 1993
Grand Salon B, 15:45–17:30
J. Margot, presiding

DA: DIAGNOSTICS

DA-21 High Resolution Fourier Transform Spectroscopy of Discharge Generated Species in Supersonic Jets, J.W. BEVAN, Texas A&M University - Application of Fourier transform (FT) microwave and infrared spectroscopic techniques to discharge generated species in argon seeded supersonic jets is presented. Pulsed-nozzle FT microwave spectroscopic investigations of excited states up to $60^0 0$ and $00^0 4$ in OCS and $10^0 0$ states of van der Waals dimers Y--HX (Y=Ar,Kr and X=F,Cl) generated in glow discharges will be reported. Rotation, distortion and quadrupole constants are precisely determined in observed excited states. Predissociative lifetime studies of the latter will be made using a time-of-flight adaptation of this microwave spectroscopic technique. Results from these investigations will be compared with theoretical predictions on $10^0 0$ Ar-HCl. Extension of previous investigations to include high resolution Fourier transform absorption of hot bands in discharge generated species will also be considered.

SESSION J: POSTER SESSION
Wednesday afternoon, 20 October 1993
Grand Salon B, 15:45–17:30
M. Fréchette, presiding

JA: MODELING AND SIMULATION

JA-14 Simulation of the Plasma Chemistry of a Pulsed Corona Discharge in Dry and Humid Air,* M. JACOB, W.L. MORGAN† and E.R. FISHER, Mich. Tech. Univ., Houghton, MI - Corona discharges are commonly used for modifying polymer surfaces to improve coatability, wetting properties, and adhesion. The wettability of polypropylene films is altered by surfaces chemistry involving oxygen containing functional groups. We have modeled the time dependent non-equilibrium plasma chemistry of a pulsed DC discharge in atmospheric pressure N_2, O_2, and H_2O mixtures in an effort to understand the radical formation chemistry and ultimately provide guidance in optimizing discharge parameters and gas mixtures for surface treatment. For this modeling we have used the general plasma chemistry code, KINEMA†, coupled with the electron Boltzmann solver, ELENDIF†, and an air chemistry model comprising some 50 species and 300 reactions. We have been able to find reasonable operating conditions that maintain high production rates of species such as O and OH and minimize the formation rates of undesirable species such as O_3 and the nitrogen oxides. We have also investigated the effects of dissociation and formation of cluster ions on the threshold for breakdown.

* Work supported by the 3M Co., Minneapolis, MN.
† Kinema Research, P.O. Box 1147, Monument, CO 80132.

JA-15 Onset of Unstable Sheaths and Anomalous Transverse Ion "Temperature" near RF an DC Conducting Boundaries, J.H. WHEALTON, R.J. RARIDON, R.G. COWAN, J. NIEMEL, K. JAMESON and D.R. GAU, Fusion Energy Div., Oak Ridge National Lab. - Investigation of sheath structure and ion distribution functions at or near RF and DC conducting boundaries are examined. A self-consistent ion-time-scale 2D and 3D hybrid plasma model is incorporated which solves the relevant subset of Maxwell's equations fully coupled to the ion Vlasov equation. The treatment evolves from previous steady state 3D plasma edge treatments[1] and from 3D ion-time-scale beam dynamics considerations.[2] One mode of sheath instability identified in the calculations is related to the Bohm sheath criteria. Structure of sheaths and ion distribution functions are studied for several situations relevant to semi-conductor processing, plasma ion implantation, and negative ion extraction. One notable finding is that even near planar boundaries, turbulence may give rise to significant transverse random motion of ions. This may have an impact on anisotropy ratios for semi-conductor processing.

[1] J.H. Whealton, R.W. McGaffey, and P.S. Meszaros, J. Comput. Phys., **63**, 20 (1986).
[2] J.H. Whealton, B.D. Murphy, R.J. Raridon, K.E. Rothe, W.R. Becraft and T.L. Owens, Phys. Rev. **A45**, 4036 (1992).

JD: MICROWAVE PLASMAS

JD-6 Results from a Recently Constructed Plasma Source for Diamond Deposition, J. KHACHAN, J.R. PIGOTT, M.J. WOUTERS, G.F. BRAND, I.S. FALCONER and B.W. JAMES, School of Physics, University of Sydney, Australia 2006 - An inexpensive and simple microwave-produced plasma source has recently been constructed for plasma-assisted chemical vapor deposition of diamond thin films. Microwave power from a 700 watts domestic microwave oven magnetron is fed into a water-cooled cylindrical stainless steel vacuum vessel. A methane/hydrogen gas mixture introduced into the vessel is excited by the microwaves to produce a well-defined plasma ball which does not interact with the walls of the vessel. Electric double probe and spectroscopic measurements on the plasma as well as intrinsic stress and point defect results in the film will be presented and discussed.

SESSION L: POSTER SESSION
Thursday morning, 21 October 1993
Grand Salon B, 10:15–12:15
G. Sauvé, presiding

LB: ION TRANSPORT AND ION-MOLECULE COLLISIONS

LB-16 Plasma Characteristics of an RF H^- Source, S.J. COX, E. SURREY and A.J.T. HOLMES, AEA Technology, Culham, Abingdon, Oxfordshire, OX14 3DB, UK - Inductively coupled RF discharges are attractive for long life high efficiency operation and are being developed as sources for the production of intense H^- beams. At Culham, a cylindrical multicusp source has been built which incorporates an external 2 MHz RF drive and a magnetic filter. The hydrogen plasma produced by this device has been characterised extensively with Langmuir probes, using a detailed three-dimensional mapping technique. This has shown that the magnetic filter produces significant radial plasma density gradients which could lead to emittance growth when a beam is extracted from the source. In addition, the spatial distribution of the H^- density has been derived from probe data. This suggests that the negative ions are produced by a mechanism which optimises when the electrons temperature is in the narrow range 0.7-1.5 eV. Furthermore, there appears to be a strong relationship between plasma density and the negative ion density which stresses the importance of plasma confinement.

46th Annual Gaseous Electronics Conference: Author Index
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JUNE

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JULY

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AUGUST

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SEPTEMBER

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OCTOBER

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NOVEMBER

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DECEMBER

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1996

JANUARY

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FEBRUARY

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MARCH

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APRIL

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JUNE

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SEPTEMBER

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OCTOBER

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NOVEMBER

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DECEMBER

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JANUARY

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FEBRUARY

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MARCH

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APRIL

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MAY

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JUNE

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JULY

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AUGUST

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SEPTEMBER

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OCTOBER

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NOVEMBER

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DECEMBER

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General Meetings

Place	Meeting Dates	Deadline Dates
Pittsburgh, PA	21–25 March 1994	3 December 1993
Crystal City, VA (joint w/ AAPT)	18–22 April 1994	7 January 1994
San Jose, CA	20–24 March 1995	
Washington, DC	18–21 April 1995	

Divisional Meetings

Place	Division	Meeting Dates	Deadline Dates
Albuquerque, NM	Particles & Fields	2–6 August 1994	

Topical Group Meetings

Place	Topical Group	Meeting Dates	Deadline Dates
Dallas, TX	Laser Science (joint w/OSA)	2–7 October 1994	Past

Sectional Meetings

Place	Section	Meeting Dates	Deadline Dates
Dallas, TX	Texas	11–12 March 1994	11 February 1994
Cambridge, MA	New England	8–9 April 1994	
Cleveland, OH	Ohio	13–14 May 1994	
Toledo, OH	Ohio	14–15 October 1994	
Dallas, TX	Texas	5–6 November 1994	
Newport News, VA	Southeastern	10–12 November 1994	

Sponsored Conferences

Place	Conference Name	Meeting Dates	Deadline Dates
Raleigh, NC	Cornelius Lanczos Intl. Centenary Conf.	12–17 December 1993	Past
New Paltz, NY	21st Conf. on the Physics and Chemistry of Semiconductor Interfaces	24–28 January 1994	
Orlando, FL	1994 North American Conf. on Smart Structures and Materials	13–18 February 1994	
Shanghai, CHINA	2nd Intl. Conf. on Thin-Film Phys. & Appl.	15–17 April 1994	10 December 1993
Rochester, NY	10th Topical Conf. on High-Temperature Plasma Diagnostics	8–12 May 1994	
Gaitlinburg, TN	Intl. Conf. on Nuclear Data for Science and Technology	9–13 May 1994	Past
St. Petersburg, FL	5th Conf. on Intersections of Particle & Nuclear Physics	31 May–6 June	
San Diego, CA	World Congr. on Neural Networks '94	5–9 June 1994	
Chengdu, CHINA	Intl. Conf. on Plasma Science & Technology '94	13–17 June 1994	
Albuquerque, NM	6th Joint MMM-Intermag Conference	20–23 June 1994	
Snowmass, CO	Particle & Nuclear Astrophysics in the Next Millenium	29 June–14 July 1994	
Amsterdam, NETHERLANDS	Intl. Conf. on Strongly Correlated Electron Systems	15–18 August 1994	
Surrey, U.K.	8th Intl. Conf. on Quantitative Surface Analysis QSA-8)	23–26 August 1994	
Cancun, MEXICO	Canadian-American-Mexican Meeting of the Physical Societies (CAM94)	26–30 September 1994	
Orlando, FL	4th Conf. on Radiation Protection & Dosimetry	24–27 October 1994	

Reminder!!!
We've Moved!!

In October, The American Physical Society relocated to the American Center for Physics building in College Park, Maryland. Please note our new address for all future correspondence:

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College Park, MD 20740-3844
Telephone: (301) 209-3200

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