Plasma Science and Technology
Room Exhibit Hall C&D - Session PS-TuP
Plasma Science and Technology Poster Session

PS-TuP1 Aluminum Nitride formed by Expanding Thermal Arc Plasma Chemical Vapor Depositon*, **G.T. Dalakos**, H. Marek,* GE Global Research Center

This work involves very-high deposition rates of aluminum nitride thin films using a novel, high-density expanding plasma source to dissociate suitable gas-phase precursors. The plasma source is produced from a DC thermal arc discharge that expands into the vacuum deposition chamber, breaking up gas feedstock and forming film precursors. Due to the large, charged species concentration present in the arc source, use of this plasma source allows us to achieve unusually large deposition rates of a few microns/min. In this regard, we discuss the differences between our approach and conventional deposition approaches. We additionally discuss how experimental processing parameters of the expanding thermal arc source affects measured film properties such as composition, morphology and crystalline nature of our deposited films.

PS-TuP2 Study of Deposition Precursors in Amorphous Silicon Nitride Film Deposited by Plasma CVD*, **Y. Ichikawa**, M. Narita,* Fuji Electric Device Technology, Japan*; S. Fujikake,* Fuji Electric Advanced Technology, Japan

To understand the deposition mechanism of hydrogenated amorphous silicon nitride film (a-SiN:H) deposited by plasma CVD, we have studied the deposition precursors and their effective sticking coefficient both in SiH@sub 4@-NH@sub 3@ and SiH@sub 4@-N@sub 2@ gas mixture systems. The a-SiN:H films were deposited on a silicon wafer where a number of trenches with a width of 1µm were formed by etching, and then their film thickness profiles and composition on the trench wall were measured. These experimental results were compared with Monte-Carlo simulation to estimate the species of precursors and their vanishing probability on the deposition surface. The results showed that in SiH@sub 4@-NH@sub 3@ system the dominant precursor is one species (with a vanishing probability of 0.08) and the composition of the film does not vary along the trench wall. On the other hand, in SiH@sub 4@-N@sub 2@ system two species have to be taken into account to fit the simulation with experimental results; one species has a vanishing probability of 0.8 and the other has that of 0.05. Moreover, the composition of the film varies along the trench wall; the ratio of nitrogen to silicon increases with increasing distance from the surface in a trench.

PS-TuP3 Deposition of SiOxNy Films by PE-CVD for OLED Passivation*, **J.H. Lee**, C.H. Jeong, J.T. Lim, J.H. Lim, S.-J. Kyung, G.Y. Yeom,* Sungkyunkwan University, Korea

To prevent the permeation of H@sub 2@O and O@sub 2@ to the devices, the encapsulation of the devices such as metal encapsulation and glass encapsulation are currently used for OLED devices, however, thin film passivation instead of the encapsulation on these devices are preferred for the lighter weight, wider viewing angle, flexibility, etc. Therefore, various permeation barrier materials and various deposition methods for these materials are intensively investigated for the passivation of the next generation flexible flat panel display (FPD) devices such as OTFTs and OLEDs. In this study, bis(tertiary-butylamino)silane (BTBAS) was used as the precursor of Si, SiO@sub x@N@sub y@ thin films were deposited on plastic substrates at a low temperature using a PECVD method and its properties were investigated. BTBAS was used as the precursor of Si because it shows a low impurity content after the deposition and it is safe, easy to handle as a liquid form, and chemically stable compared to other silicon precursors such as SiH@sub 4@, SiH@sub x@Cl@sub y@, etc. Also, by forming multiple layers of SiO@sub x@N@sub y@/parylene, the water permeation properties of the deposited SiO@sub x@N@sub y@ films were also investigated. In this presentation, we will report the deposited film characteristics for an OLED passivation layer such as deposition rate, film crystallization, chemical composition, H@sub 2@O permeation, and optical transmittance measured using an alpha-step, XPS, FT-IR, ellipsometer, and UV spectrometer, respectively.

PS-TuP4 Linearized Process Model Analysis As a Means of Understanding the Behavior of the Reactive Sputtering Process*, **D.J. Christie**,* Advanced Energy Industries, Inc.

Reactive sputtering processes exhibit unique control space behavior which has been effectively explained by mathematical models. The reactive gas partial pressure can have multiple possible values for a range of reactive gas flows which leads to hysteresis in the process control space. A model which effectively explains the process dynamics consists of three coupled non-linear differential equations. Jacobian linearization of the model equations can be used to create a linearized model whose eigenvalues can be determined explicitly.@footnote 1@ Evaluation of the linearized model eigenvalues as a function of reactive gas partial pressure shows the specific partial pressures where hysteresis is likely to occur. In this work, a representative reactive sputtering process is modeled. The small (control) signal analysis and stability are correlated to the reactive gas partial pressure and flow characteristics. In particular, the real and imaginary components of the eigenvalues and the reactive gas flow are evaluated for a realistic range of reactive gas partial pressures. The points where hysteresis is expected to occur based on the two approaches (flow versus pressure, eigenvalues versus pressure) are compared. Insights on process dynamics and potential closed-loop control issues are also extracted from the linear analysis. @FootnoteText@ @footnote 1@ C. Li, J-H Hsieh, Surface and Coatings Technology 177-178, 824 (2004).

PS-TuP6 Stabilization of the Atmospheric Glow Plasma*, **E. Aldea**, P. Peeters,* Eindhoven University of Technology, The Netherlands*; H. de Vries,* Fuji Photofilm B.V*; M.C.M. Van De Sanden,* Eindhoven University of Technology, The Netherlands

*****PLEASE NOTE: YOU MUST IDENTIFY A DIFFERENT PRESENTER FOR THIS ABSTRACT. YOU MAY ONLY PRESENT ONE (1) PAPER AT THE CONFERENCE.*****Due their huge potential for cost efficient industrial applications uniform atmospheric plasmas (atmospheric glow) attracted a lot of interest in the recent years. Commonly atmospheric glow plasma can be straightforwardly generated only in He or very pure nitrogen and at relatively low power density. It is widely believed that atmospheric glow generation is related to a large pre-breakdown pre-ionization but the link between pre-ionization and atmospheric glow remains debatable. In this paper it is argued that not the pre-ionization but thermal/ionization instability is the key factor, which is preventing the atmospheric glow generation. Excepting He atmospheric plasma generation requires the suppression of the unstable plasma modes. In this way we succeeded to generate the atmospheric glow at high power density and for a large variety of gases. Several dedicated electronic circuits were developed for the suppression of the unstable plasma varieties. The plasma stabilization electronics is exploiting the peculiar low ratio of the dynamic to static resistance of the unstable plasma varieties.

PS-TuP8 Frequency and Dimensional Scaling of Microplasmas Generated by Microstrip Transmission Lines*, **I. Rodriguez**, J. Hopwood,* Northeastern University

A microplasma is generated in a gap formed between the ends of a microstrip transmission line. The microstrip is fabricated in the shape of a circular ring, and the discharge gap is micromachined through the microstrip such that the device resembles a nearly closed C. This geometry resonates if microwave power is coupled to the split-ring at a frequency for which the circumference is one-half of the wavelength. At resonance, a strong electric field is generated in the discharge gap region and a microplasma may be ignited. Split-ring resonator microplasmas operating at 900 MHz have been reported in the literature@footnote 1@ and operate from 0.1 Torr to 760 Torr in air as well as inert gases. The primary advantage of this device in comparison to low frequency and DC microplasmas is the elimination of ion-induced erosion of the micro-electrodes. The ions are not accelerated toward the electrodes because the split-ring is at a constant DC potential. In addition, the ions cannot respond to the microwave field. In this presentation, we report scaling the split-ring resonator. Using an aluminum oxide substrate (@epsilon@@sub r@ = 10.2), the 900 MHz device must be 20 mm in diameter. By increasing the operating frequency to 1.8 GHz, the split-ring resonator is scaled down to approximately 10 mm. Higher frequency operation also improves the confinement of the electrons within the discharge gap by decreasing the amplitude of electron oscillation. The scaled split-ring resonator operates in argon at 1 atm using 0.3 watts supplied by a power amplifier chip from a cell phone. Electromagnetic simulations and measurements of the physical device compare favorably@footnote 2@. @FootnoteText@ @footnote 1@F. Iza and J. Hopwood, IEEE Transactions on Plasma Science, Vol. 31(4), pp. 782-787 (2003).@footnote 2@This work is supported by NSF Grant No. CCF-0403460.

PS-TuP9 Effect of Gas Flow on the Gas Temperature in a High Pressure DC Micro-discharge, ***F. Doll***, *Q. Wang, V.M. Donnelly, D.J. Economou,* University of Houston*; G.F. Franz,* University of Applied Sciences, Germany

The gas temperature of a high pressure DC micro-discharge in mostly Ar or He was deduced by spectroscopic measurements of the rovibrational bands of the second positive system of N2, added as a trace species. The micro-discharge was sustained in a slot between two molybdenum electrodes separated by a distance of 200 microns. The gas temperature in He was significantly lower (350-550 K) than that in Ar (over 1000 K), a reflection of the much higher thermal conductivity of He. Increasing the gas flow rate had little effect on the gas temperature in He, but significantly reduced the gas temperature in Ar. This is consistent with the fact that conductive heat losses dominate in the helium micro-discharge, while heat losses by convection play a role in the Ar micro-discharge. The experimental findings were verified with a two-dimensional flow and heat transfer calculation in the micro-plasma reactor. Finally, the cathode temperature was measured with a thermocouple located 1 mm from the face of the electrode exposed to the plasma. The cathode temperature in the Ar micro-discharge was generally less that 400 K. Work supported by DoE/NSF.

PS-TuP10 Plasma-Deposited Silver Containing Nanocomposite Coatings with Bactericidal Properties, ***P. Favia,*** University of Bari, IMIP-CNR, Plasma Solution Srl, Italy*; E. Sardella, M. Nardulli,* University of Bari, Italy*; R. Gristina,* Institute of Inorganic Methodologies and Plasmas (CNR-IMIP) Bari*; R. d'Agostino,* University of Bari, IMIP-CNR, Plasma Solution Srl, Italy

Silver has been considered for centuries for its antibacterial properties,@footnote 1@ that are explained with different mechanisms, including strong interactions with thiol groups of the respiratory enzymes of bacteria. Silver has a broad spectrum of action, from anaerobic bacteria to viruses, yeasts, and fungi. The overuse of silver compounds causes argyria, a discoloration of the skin, often due to the uptake of improperly prepared and unstable colloidal silver. For this reason the interest is often focused on products for topical therapies@footnote 2,3@ instead of systemic, able to release in a controlled way the minimum quantity of silver effective. Nanocomposite coatings (i.e. dispersions of Ag clusters embedded into an organic/inorganic matrix) are under investigation in our lab as silver delivery systems, as alternative to available medical products, since they allow to control the release rate of silver as a function of their chemical composition.@footnote 4,5@ In this work the attention is focused on the ability of such coatings to release a minimum quantity of silver in cell-culture medium without losing bactericidal effect. Coatings have been deposited in RF (13.56 MHz) Glow Discharges fed with a mixture of Diethyleneglycole di-methyl ether (DEGDME) and Ar. Sputtering from the Ag-coated cathode of the reactor occured simultaneously in certain conditions, to give Ag clusters dispersed in the Polyethyleneoxide (PEO)-like coating. Different PEO-like and Ag/PEO-like coatings have been deposited, that have been characterized with different surface analysis techniques. The role of silver and its cytotoxycity in cell culture media has been evaluated with 3T3 Murine Fibroblasts at different time of incubation. The bactericidal effect of Ag+ ions was evaluated with different bacteria. Biological results have been correlated with the quantity of silver released in water at 37°C, as measured with ICP Emission spectroscopy. Acknowledgements: The project MIUR-FIRB RBNE01458S_006, is gratefully acknowledged for funding this research @FootnoteText@ @footnote 1@ Russell et al, Hugo. Antimicrobial Activity and Action of Silver. Prog Med Chem. 1994, 31:351;@footnote 2@ Thomas et al, J Wound Care 2004; 13(9):392;@footnote 3@ Dowling et al, Thin Solid Films 2001; 398-399: 602;@footnote 4@ Favia et al, Plasmas and Polymers 2000, 5(1):1;@footnote 5@ Sardella et al, Plasma Proc. and Polym., 2004, 1:63.

PS-TuP13 Functionalization of Rough Polymer Surfaces and Porous Micron-Sized Beads Using Atmospheric Pressure Plasmas@footnote 1@, ***A.N. Bhoj,*** University of Illinois at Urbana-Champaign*; M.J. Kushner,* Iowa State University

Pulsed atmospheric pressure plasma discharges, such as corona and dielectric barrier discharge devices, are commonly used to functionalize surfaces (e.g., polymer sheets) with the advantages of high throughput and in-line continuous processing. These materials have surface roughness of 100s nm to 10s µm often resulting from the manufacturing process. Porous materials also have highly non-planar surfaces that can be functionalized for novel applications such as drug delivery. In this paper, results from a computational multiscale investigation of atmospheric pressure plasma treatment of rough polymer surfaces and porous polymeric beads are discussed. The investigation was conducted with a 2-dimensional plasma hydrodynamics model using an unstructured mesh capable of resolving a dynamic range of 1000 in spatial scale.@footnote 2@ This capability enables a multi-scale approach in which the reactor scale plasma hydrodynamics and penetration of plasma produced species into surface structures can be simultaneously addressed. A surface kinetics model is integrated with the plasma hydrodynamics model to assess the uniformity of treatment of the surface structures. The model geometry is a dielectric barrier-corona configuration at atmospheric pressure with a gap of a few mm to the surface. Nitrogen-containing gas mixtures produce amine functionalities on rough polymer surfaces and porous polymer beads of 10s µm sizes with pore diameters less than 2 µm. Radicals and ions generated in the plasma diffuse through the pores and access the internal surfaces, a process that depends on polarity of the corona. The uniformity of treatment of the nooks-and-crannies of the rough surfaces and on the internal surfaces of the polymer beads depends on the relative rates of transport and reaction limited processes, and evolves over successive pulses as the surface functionalization is saturated. @FootnoteText@ @footnote 1@ Work supported by NSF (CTS03-15353). @footnote 2@ A. N. Bhoj and M. J. Kushner, J. Phys. D. 37, 2910 (2004).

PS-TuP14 Plasma Simulation for Plasma-based Ion Implantation Sterilization Technique, ***T. Tanaka,*** Hiroshima Institute of Technology, Japan*; M. Tanaka,* PEGASUS Software Inc., Japan*; D. Nakamura,* TWO CELL CO. Ltd., Japan*; H. Fukuyama,* Kobe Steel Ltd., Japan*; T. Takagi,* Hiroshima Institute of Technology, Japan

Plasma-based ion implantation (PBII) sterilization technique is one of the promising sterilization process for three-dimensional work pieces with low temperature, short process time, and no toxic gas. The energy of nitrogen ion used PBII sterilization process with a pulsed negative high voltage (5 usec pulse width, 300 pulses/s, -800 V to -13kV) was estimated using a simple method based on secondary-ion mass spectroscopy analysis of the vertical distribution of nitrogen in PBII-treated Si. The ion energy was calculated based on the depth profile of nitrogen in ion implanted and was low compared to the nitrogen energy calculated based on the voltage applied during processing. It was shown that the experimentally estimated ion energy was at the same level of the value estimated using the plasma simulation. It was shown that the possibility of the design sterilization process and apparatus by using the plasma simulation.

PS-TuP15 Extraction and Collimation of Laser Photoionized Neodymium Ion Beam, ***K.T. Tamura,*** Japan Atomic Energy Research Institute, Japan

Based on the laser isotope separation, ions are produced by the selective photoionization of evaporated atoms. By the effective extraction and collection of these ions, they are considered to be a useful ion source for the applications such as ion implantation. To increase the beam intensity for these applications, a pair of semispherical electrodes was set outside the parallel plate electrodes, and the obtained intensity distributions were measured by scanning a multichannel Faraday cup. Atomic beam of neodymium were generated by electron beam evaporation, and was introduced between electrodes for ion extraction. The atomic beam was photoionized by the irradiation of the third harmonics of YAG laser operated at 10 Hz, and the produced ions were extracted from the electrode. The intensity distributions of the ion beam were detected with a multichannel Faraday cup which has five detection holes arranged horizontally. The distributions were mapped by vertically scanning the detector manually. The vertical and horizontal widths of the ion beam at the detector were reduced by the electric field formed with these electrodes. The central ion beam intensity increased about 36 times compared with that in the case without the additional electric field. The energy spread of the neodymium ion beam corresponded to the potential of the laser photoionized region between ion extraction electrodes. Ions with the central energies of 300~1400 eV were then produced, and it was shown from ion distribution measurements that collimated ion beam was produced for these ion energies. These results show that the application of these electrodes is useful for the extraction and collimation of the laser photoionized ions.

PS-TuP16 Time-Dependent Recombination Reactions of Oxygen Atoms on an Anodized Aluminum Plasma Reactor Wall, Studied by a Spinning Wall Method, *P.F. Kurunczi,* ***J. Guha,*** *V.M. Donnelly,* University of Houston

We have studied the pressure, power, and time dependence of recombination of O atoms on an anodized Al surface, using a new "spinning wall" technique. With this method, a cylindrical section of the wall of the plasma reactor is rotated, and the surface is periodically exposed to the plasma and then to a differentially pumped mass spectrometer (MS). By varying the substrate rotation frequency (f), we vary the reaction time, t@sub r@ i.e. the time between exposure of the surface to O-atoms in the plasma and MS detection of desorbing O@sub 2@ (t@sub r@=1/2f). At 600 W and 5 mTorr, the O@sub 2@ desorption signal decreases by a factor of 6 as t@sub r@ is increased from 0.7ms to 40ms. (The signal is zero at f=0.) The O@sub 2@ signal decay rate is highly non-exponential, slowing at longer times. As power is lowered, the signal decreases more strongly at short t@sub r@ than at long t@sub r@. For constant power, signals also decrease at pressures above or below 5 mTorr. The shape of the decay curve is determined solely by the O@sub 2@ desorption signal extrapolated to t@sub r@=0, which is determined by the absolute O flux in the plasma. We have also studied the time dependence of recombination by spinning the substrate at a rapid rate and then turning the plasma on and off. The rate of rise and decay in signal is again highly non-exponential; O@sub 2@ desorption decays by 1/e in ~30ms and is still detectable ~200ms after the discharge extinguishes. When the plasma is turned on, the rise time in O@sub 2@ signal mirrors the decay (~30ms and ~200ms components) if the plasma was recently operated (within the last minute) and is much longer (~2s) if the plasma was off for more than 1 hr, indicating some initial conditioning of the surface. Mechanisms and modeling of O-atom recombination will be compared with these time-dependent results. Supported by ACS-PRF. @FootnoteText@ P.F. Kurunczi - Present affiliation: Varian Semiconductor Equipment, Gloucester, MA 01930.

PS-TuP17 Effect of Coulomb Collision on Oxygen Plasma*, K. Nanbu,* ***T. Furubayashi,*** Tohoku University, Japan

Plasma processing has been used for fabricating semiconductors. The requirement of high aspect ratio etching is satisfied by using low pressure and high density plasmas. When simulating high density plasmas (n@sub e@ = 10@super 17@-10@super 18@m@super -3@), collision between charged particles should also be taken into consideration. Generally, in simulating plasma using the particle model, we consider only electron-molecule collisions and ion-molecule collisions. In this study, we consider not only such collisions but also electron-electron collisions using Bobylev and Nanbu method,@footnote 1@ because it is most probable that Coulomb collision have effect on the electron energy distribution. We examined the effects of Coulomb collision on plasma parameters. Especially, the effect on electron energy distribution function (EEDF) is important because it influences reaction rate of radicals production and hence, affects the etch rate. The effect of electron-electron collisions on argon plasma was examined previously,@footnote 2@ and we found that there is an effect on electron temperature but little effect on the EEDF. In this study, we simulated oxygen plasma using PIC/MC method considering four species, e@super -@, O@super +@, O@sub 2@@super +@, and O@super -@. The threshold energy of ionization in the collisional events of electron-oxygen collision is much lower than that of argon. So it is expected the electron-electron collisions have large effects on plasma parameters. @FootnoteText@ @footnote 1@ A. V. Bobylev and K. Nanbu, Phys. Rev, E, Vol.61(2000), pp. 4576-4586@footnote 2@ K. Nanbu, T. Furubayashi and H. Takekida, Thin Solid Film(to be published).

PS-TuP18 The Role of Ar Metastables in Distorting Gas Temperature Measurements Derived from Trace N@sub 2@ Optical Emission Rotational Spectroscopy in Ar-Containing Discharges*,* ***S.J. Kang,*** *V.M. Donnelly,* University of Houston

Gas temperature (T@sub g@) is an important parameter in plasma prosessing. One method for obtaining T@sub g@ is to add small quantities of N@sub 2@ to the discharge and determine the rotational temperature (T@sub rot@) of N@sub 2@ from electron-impact induced emission. The assumption is that collisions with electrons transfer the rotational distribution of the ground state intact to the emitting state. Usually the 0->0 and 1->0 vibronic bands of the C@super 3@@PI@@sub u@ -> B@super 3@@PI@@sub g@ transition are observed. We have found that when the plasma contains large amounts of Ar these emissions do not yield reliable values for T@sub g@. For example, in a 98% Ar/ 2% N@sub 2@ inductively-coupled plasma (ICP), these bands yield an apparent T@sub g@ that decreases with increasing power. This erroneous result is due to a second mechanism of N@sub 2@ C@super 3@@PI@@sub u@ excitation by collisions with Ar metastables (Ar*). Kinetic modeling shows that at low powers, this Penning excitation mechanism dominates over electron-impact excitation, while at high power, the converse is true. Penning excitation releases a large amount of energy into N@sub 2@ (C@super 3@@PI@@sub u@) rotations. When this process dominates, the observed T@sub rot@ is very high and greatly exceeds T@sub g@. Consequently, T@sub rot@ decreases with increasing power. When N@sub 2@ emission is observed from vibrational levels above that of Ar (@super 3@P@sub 0@) (11.72 eV), i.e., for v' > 4, Ar* energy transfer is no longer possible. So T@sub g@ derived from the 3->3 vibronic band is lower and increases slightly with power. This trend is more reasonable than the high values and inverse dependence on power from the 0->0 transition, consistent with emission from the 3->3 vibronic band arising only from collision with electrons. Thus the 3->3 band provides a reliable measure of T@sub g@.

PS-TuP19 PLAD Dopant Depth Profile Based on Ion Mass and Energy Distribution for Ultra Low Energy Implantation*,* ***L. Godet,*** *S. Walther, S. Radovanov, Z. Fang, J. Scheuer,* VSEA*; G. Cartry, C. Cardinaud,* Nantes University, France

With standard ion implantation technology, the energy and the mass of the ions striking the wafer are well known and simulations such as Transport of Ions in Matter (TRIM)@footnote 1@ are available to predict dopant depth distribution. During the plasma doping process,@footnote 2@ all the ion species present during the negative voltage pulse applied to the substrate are implanted with an energy spread that is dependent on many plasma parameters. To predict the junction depth and the dopant concentration of a plasma doping implant, the knowledge of the chemical nature of the ion species bombarding the wafer, their energy and their proportion of the total ion flux incident on the wafer are needed. In order to provide this essential information, an ion mass and energy spectrometer is installed below the wafer. The ion mass and energy distributions of the ions striking the wafer with energy range from 250V to 1kV have been measured. Secondary Ion Mass Spectrometry (SIMS) was performed to measure the dopant depth profile under the same conditions. Based on the knowledge of the energy distribution of each species of dopant ion present in the pulsed discharge, a TRIM simulation was performed to model the dopant depth profile in the silicon and compared to SIMS profile. @FootnoteText@ @footnote 1@The Stopping and Range of Ions in Solids, J. F. Ziegler,1985@footnote 2@Plasma Diagnostics in pulsed plasma doping system, B.-W. Koo, IEEE, 2004

PS-TuP21 Characteristics of Inductively Coupled Plasma Source with a Multiple U-Type Internal Antenna for Flat Panel Display Applications*,* ***K.N. Kim,*** *C.K. Oh, G.Y. Yeom,* Sungkyunkwan University, Korea

The development of large-area and/or large-volume plasma source with a high plasma density is desired for various plasma processes from microelectronic fabrication processes to flat panel display device fabrication processes. The plasma sources developed to date for the production of high-density and large-area plasmas are mainly focused on the externally planar ICP. However, scaling up to a conventional spiral-type external plasma sources to a large area sources causes some problems when they are applied to TFT-LCD, and by inserting an antenna into the plasma, more production applicable large area ICP is feasible due to the induction of a strong electric field in the plasma and the efficient power transmission to the plasma. In this study, an internal type large-area plasma source with U-type internal linear- antennas has been proposed as a promising candidate for an efficient high-density plasma source. The characteristics of the plasmas were measured using a Langmuir probe located on the sidewall of the chamber. The results showed a strong dependence of the plasma characteristics such as plasma density and plasma uniformity on the antenna arrangement.

PS-TuP22 Electron Density Measurements with Surface Wave Probes in Magnetized Plasmas*,* ***K. Nakamura,*** Chubu University, Japan*; S. Yajima, H. Sugai,* Nagoya University, Japan

In this paper, the surface wave (SW) probe for measuring electron densities@footnote 1@ was applied to magnetized plasmas, and the characteristics of the SW probe located in parallel to the field were examined experimentally and theoretically under a condition of low plasma density and/or high magnetic field corresponding to magnetron discharges. The experiments were made in inductively-coupled argon magnetized plasmas, and absorption frequencies of the SW probe measured by a network analyzer was examined as a function of the plasma frequency measured by the Langmuir probe. At the low magnetic field, the absorption frequency decreased with a decrease in the plasma, thus proportional to the plasma frequency. However, as the magnetic field increased, a saturation of the decrease in the absorption frequency was observed, especially for the low plasma frequency. The saturated absorption frequency were very close to the electron cyclotron frequency obtained from the applied magnetic field, suggesting that the absorption frequency was seriously affected by the magnetic field under the low density conditions. Actually, plotting absorption frequency @omega@ over cyclotron frequency @omega@@sub c@ as a function of plasma frequency @omega@@sub p@ normalized by @omega@@sub c@, its slope approached to zero with an decrease in @omega@@sub p@/

@omega@@sub c@. This result suggested that the absorption frequency became independent of the plasma frequency as a decrease in @omega@@sub p@/ @omega@@sub c@ and that the density measurements was difficult under the low density and/or high field conditions of @omega@@sub p@/ @omega@@sub c@~0.5. Such a saturation was improved by optimization of dimensions of the probe. Especially, reducing the diameters of the rod antenna and the quartz cover tube of the probe was effective and extended measurable range of @omega@@sub p@/ @omega@@sub c@. @FootnoteText@ @footnote 1@ H. Kokura et al: Jpn. J. Appl. Phys 38 (1999) 5262.

PS-TuP23 Optical Emission Measurements of Dual Frequency Capacitively Coupled Plasmas*, **E.C. Benck**, K.L. Steffens,* National Institute of Standards and Technology

Dual frequency capacitively coupled plasma sources are becoming increasingly important in semiconductor manufacturing processes. By having the two frequencies separated sufficiently far apart, it is possible to essentially independently control the plasma density and ion energies impacting wafers. This significantly increases the operating range and etching control over that of a single frequency CCP. An imaging spectrometer combined with a high speed intensified CCD camera is utilized to obtain spatially and temporally resolved measurements of the optical emissions from dual frequency fluorocarbon plasmas created in a Gaseous Electronics Conference (GEC) reference reactor. Plasma behavior is characterized for a variety of operating conditions. In particular, the influence of a single vs. multiple powered electrodes will be presented.

PS-TuP24 Characterization of an Energetic Neutral Beam Source*, **C. Helmbrecht**, Q. Wang, V.M. Donnelly, D.J. Economou,* University of Houston*; G.F. Franz,* University of Applied Sciences, Germany

The residual ion beam and the energetic neutral beam of a neutral beam source were characterized using an ion energy analyzer in combination with a calorimeter. The beam was extracted through a neutralizer metal grid with high aspect ratio holes separating a 13.56 MHz inductively coupled argon plasma from the differentially-pumped beam characterization chamber. By biasing an acceleration electrode in contact with the plasma, ions in the plasma were expelled through the neutralizer grid, and turned into energetic neutrals by colliding with the internal walls of the holes of the grid. Several Al neutralizer grids were used to study the effect of hole diameter (190-630 microns) and aspect ratio (7:1 and 10:1) on neutralization efficiency and flux. The energy distribution of the residual ions was generally bimodal and the average energy varied in the range of 50-100 eV depending on acceleration voltage and plasma gas pressure. The neutralization efficiency increased with larger holes and higher aspect ratios, approaching complete neutralization of the beam. By assuming that the energy of the energetic neutral beam is approximately the same as that of the residual ion beam, the flux of energetic neutrals was also found. The variation of flux with source operating conditions will be discussed and explained based on plasma molding inside the holes of the grid. Work supported by the Texas Advanced Technology Program.

PS-TuP25 Helicon Discharges with Permanent Magnets*, **H. Torreblanca**, F.F. Chen,* University of California, Los Angeles

Industrial helicon sources have been shown to produce higher plasma densities than unmagnetized ICPs but require the addition of a dc electromagnet and its power supply. This requirement can be obviated by using permanent magnets (PMs). However, injection is a problem, since the field lines of PMs normally do not allow the electrons to leave the source region. Using PMs, we have measured the plasma properties both inside the source and downstream in various helicon discharges, including the Big Blue Mode. To overcome the injection problem, we have tried various types of antennas and various ways to shape the magnetic and electric fields.

PS-TuP26 Discharge Electrode Impedance Effect on Harmonics Generation*, **Y. Yamazawa**, M. Nakaya, M. Iwata, A. Shimizu,* Tokyo Electron AT LTD, Japan

The radio frequency (rf) power is commonly used to excite plasma or biasing the wafer in a plasma reactor for processing of microelectronics materials. Due to the nonlinear behavior of the plasma sheaths, the rf power imposes harmonics of the drive frequency. The generation of the harmonics is of great technological importance, since it contributes significantly to the plasma property and process result. This paper reports the control of the harmonics generation by means of the electrode impedance in a dual-frequency capacitively coupled plasma reactor. The 2nd ,3rd and 4th harmonics of the bias RF frequency were observed to behave with resonant growth by tuning the electrode impedance adequately. A simple nonlinear equivalent circuit model can reproduce the experimental result. A remarkable change in the radial distribution of electron density was observed at the harmonic resonances. This technique can be applied to control the plasma uniformity of the etch chamber. In addition, this technique can be used for reducing chamber-variation by avoiding the unexpected resonance.

PS-TuP27 Electron Beam-Generated Plasmas Produced in Nitrogen and Applications to Materials Processing*, **S.G. Walton**, D. Leonhardt, R.F. Fernsler,* US Naval Research Laboratory*; C. Muratore,* US Air Force Research Laboratory

Electron beam-generated plasmas produced in a nitrogen background have several unique characteristics that make them attractive for materials processing applications that utilize nitrogen species. The US Naval Research Laboratory has developed a plasma processing system that relies on a magnetically collimated, sheet of multi-kilovolt electrons to ionize the background gas and produce a planar plasma. High-energy electron beams are efficient at producing high-density plasmas (n@sub e@ > 10@super 11@ cm@super -3@) with low electron temperatures (T@sub e@ < 0.5 eV) over the volume of the beam, resulting in large fluxes of low-energy ions (< 4 eV) at surfaces located adjacent to the electron beam. Of particular interest to nitrogen-based processing applications are the relative concentrations of atomic ions, molecular ions, and radicals, which are significantly different from other plasma sources. Large atomic-to-molecular ion flux ratios (>1) and radical-to-ion fluxes ratios are possible using simple adjustments to system operation, such as substrate position or plasma duty factor. In this work, we discuss in situ plasma diagnostics of pulsed, electron beam-generated plasmas produced in pure nitrogen and nitrogen mixtures. A Langmuir probe and a dual energy/mass analyzer is used to provide a spatio-temporal description of the processing system. The diagnostic results are correlated to the latest results from materials processing applications under study in our laboratory including metal nitriding, reactive sputter deposition, and polymer modification. This work was supported by the Office of Naval Research.

PS-TuP29 A High Density Negative Ion Plasma in a Very High Dielectric-Constant Discharge Tube*, **Y. Ikeda**,* KYOSERA Co. LTD., Japan*; K. Endo, H. Shindo,* Tokai University, Japan

Negative ions in plasmas are much attractive species in material processing, such as ion implantation, CVD and etching in ULSI fabrications. The objective of this work is to study a negative ion plasma source. In particular, an innovative method to produce a negative ion rich plasmas is proposed by employing RF surface-wave plasma with a extremely high dielectric constant discharge tube. As well-known, the surface-wave can only be existed above the resonance density, which depends on the permittivity of the discharge tube. In this work, a negative ion plasma is produced by employing the after-glow appeared in the resonance density of the surface-wave which is enhanced by a extremely high dielectric constant discharge tube. The surface-wave plasmas of O2 and SF6 were produced in a discharge tube by supplying 13.56 and 60 MHz power. The two discharge tubes of a ceramic of TiCa-TiMg, K-140, which is commercially available from KYOCERA Co. and a quartz are employed, and their permittivities are, respectively, 140 and 3.8. The optical emission line measurements were carried out from the lateral view. The axial decay rate of the intensities of the optical emission lines FI in SF6 plasma were 5 times faster in the K-140 discharge tube than in the quartz. In particular, a sudden precipitation of the line intensity could be observed, and this is due to the surface-wave ending at the resonance density, providing a high density after-glow. In O2 plasma, in this after-glow region, the OI emission lines of 777 and 845 nm, which are originated from the mutual neutralization of O- and O+, were observed to be very much enhanced after the sudden precipitation, indicating the rich negative ions populated in this region. While in the quartz discharge tube the line intensity decayed just simply and monotonically. Thus it was concluded that the surface-wave plasma with a extremely high dielectric constant discharge tube was an innovative method of negative ion rich plasma.

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