Plasma Science and Technology
Room 3rd Floor Lobby - Session PS-ThP

High Pressure Discharges and Novel Diagnostics & Sources Poster Session

PS-ThP2 Numerical Analysis of Oxygen Positive Column in Atmospheric Pressure Glow Discharge Plasmas*, **Y. Ichikawa**, T. Suzawa, M. Narita,* Fuji Electric Device Technology, Japan

Recently, atmospheric pressure (AP) glow discharge plasmas have been studied by a number of researchers, because many applications are expected. The properties of AP plasmas, however, have not been understood very well yet. Thus, we have made an attempt to extend a positive column theory based on the ambipolar diffusion model to the AP range. Oxygen discharges have been widely used to various applications such as surface treatment for removal of organic materials, ashing, and ozonizing. For this reason, it is interesting to analysis oxygen AP positive column plasmas. Thus we carried out a numerical analysis of this discharge. In the simulation, we took into account four neutral species, O, O@sub 2@, O@sub 3@ and O@sub 2@(a@super 1@@DELTA@@sub g@), and eight ion species, O@super +@, O@sub 2@@super +@, O@sub 3@@super +@,O@sub 4@@super +@, O@super -@, O@sub 2@@super -@, O@sub 3@@super -@ and O@sub 4@@super -@. The transport equations for these charged and neutral species were solved simultaneously, and obtained the electron temperature and the abundance ratio of species self-consistently. The obtained results showed that the behavior of the plasma at the atmospheric pressure is quite different from that of the medium gas pressure range. The plasma density is higher than the electron density by more than an order of magnitude at higher gas pressures, and the major negative species is O@sub 3@@super -@ at the atmospheric pressure. For the positive ions, O@sub 4@@super +@ becomes the majority ion at around the atmospheric pressure. The obtained composition of neutral species showed that O@sub 3@ increases as the tube radius decreases at the atmospheric pressure.

PS-ThP3 A New Production Method of Negative-Ion-Plasma in an Extremely High Dielectric-Constant Discharge Tube*, **K. Kusaba**,* Tokai University, Japan*; Y. Ikeda,* KYOCERA Co. LTD., Japan*; K. Shinohara,* Japan High Frequency Co., LTD*; 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 new negative ion plasma source. In particular, an innovative method to produce a high density negative ion plasmas is proposed by employing RF surface-wave plasma with a extremely high dielectric constant 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 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. Furthermore, the emission line of OI 645 nm, which is known free from the mutual neutralization, was not observed in the after-glow. This fact clearly demonstrates that the line intensity enhancement in the downstream is due to the negative oxygen ion. While in the quartz discharge tube the line intensity decayed just simply and monotonically.

PS-ThP4 Spectroscopic Study of Fluorocarbon Plasma Gas Phase Chemistries in High Density Plasma for a Submicron Contact Hole Etching*, **G.H. Kim**,* ETRI, Korea*; K.T. Kim, C.I. Kim,* Chung-Ang University, Korea*; S.G. Kim,* ETRI, Korea*; J.G. Koo,* ETRI*; T.M. Roh, J.D. Kim,* ETRI, Korea

As ultra large scale integrated (ULSI) devices are scaled down, highly selective SiO@sub 2@ etching and submicron contact hole etching process are increasingly required. Silicon nitride is used as a passivation layer that protects circuits from mechanical and chemical attack, or as an etch stop layer, enabling the fabrication of certain damascene and self-aligned contact (SAC) structures. Previous studies focused on either anisotropic etching or selective etching of SiO@sub 2@ over Si@sub 3@N@sub 4@ or Si using conventional low density plasma sources. Recently, high density plasma (HDP) single wafer etching tools have attracted a lot of attention, mainly because HDP sources operate at low pressure and allow independent control of ion flux and ion energy. Consequently, the plasma-surface interactions become significant, and surface conditions such as the temperature and cleanliness of the reactor wall play an important role determining both the gas phase chemistries and the surface reactions deposition and etching on the wafer surface. In this study, we present a highly selective SiO@sub 2@ etching and submicron contact hole etching with a hydro-fluorocarbon gas (CHF@sub 3@ and CH@sub 2@F@sub 2@) in addition to CF@sub 4@ and C@sub 4@F@sub 8@ plasma chemistry in high density plasma and discuss the important species required for protecting the nitride surface and controlling the polymer inhibitor by using optical emission spectroscopy and X-ray photoelectron spectroscopy.

PS-ThP5 Electron Density and Electron Temperature of Narrow-Gap RF Plasma Polymerization System Measured by Highly-Sensitive Double Surface Wave Probe Technique*, **K. Kinoshita**,* MIRAI-ASET, Japan*; K. Nakamura, O. Hirano,* Chubu University, Japan*; Y. Hyodo,* MIRAI-ASET, Japan*; O. Kiso,* MIRAI-ASRC, AIST, Japan*; J. Kawahara,* MIRAI-ASET, Japan*; Y. Hayashi,* NEC, Japan*; S. Saito,* Selete, Japan*; H. Sugai,* Nagoya University, Japan*; T. Kikkawa,* Hiroshima University, Japan

A plasma copolymerization technique has been developed to achieve scalability of low-k materials for two or three technology nodes of ULSIs. In-situ QMS analysis showed that multistep dissociation of the precursor monomers progressed in the plasma.@footnote 1@ Low-k property of the deposited film was lost by over dissociation. Thus, the following three points are indispensable; (a)reduction of electron density (Ne), (b)lowering electron temperature (Te), and (c)reduction of gas residence time. In this study, electron temperature was measured for actual deposition plasma by double surface wave probe technique. This technique enables to measure Ne and Te by the difference of surface wave resonance frequencies.@footnote 2@ An RF plasma CVD system for 300 mm wafer was used. A cyclosiloxane monomer with six-member ring and organic functional groups was used as a precursor monomer with helium carrier gas.@footnote 3@ While increasing precursor flow rate from 0 sccm to 10 sccm (1.7 %), Ne decreased rapidly from 5.2E10 cm@super -3@ to 1.4E10 cm@super -3@. On the other hand, Te decreased gradually from 2 eV to 0.5 eV at the flow rate from 0 sccm to 40 sccm (6.7 %), and kept constant over this flow rate range up to 100 sccm. These results indicate that Te of the plasma polymerization process was low enough even in the helium discharge. Radial distributions of Ne and Te were affected by the gas pressure change. Uniform discharge was obtained at the gas pressure of 400 Pa, and the source power of 200 W (Ne=1.5E10 cm@super -3@). To optimize plasma polymerization process, some hardware knob for uniformity control would be effective to achieve better process margins. This work was supported by NEDO. @FootnoteText@ @footnote 1@ K. Kinoshita, et al., Proc. Dry Process Symp. 2003, Tokyo, 3-1, 61 (2003).@footnote 2@ O. Hirano, et al., Abst. Spring Meeting Jpn. Soc. Appl. Phys., 25a-W-7, (2006)@footnote 3@ Y. Hayashi, et al., Proc. 2004 IEEE Int. Interconnect Technol. Conf., 12.3, (2004).

PS-ThP6 Predicting Ion Energy Distribution Function for Multi-Frequency Capacitive Discharges*, **A. Wu**, M.A. Lieberman, J.P. Verboncoeur, A.J. Lichtenberg,* University of California, Berkeley

In single and multiple frequency capacitive discharges used for semiconductor processing, the ion energy distribution function (IEDF) is important for determining the effects of ions at the wafer. The ability to predict the IEDF from the applied discharge voltages is greatly desired. We present particle-in-cell simulations for different frequencies and voltages to determine the IEDF, and we develop a theoretical model to predict the IEDF for any number of frequency drives, as long as the voltage across the sheath is known. In the model, we use a frequency filtered version of the voltage applied to the wafer to determine the ion response function. The filter function shape depends mainly on the ratio of the ion transit time across the sheath to the various applied frequencies, and is implemented in the model using Fourier transform techniques. We are exploring the use of a filter function given by Benoit-Cattin (1968)@footnote 1@ to determine the ion response, in order to predict the IEDF. A further refinement can be used for the regime where the driving frequency is approximately the same as the ion transit time. @FootnoteText@@footnote 1@P. Benoit-Cattin and L. C. Bernard, "Anomalies of the Energy of Positive Ions Extracted from

High-Frequency Ion Sources. A Theoretical Study," J. Appl. Phys. 39, 5723 (1968).

PS-ThP7 A Transmission Line Microwave Interferometer for Monitoring of Electron Density in Plasma Processing Tools, ***C.H. Chang**, J.Y. Jeng, C. Lin, K.C. Leou,* National Tsing Hua University, ROC

We developed a transmission line microwave interferometer for monitoring of electron density for applications in process real-time feedback control of plasma based semiconductor fabrication tools, such plasma etchers or PECVDs. The sensor was a dielectric transmission-line where microwave propagates at a phase velocity determined by the structure and the electron density of the surrounding plasma. Thus the variation of plasma density can be estimated from the phase shift of the transmitted microwave from one to the other end of the transmission-line. For the proof-of-principle study, a coaxial type transmission-line was adopted with a Teflon outer dielectric and a copper inner conductor operated at a freqeuncy of 2.4 GHz. Analytical analysis of dispersion characteristics of the transmission line structure was carried and the resulting propagation constants were in good agreement with results from calculation using a commercial high frequency structure simulation code (HFSS by ANSOFT). Experimental demonstration have been performed with an inductively-coupled plasma. The sensor was mounted on the inner wall of plasma chamber with a coaxial line length of 6 cm and a distance of 5 cm between input and output ports. Measurement results show that the dependence of electron density of plasma source RF power predicted by the sensor agrees well with the Langmuir probe measurements. Compared to conventional microwave interferometers where line-averaged plasma density is measured, the trainsmission-line type microwave sensor will be less susceptive to the interference caused by multi-passes reflection/refraction effect resulting from nonuniformity of plasma density profiles. Therefore, it provides a measurement of higher sensitivity and wider dynamic range.

PS-ThP8 Floating Probe for Electron Temperature and Ion Density Measurement Applicable to Processing Plasmas, ***C.W. Chung**,* Hanyang University, South Korea

A floating type probe(FP) and its driving circuit using the nonlinear characteristics of the probe sheath was developed and the electron temperature and the plasma density which is found from ion part of the probe characteristic(ion density) were measured in inductively coupled plasmas(ICP). The FP was compared with a single Langmuir probe and it turned out that the FP agrees closely with the single probe at various rf powers and pressures. The ion density and electron temperature by the FP were measured with a film on the probe tip coated in CF@super 4@ plasma. It is found that the ion density and electron temperature by the FP were almost the same regardless of the coating on the probe tip while a single Langmuir probe does not work. Because the floating type probe is hardly affected by the deposition on the probe tip, it is expected to be applied to plasma diagnostics for plasma processing such as deposition or etching.

PS-ThP9 EEPF Measurement in SF6/O2 and CF4/O2 Gas Mixture Capacitively Coupled Plasma, ***S.K. Ahn**, S.J. You, H.-Y. Chang,* Korea Advanced Institute of Science and Technology, Republic of Korea

We have been measured the plasma parameters and EEPF (Electron Energy Probability Function) in a capacitive discharge with some mixtures of processing gases, such as SF6/O2 and CF4/O2. The measurements were achieved at various gas mixing ratios under constant discharge current and pressure conditions. Through the experiment, we have found that as the mixing ratio of SF6 increase, the effective electron temperature increases, while the electron density decreases. And in case of CF4 mixing, the variation trend of the effective electron temperature and the electron density is very similar to that of SF6 mixing case. Thus, it apparently looks like mixing SF6 or mixing CF4 in O2 discharge affect the plasma parameters with similar discharge physics. However in our EEPF measurement, it has been found that mixing SF6 and mixing CF4 in O2 discharge influence the plasma with quite different manners. The low energy part of EEPF is depleted in both case of increasing SF6 mixing ratio and increasing CF4 mixing ratio. But the high energy electron population in EEPF only depends on SF6 mixing ratio. That is, the high energy electron population in EEPF is enhanced with increasing SF6 mixing ratio, while almost independent of CF4 mixing ratio. These gas mixing effects can be analyzed by considering elastic collision and vibrational excitation collision between electrons and the fluoride gases.

PS-ThP10 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. An imaging spectrometer combined with a high speed intensified CCD camera was used to obtain spatially and temporally resolved measurements of the optical emission from dual frequency (2 MHz & 13.56 MHz or 2 MHz & 27.12 MHz) plasmas created in a Gaseous Electronics Conference (GEC) reference reactor. The vertical distribution of the argon 750.4 nm transition was measured at the center of the discharge. Significant changes in the temporal and vertical optical emission distributions were observed with changing feed gas (Ar, CF@sub 4@, and O@sub 2@) and gas pressure (100 mT to 1000 mT). The temporal distributions were insensitive to the amplitude of the lower frequency voltage. Changing from a single powered electrode to two separate powered electrodes also had a significant impact on the time resolved optical emission.

PS-ThP11 Anisotropic Deposition of Cu with a Plasma CVD Reactor Equipped with a High Power ICP H Source, *M. Shiratani, J. Umetsu, **S. Iwashita**, K. Koga,* Kyushu University, Japan

We have realized anisotropic deposition of Cu, for which Cu is filled preferentially from bottom of trenches without being deposited on their sidewall, by H-assisted plasma CVD.@footnote 1,2@ Such type of deposition has a potential to overcome common problems associated with conformal filling: namely, small crystal grain size below half of the trench width, and formation of a seam with residual impurities of relatively high concentration. A high flux of H atoms is required to deposit high purity Cu films at a high rate, because H irradiation to Cu films is effective in reducing impurities in the films. For this purpose, we have increased the maximum discharge power P@sub H@ of the ICP H source from 150 W to 1000 W. To obtain information about the H flux, we have examined dependence of optical emission intensity of H@alpha@(656 nm) on P@sub H@ as a parameter of a gas flow rate ratio R=H@sub 2@/(H@sub 2@+Ar). The following results are obtained in this study. 1) H@alpha@ intensity increases with P@sub H@. 2) H@alpha@ intensity is 10-100 times as high as that for our previous H source. 3) We have filled trenches completely with high purity Cu at a rate above several nm/min for R=11% using anisotropic deposition. Moreover deposition stops automatically just after filling trenches completely. @FootnoteText@ @footnote 1@K. Takenaka, et al., Pure. Appl. Chem. 77(2005)391.@footnote 2@K. Takenaka, et al., J. Vac. Sci. Technol. A22(4) (2004) 1903. .

PS-ThP12 Characteristics of Inductively Coupled Plasma Using Internal Multiple U-type Antenna for Ultra Large-area FPD Processing, ***J.H. Lim**, K.N. Kim, G.Y. Yeom,* Sungkyunkwan University, Korea

Inductively coupled plasmas (ICP) have been investigated for the processing of various materials as one of the high density (1011~1012 cm@super -3@) and low gas pressure plasma sources. But this ICP source have some problems in the processing of large-area, due to the cost and thickness of its dielectric material and the large impedance of the antenna when scaling up to large areas. However, 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 work, an internal-type antenna (multiple U-type antenna) was used as a large-area (2,300 mm x 2000 mm) inductively coupled plasma (ICP) source. Characteristics of the plasma were measured using a Langmuir probe located on the sidewall of the chamber and the use of the multiple U-type antenna showed higher plasma density. Electrical properties of multiple U-type antenna were measured by impedance analyzer. By changing the antenna arrangement and distance of antenna array, the uniformity of the plasma has changed significantly. By optimizing the antenna arrangement, the plasma uniformity less than 10% could be also obtained within the substrate area.

PS-ThP14 New Method for Measurement of Electron Temperature using Wave Cutoff Frequency and Wave Absorption Frequency in Plasmas, ***J.H. Kim**,* Korea Research Institute of Standards and Science, Korea*; D.-J. Seong, Y.H. Shin,* Korea Research Institute of Standards and Science

Wave absorption probe@footnote 1@ and wave cutoff probe@footnote 2@ were developed for the measurement of electron density. The wave absorption probe relies on the resonant absorption of surface waves excited in a cavity at the antenna head. A network analyzer feeds a microwave to the antenna and displays the frequency dependence of power absorption by measuring reflected power. The wave absorption frequency can give the electron density when the electron temperature is known. For measuring the cutoff frequency, a microwave is introduced through the radiating antenna to the plasma and the transmitted wave is detected on the other antenna connected to the receiving port of network analyzer. The wave cutoff frequency can directly give the electron density. Therefore, we can measure both of the absorption frequency and the cutoff frequency with one cutoff probe system. In dispersion relation of surface wave, the absorption frequency is related with the electron density and the electron temperature. Therefore, we can deduce the electron temperature using the absorption frequency and the electron density measured by the cutoff frequency. The measured electron temperature is compared with those got by using a Langmuir probe. @FootnoteText@ @footnote 1@ K. Nakamura et al., J. Vac. Sci. Technol.A 21, 325 (2003)@footnote 2@ J. H. Kim et al., Review of Scientific Instruments Vol. 75, 2706 (2004) .

PS-ThP15 Measurements of Cu Densities at the Ground and Metastable States in a Magnetron Sputtering Plasma Source with a Cu Target*, K. Sasaki, J.-S. Gao, N. Nafarizal, H. Toyoda, S. Iwata, T. Kato, S. Tsunashima, H. Sugai,* Nagoya University, Japan

In the cases of light elements and rare gases, the densities of metastable states are negligible in comparison with the densities of the ground states. On the other hand, in the cases of metal atoms, the densities of metastable states are possibly much higher because of the low excitation energies. The excitation energy of the metastable @super 2@D state of Cu is 1.39 eV, which is lower than electron temperatures of usual magnetron sputtering plasmas. In this case, the density of the metastable state could be comparable to the ground-state (@super 2@S state) density. In this work, we measured the spatial distributions of the Cu atom densities at the ground and metastable states in a conventional magnetron sputtering plasma source with a Cu target by laser-induced fluorescence imaging spectroscopy. The absolute densities of the ground and metastable states were determined by ultraviolet absorption spectroscopy employing a Cu hollow cathode lamp as the light source. As s result, it was found that the density of the metastable state was on the same order as the ground-state density. The spatial distributions of the ground and metastable densities were different. Accordingly, the metastable density affects the total Cu atom density and the distribution. In addition, since the chemical reactivity of the metastable state may be different from that of the ground state, it is necessary to consider the influence of the metastable state in the kinetics of Cu in the gas phase and on the surface. @FootnoteText@ This work was supported by 21st century COE (Center of Excellence) Program "Information Nano-Devices Based on Advanced Plasma Science" of Nagoya University.

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