Thursday Afternoon, November 3, 2005

Plasma Science and Technology
Room 304 - Session PS-ThA

Plasma Sources and Equipment

Moderator: G.F. Franz, Munich University of Applied Sciences, Germany

2:00pm **PS-ThA1 Characteristics of Large-diameter Plasma using a Radial Line Slot Antenna*, C. Tian,*** *T. Nozawa, K. Ishibasi, H. Kameyama, T. Morimoto,* Tokyo Electron LTD., Japan

A radial line slot antenna (RLSA) for surface-wave-plasma at 2.45GHz is a promising candidate with respect to increased process requirements for the large-diameter plasma as well as the gas dissociation control and free plasma damage. Characteristics of such a kind of plasma have been studied by both direct plasma probe measurements and numerical simulations. The discharge chamber is 40 cm in diameter and 30 cm in depth with a quartz glass window 3 cm thick on the top. A custom inductively coupled plasma (ICP) is also evaluated for comparison by replacing the RLSA with an RF coil mounted on the top window. Some unique characteristics of RLSA has been found by both radial and vertical direction plasma measurements, which are: (1) the electron temperature of RLSA is about 0.9eV-1.2eV low under the various power input and gas pressure conditions, half as many as the ICPs; (2) the main plasma generation area of RLSA is limited in the plasma surface just below the quartz glass window, while the ICP involve a much wider range; (3) the electron energy distribution functions (EEDFs) of RLSA plasma show few high energy electrons existing in the plasma diffusion area as compare to the ICPs. Numerical simulations are implemented to reveal the more essential difference in plasma generation between the RLSA and the ICP, where the superiority of RLSA plasma has been confirmed. The critical uniformity of the radial plasma distribution has been evaluated by the view of RLSA optimization. Optimal design of the slot pattern and the top glass window shape are effective in keeping the high plasma uniformity robustly from various processing conditions. Numerical analysis of microwave propagation helps to achieve the RLSA optimal design. The features of high plasma uniformity and low electron temperature lead to free plasma damage in our associated etching process.

2:20pm **PS-ThA2 Application of the Shaped Electrode Technique to a Large Area Rectangular Capacitively-Coupled Plasma Reactor to Suppress Standing Wave Non-Uniformity*, L. Sansonnens,*** Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland*; C. Ellert, A. Buechel,* UNAXIS-Balzers AG, Liechtenstein*; H. Schmidt, A.A. Howling, C. Hollenstein,* EPFL, Switzerland

The use of VHF (very high frequency) instead of the standard 13.56 MHz excitation frequency in capacitively-coupled plasma reactors has been shown to be a promising technique for plasma-enhanced chemical vapor deposition of thin films such as amorphous or microcrystalline silicon used for the production of photovoltaic solar cells or thin film transistors for flat screens. In particular, the use of VHF has been shown to increase the deposition rate and to reduce the sheath voltage and maximum ion energy bombardment at constant plasma power. Both effects favor deposition at higher rates without degrading the thin film electronic properties. However, these advantages have generally been demonstrated in small area plasma reactors, and it has been shown that electromagnetic standing wave effects becomes the main source of non-uniformity limiting the use of VHF in large area reactors exceeding 1 m@super 2@ required for industrial applications. Recently, it has been proposed to use a shaped electrode (together with a thin dielectric plate in order to confine the plasma in a constant interelectrode gap) in place of the conventional flat electrode in order to suppress the standing wave non-uniformity. In this work, the application of the shaped electrode technique for standing wave suppression in a large area rectangular industrial reactor (substrate area: 1.1 m x 1.25 m) will be presented. In particular, film thickness uniformities for amorphous silicon deposited with and without shaped electrode at an excitation frequency of 41 MHz will be compared, and some of the implementation difficulties of the shaped electrode technique for industrial processes will be discussed.

2:40pm **PS-ThA3 Characteristics of Internal Linear Inductively Coupled Plasma and Its Etching Properties for Flat Panel Display Applications*, G.Y. Yeom,*** *K.N. Kim, C.K. Oh,* Sungkyunkwan University, Korea **INVITED**

The increase of substrate size and the requirement of high rate processing for both microelectronics and flat panel display industry require large-area high density plasma sources. Among the various high density plasma sources, inductively coupled plasma sources are preferred due to its simple physics and scalability. However, conventional spiral-type external inductively coupled plasma sources can not be easily applied to the flat panel display processing due to the standing wave effect, increased capacitive coupling, etc. In this study, characteristics of an internal linear inductively plasma source was investigated as a possible high density plasma source for the application to flat panel display processing larger than 7th generation of TFT-LCD substrates. By varying the arrangements of the antenna arrays, the uniformity of the plasma has changed significantly, and, by optimizing the antenna arrangement, the plasma uniformity of 4% with the plasma density higher than 2x10@super11@ /cm@super3@ could be obtained on the substrate. Electrical characteristics of the plasma source measured by an impedance analyzer showed the low impedance and high power transfer efficiency for the optimized antenna arrangement.

3:20pm **PS-ThA5 Investigation of Frequency and Magnetic Field Effect on Single and Multiple Frequencies Capacitively Coupled Plasma Reactors*, T. Panagopoulos,*** *A.M. Paterson, J.P. Holland,* Applied Materials Inc.

The effect of driving frequency and magnetic field has been investigated for a 300 mm MERIE reactor for an argon discharge using the HPEM hybrid-fluid computational model. The driving frequency varied from 2 MHz up to 200 MHz for either single or multiple frequency operation, while the magnetic field range was 0 to 225 G. Pressure was maintained low, at 30 mTorr, where the magnetic field has the most dominant effect and the power was held constant at 400 W. As the magnetic field increases the dc bias becomes less negative and the difference between plasma potential and dc bias is reduced and becomes minimal at high values of magnetic field. For low driving frequencies, up to 20 MHz, the dc bias increases (becomes more negative) with a small increase in magnetic field (40 MHz), the dc bias becomes less negative monotonically with the B field intensity. For high magnetic field (~170 G), the frequency effect on dc bias is rather weak. The electron temperature at reactor centerline decreases with increasing frequency and increasing magnetic field intensity, while the argon metastable and argon density follow opposite trends with one another at the same location. The plasma density increases with the frequency and magnetic field, while the argon metastable density peaks at low B field initially and then decreases at higher B field. The plasma potential decreases both with increasing magnetic field and driving frequency. At higher frequencies (>20 MHz) and values of magnetic field greater than 50 G, the plasma potential increases with the magnetic field and saturates at values around 200 G. Experimental results using langmuir and V-I probes confirm the trends observed in the simulation study.

3:40pm **PS-ThA6 Independent Control of Backscattering Energy and Sputter Rate in a VHF-DC Superimposed Magnetron Source*, H. Toyoda,*** *Y. Sakashita, Y. Takagi, K. Sasaki, J. Gao, T. Kato, S. Iwata, S. Tsunashima, H. Sugai,* Nagoya University, Japan

Recent application of magnetron plasma to nano-scale thin film deposition requires damage-free atomic-scale flat surfaces of the deposited film. In general, surface qualities of sputter deposited films are influenced by the incidence of particles with high kinetic energies. Thus, control of energetic ions and neutrals impinging on substrate is an important issue, in order to clarify a correlation between energetic particles and film qualities. In the magnetron discharge in argon gas, a significant amount of energetic Ar atoms is backscattered from the target surface and incident on the substrate. The backscattering energy can be reduced by lowering the target voltage, but it results in a decrease in the sputter deposition rate. In this study, we present independent control of the backscattering energy and the sputter deposition rate by superimposing VHF and DC voltage to the target. Discharge characteristic and sputter deposition rate are investigated by a Langmuir probe, a quadrupole mass spectrometer (QMS) with an energy analyzer and a quartz crystal microbalance. From the QMS measurement of energetic Ar ions, a decrease in the energy of backscattered Ar atoms is inferred. It is confirmed that the sputter deposition rate of the VHF-DC superimposed magnetron discharge at lower target DC voltage (~100 V) is almost comparable to that of the conventional DC magnetron discharge at higher target voltages (>400 V).

4:00pm **PS-ThA7 Extraction of a Directional, Nearly Mono-energetic Ion Beam Using an Inductively Coupled Pulsed Plasma with an Internal Coil*, L. Xu,*** *D.J. Economou, V.M. Donnelly, P. Ruchhoeft,* University of Houston

Ion beams with narrow energy and angular distributions are important for large-area sub-10 nm feature etching and deposition. In this work, a 13.56 MHz pulsed (typically 100µs ON/100µs OFF) inductively coupled plasma reactor with a two-turn nickel coil immersed in the plasma was developed to generate a nearly mono-energetic, directional ion beam. This beam may be used for etching (Ar@super +@ ions on silicon exposed to chlorine) or deposition (low energy Ni@super +@ ions on silicon). The plasma chamber was separated from the differentially pumped processing chamber by an ion drift region. A three-grid ion energy analyzer located in the processing chamber, 75 cm from the ion source, was employed to measure the ion energy distribution (IED) and ion current density. A positive voltage pulse synchronized with the power-OFF (afterglow) period of the pulsed discharge was applied to an extraction ring electrode surrounding the plasma, raising the plasma potential (V@sub p@) and "pushing" positive ions out of the plasma through a grounded grid. With 100 V applied to the extraction ring electrode during the afterglow, the energy of the extracted ion beam peaked at 100.5 eV, and the FWHM of the IED was 3.0 eV. The corresponding ion current (measured by the analyzer with 1 degree acceptance angle) was 20 times higher than the ion current extracted during the power-ON (active glow, no acceleration voltage) period. This is because ions exiting the plasma during the afterglow have a lower divergence angle, due to the vertical acceleration and low T@sub e@. The ion drift tube downstream of the plasma was found to be a "natural filter" to effectively screen out ions in the wings of the energy and angular distributions, allowing a directional and nearly mono-energetic ion beam to reach the sample. This work was supported by the National Science Foundation (NSF-NIRT-0303790).

4:20pm **PS-ThA8 Ion Energy Selection in Expanding Thermal Plasmas by Means of Pulse-Shaped Substrate Bias***, **M.A. Blauw**, A.H.M. Smets, M. Creatore, M.C.M. Van De Sanden,* Eindhoven University of Technology, The Netherlands

Pulse-shaped substrate bias was applied to the expanding thermal plasma. In contrast to a sinusoidal RF-waveform, a pulse-shaped RF-waveform can result in a mono-energetic ion flux to the substrate at much lower frequencies.@footnote 1@ A nearly constant substrate potential was observed between two consecutive pulses for argon-hydrogen and argon-oxygen gas mixtures. It implies that the ion flux is nearly mono-energetic because the plasma sheath transit time is much shorter than the pulse period. The ions that reach the substrate during the pulse have energy comparable to the ions at floating potential so that they do not influence the surface processes significantly. All details of the observed substrate potential can be fully described with the equivalent circuit diagram of the substrate bias system. Besides, the ion current density was derived from the linear voltage increase over the coupling capacitor between two consecutive pulses. The absolute ion density was calculated from the measured ion current density using the electron temperature of the bulk plasma. In contrast to a 13.56 MHz sinusoidal substrate bias, which creates a bright glow around the substrate, the pulse-shaped substrate bias does not influence the plasma visibly. The pulse-shaped substrate bias is particularly suitable to improve the properties of several plasma-deposited materials. The reason is that a mild ion bombardment enhances the rearrangement of surface atoms into an ordered structure, whereas highly energetic ions cause permanent damage.@footnote 2@ For example, the pulse-shaped substrate bias could be used to reduce the defect density in amorphous silicon, to increase the compactness of silicon oxide films on polymers, and, to improve the hardness of diamond-like carbon coatings. @FootnoteText@ @footnote 1@S.B. Wang and A.E. Wendt, J. Appl. Phys. 88, 643 +(2000). @footnote 2@J.W. Rabalais et al., Phys. Rev. B 53, 10781 (1996).

4:40pm **PS-ThA9 A Toroidal Plasma Source for Generation of High Throughput, Low Contamination Atomic Gases***, **X. Chen**, W.M. Holber, P. Loomis, J. Gunn, S.Q. Shao,* MKS Instruments, Inc.

A high power, low-field toroidal RF plasma source has been developed for generation of activated gases, such as O, H, N and F. In the plasma source, RF power is coupled through ferrite cores into the plasma that acts as a secondary of an RF transformer and is confined within a toroidal quartz chamber. A combination of toroidal plasma geometry, a quartz plasma chamber, and extremely low electric field (<8 V/cm) minimizes chamber surface erosion and associated contamination. More than twice as much of atomic oxygen is generated as compared with the current generation of remote plasma sources, resulting in 2-3 times increase in throughput for photoresist stripping. Other applications include gate dielectric modification, atomic layer deposition, annealing, and wafer cleaning. This paper characterizes the plasma source and its operation with O@sub 2@, N@sub 2@, H@sub 2@, H@sub 2@O, H@sub 2@/N@sub 2@ and H@sub 2@/He gasses. Experimental measurements of plasma density and atomic gas flux of O, N, and H, using Langmuir probes, recombination probes and calorimetry, are presented. Typical plasma density is in the order of 10@super 13@ cm@super -3@. Transport of the charged species and activated neutral species through quartz and sapphire ducts, materials commonly used as liners in semiconductor process chambers, are also reported.

5:00pm **PS-ThA10 Characterization and Modeling of a Transformer-Coupled Toroidal Plasma Source for Remote Chamber Cleaning***, **B. Bai**, J.J. An, H.H. Sawin,* M. I. T.

The transformer-coupled toroidal plasma source is widely used for remote cleaning of Chemical Vapor Deposition(CVD) chamber, in which fluorine containing gases are dissociated to form fluorine atoms for downstream etching. It was found that with the addition of a small amount of N2(0.5% of the total flow) into the fluorocarbon plasmas(C2F6 or C4F8), the etching rate of silicon dioxide film was doubled, making the etching rate comparable to NF3 plasmas under the same conditions. The increase of etching rate of silicon dioxide when N is added is due to the surface modification of the transfer tube between the source and downstream chamber, where N atoms or N containing radicals block the recombination site to form COF2 and favors the formation of CO2 thereby causing more fluorine atoms to be delivered to the downstream chamber. The toroidal plasma source was experimentally characterized. Rovibrational bands of N2 and C2 were fitted to obtain the neutral gas temperatures for NF3 and C2F6 plasmas, and they were found to be in the range of 3000-6000K, which is consistent with the high power density(>15W/cm3) coupled into the plasmas. The electron temperatures were found to be 1-4 eV, as determined by the line ratios of atomic argon spectrum. The concentrations of fluorine and oxygen atoms in the plasma source were measured by the actinometry technique and other species were detected by both the Mass Spectrometer and the FTIR. It was found that NF3, C2F6, C4F8 all had nearly 100% dissociation while CF4 had only about 50% dissociation, which makes CF4 unfavorable for the remote cleaning. Global and 1-D models were set up to simulate the toroidal plasma source as an infinite cylindrically symmetrical DC positive column. Detailed plasma chemistries were considered and first three moments of the Boltzmann's equations were applied to decide the equilibrium condition of the plasmas. The model was found to explain the experimental trend very well.

Author Index

Bold page numbers indicate presenter