Plasma Science and Technology
Room 314 - Session PS-MoA

Plasma Sources

Moderator: E.V. Barnat, Sandia National Laboratories

2:00pm **PS-MoA1 Ion-Acoustic Solitons in a High Power Pulsed Magnetron Sputtering Discharge***, K.B. Gylfason,* University of Iceland, Iceland*; **J. Alami**, U. Helmersson,* Linkoping University, Sweden*; J.T. Gudmundsson,* University of Iceland, Iceland

We report on the formation of ion acoustic solitons in an unipolar pulsed magnetron plasma. A high density plasma > 10@super 18@ cm@super -3@ is created by applying a high power pulse (6-17 J) with pulse length 100 µms and repetition frequency 50 Hz to a planar magnetron discharge. The temporal behaviour of the electron density measured by a Langmuir probe shows oscillations as the plasma density decays. We relate these oscillations to solitons traveling away from the target followed by stationary oscillations. The velocity, width, and amplitude characteristics of the soliton are discussed and compared to the properties of the soliton solutions of the Korteweg-de Vries equation. The speed of the soliton along the axis of the discharge decreases with increased gas pressure. We relate this decrease in travelling speed to the decrease in the fractional density modulation dn/n@sub 0@.

2:20pm **PS-MoA2 Next Generation RF Ion Beam Source for Three-Dimensional and other Critical Etching Applications***, **A.V. Hayes**, V. Kanarov, R. Yevtukhov, C. Borges, K. Williams, M. Campo, B. Druz,* Veeco Instruments, Inc.

Rf plasma broad ion beam etch technology is used in manufacturing of magnetic, optical, and other types of thin film devices due to its unique capabilities to etch difficult materials and control ion energy and incidence angles. Requirements for increased critical dimension (CD) control and directional "static etch" processes have started to exceed the ion current density and directionality uniformity capabilities of conventional ion sources. "Static etch" processes in which the substrate is tilted at ion incidence angles of up to 70°-80° with no or only partial substrate rotation, are particularly challenging, requiring the ion beam to be very uniform and collimated across a three dimensional space within the beam occupied by the wafer. Development of a novel rf ICP broad ion beam source with dynamic plasma magnetic field configuration designed to achieve these requirements will be described. In addition, the role of the beam divergence angle and other beam dispersion parameters on the CD and static etch uniformity will be discussed. Results will be measured in terms of etch uniformity on silicon oxide coated wafers and etch divergence using a shadow mask type measurement fixture. In an optimum configuration the source is capable of achieving a uniformity of less than 1% sigma/mean on a static wafer (about a 4-5X improvement compared with current technology sources) and less than 0.5% on a rotated wafer (a 2-3X improvement) with excellent repeatability. The full etch divergence angle is less than 3°, and uniform across the substrate within 0.5°. Other applications of this source could include uniform etching of features mounted on 3-dimensional substrates.

2:40pm **PS-MoA3 The Use of Reactive Gases with Broad-beam RF Ion Sources for Industrial Applications***, **St. Schneider**,* Forschungszentrum Juelich, Germany*; T.W. Jolly,* Oxford Instruments Plasma Technology Ltd.*; H. Kohlstedt, R. Waser,* Forschungszentrum Juelich, Germany

Broad-beam ion sources are used for a number of important industrial etching and deposition applications, and the use of inductively-coupled plasmas has greatly increased the feasibility of using beams of reactive gases, especially of chlorine and oxygen, but also of CO, CO@sub 2@, CF@sub 4@, CHF@sub 3@, SF@sub 6@ etc. In order to gain more understanding of the factors that affect the composition of beams of these gases, we have used a Hiden energy-dispersive quadrupole mass spectrometer to analyze the flux of ions and energetic particles produced by an Oxford Instruments 15cm RF ion source. For all of the above gases, we have analyzed the effects of changing the operating conditions on the composition of the ion beam, and the fractional production of multiply-charged ions; on the plasma potential (and the consequential divergence of the ion beam) and on the spread in energy of the ion beam. We discuss how these factors influence the correct use of the ion source in etching applications with these gases. It is important that the design of the ion source should be optimized for the process gases that are used. The source was originally optimized for use on argon. We discuss the effect of the design on the source's performance with the different gases, and we consider whether design changes could be appropriate for optimum performance on different gases.

3:00pm **PS-MoA4 Reactive Sputter Deposition of Nanocrystalline Compound Thin Films with a Hollow Cathode Source Operated in a Static Mode***, **A. Pradhan**[1], S.I. Shah,* University of Delaware

Hollow Cathode Sources (HCS) are unique sputtering sources that sputter material from the inner surface of a cylindrical tube. Due to their geometry, HCS offer several advantages such as lack of hysteresis, low consumption of the reactive species, high plasma density and high deposition rates. We have characterized a titanium HCS for reactive deposition of titania films in static mode. In this mode the sputtering is carried out in a static gas volume. Stoichiometric films growth could be sustained even after 3 hours of continuous sputtering. This new method of reactive sputtering offers several advantages over conventional techniques such as ease of operation, lower equipment cost, lower environmental load, etc. Langmuir probe measurements were used to determine the plasma parameters in a static HCS. The plasma density was 2-3 orders of magnitude greater than that obtained in planar sputtering. The high-density plasma can be used to deposit stoichiometric nanocrystalline oxide films by negatively biasing the substrate and allowing the ion bombardment to provide the energy required for crystallization of the growing film. X Ray Diffraction (XRD) of the films grown with a substrate bias of -80V shows the presence of the rutile phase. The particle size was estimated from the XRD peak broadening to be around 20nm. The films were also characterized by X-Ray Photoelectron Spectroscopy (XPS), Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). Films were found to be nanocrystalline only when the sputtering gas was rich in oxygen. Monte Carlo simulations were carried out using SRIM program to determine the energy transferred by the ions to the growing surface. It was found that backscattered ion count was much higher in the case of O2 when compared to Ar, which could be responsible for the formation of nanocrystalline films.

3:20pm **PS-MoA5 Evolution of Radiofrequency Plasma Sources***, **F.F. Chen**[2],* University of California, Los Angeles **INVITED**

Though this is the 50th AVS Symposium, RF plasma sources have a shorter history. Their development, driven by the explosive growth of the computer industry, did not really start until the 1970s. There are three main types: capacitive discharges called Reactive Ion Etchers (RIEs), Inductively Coupled Plasmas (ICPs), and the newcomer on the block, Helicon Wave Sources (HWS). Development of RIEs and ICPs has progressed mainly by trial and error, but in the last ten years their evolution has been aided by computer modeling, a result of the fast chips that these sources themselves make possible. From a plasma physics standpoint, each of these sources poses interesting problems. RF energy penetrates into ICPs much farther than skin depth theory would predict. Helicon sources produce much higher densities than ICPs at the same power. RIEs, with all their deficiencies, still perform better in many applications. Are we simply lucky, or are there physical reasons for this?

4:00pm **PS-MoA7 Physics of High-pressure Helium and Argon Plasmas***, **M. Moravej**, S.E. Babayan, X. Yang, G.R. Nowling, R.F. Hicks,* University of California, Los Angeles

The physics of helium and argon plasmas was investigated in the pressure range of 10 to 1000 Torr. The current and voltage waveforms and the current-voltage plots were obtained at varying pressures for both gases. The waveforms indicated that before the plasma was struck the load was purely capacitive for both gases, however, after the discharge was ignited, the argon plasma exhibited a greater resistive nature than the helium. The IV curves at 760 Torr indicate that the breakdown voltage for argon was approximately 500 V higher than that of helium. From these IV measurements, the helium and argon plasma densities were calculated to be 3.48*10@super 11@ and 3.15*10@super 11@ cm@super -3@, respectively and the electron temperatures were determined to be 1.3 and 0.3 eV, respectively. The effect of pressure and of impurities, O@sub 2@ and CF@sub 4@, on the physics of the plasma was investigated by these measurements and will be presented at the meeting.

[1] **PSTD Coburn-Winters Student Award Finalist**

[2] **AVS 50th Anniversary Invited Speaker**

4:20pm **PS-MoA8 Two-dimensional Self-consistent Modeling of Wave Propagation and Plasma Dynamics in a Helicon Source*, D. Bose,*** Eloret Corp.*; T.R. Govindan, M. Meyyappan,* NASA Ames Research Center

Helicon plasma sources are of interest in a variety of applications such as space plasma propulsion, fusion experiments, materials processing reactors, etc. The interest in these devices stems from their ability to generate high density plasmas by efficiently absorbing the applied radio frequency power. In this paper we will present results form a two-dimensional helicon plasma model that enforces self-consistency between wave propagation and plasma dynamics. Plasma fluid equations relevant for plasma generation, heating, and transport with externally applied dc magnetic field are solved self-consistently with Maxwell's equations for rf electric field, Ohm's law for rf plasma current, and space charge waves. The absorption and propagation of Trivelpiece-Gould waves generated due to a finite electron mass are implicitly included. This wave is highly dissipative and is the chief mode of energy transfer to the plasma. A parametric study will be performed to isolate the factors that affect bulk versus peripheral power absorption, downstream plasma density and uniformity. The effect of altering the dc magnetic field on plasma and wave characteristics will be presented. Our current results show that the applied magnetic field profile can be adjusted to move the peak plasma density from the near antenna source region to the process chamber. Comparisons with the available experimental data on plasma density and uniformity will also be presented.

4:40pm **PS-MoA9 Large Area Electron-Beam Generated Plasma Processing System@footnote 1@***, **D. Leonhardt**, C. Muratore, S.G. Walton,* Naval Research Laboratory*; D.D. Blackwell,* SFA Inc.*; R.F. Fernsler, R.A. Meger,* Naval Research Laboratory

NRL has developed a 'Large Area Plasma Processing System' (LAPPS) using an electron beam (e-beam) to initiate the gas ionization process with the goal being the increased control over the flux of reactive species to the surface and the ability to modify surfaces over large areas. Our system demonstrates that the e-beam ionization process is largely independent of gas composition and capable of producing low temperature plasma electrons in high densities over large areas (square meters). The system consists of a planar plasma distribution generated by a magnetically collimated sheet of 2 keV, < 1 mA/cm@super 2@ electrons injected into a neutral gas background (oxygen, nitrogen, sulfur hexafluoride, argon). Typical operating pressures range from 20-200 mtorr with beam-collimating magnetic fields (100-200 Gauss) for plasma localization. This presentation will focus on (1) the production of a large area (> 0.5 m@super 2@) system and (2) applications of these plasma sources for surface modification. Construction, scaling and uniformity at the substrate in the large plasma source will be discussed, including the processing stage configurations and layout. General characteristics of these plasmas will be discussed and illustrated through time-resolved in situ plasma diagnostics (Langmuir probes, microwave transmission and mass spectrometry). @FootnoteText@@footnote 1@ Work supported by the Office of Naval Research@footnote 2@ Muratore, C., NRL/ASEE Postdoctoral Research Associate.

5:00pm **PS-MoA10 Post-etch Wafer Cleaning by a New Dry-cleaning Technique using Both Gas Flow and Plasma*, Y. Momonoi,*** *K. Yokogawa, M. Izawa,* Hitachi Ltd., Japan

Because wafer cleaning ultimately affects yield and reliability, it is one of the crucial issues in fabricating semiconductor devices. Regarding devices, scaling-down and adoption of new materials impose an imminent demand for new developments in particle cleaning. Dry-cleaning techniques have been proposed recently as other approaches for particle removal. Their removal efficiency, however, is less than that of wet cleaning, because it is difficult to balance chemical cleaning and physical cleaning. In light of the above circumstances, the authors have developed a new concept of dry particle cleaning, named dry scrubber.@footnote2@ The dry scrubber utilizes both the mechanical effects of gas flow and the chemical effects of a down-flow plasma. Regarding the gas flow, narrowing the flow space along the wafer increases the viscous friction, which causes particles to remove from the wafer surface, and they are transported away. Regarding the plasma, a gas mixture of CF@sub 4@ and O@sub 2@ is induced in it, which weakens the adhesion force of particles chemically. The basic cleaning capabilities of the dry scrubber were evaluated by using it to remove Al@sub 2@O@sub 3@ particles on 8-inch p-type bare silicon wafers. The evaluation showed that the plasma enhanced the particle removal of the gas flow; namely, the combination of a down-flow plasma and a fast gas flow removed particles at an efficiency of 98% in 60 sec. It was also found that the dry scrubber produces an etching depth for poly-silicon of 0.17 nm. The cleaning capabilities of the sample with etched contact-hole patterns were also evaluated. This sample had residues of photo-resist on its surface and particles in the holes. These results confirm that the new cleaning technique can effectively removes the residues and the particles from a patterned surface. @FootnoteText@@footnote 1@Dr. K. Mosig et al., IITC2001@footnote 2@Y. Momonoi, K. Yokogawa, M. Izawa, Proc. Inter. Sym. Dry Process, (2002), p.113.

Author Index

Bold page numbers indicate presenter