Plasma Science and Technology

Room: 606 - Session PS1-ThA

Plasma Diagnostics II

Moderator: C.B. Labelle, Advanced Micro Devices, Inc.

2:00pm **PS1-ThA1 Development of Atomic Radical Monitoring Probe for Spatial Distribution Measurements and its Application to Reactive Plasma Processes**, ***S. Takashima,*** Nagoya University, Japan*, S. Takahashi, K. Yamakawa, S. Den,* Katagiri Engineering Co., Ltd., Japan*, H. Kano,* NU-EcoEngineering Co., Ltd., Japan*, M. Hori*, Nagoya University, Japan

Atomic radicals such as hydrogen(H), nitrogen(N), oxygen(O), and carbon(C) play important roles in the reactive plasma processes. In order to realize nano-scale etching processes and fabricate high functional nano-structure materials using the plasma processes, it is indispensable to clarify the mechanism of the etching or the deposition processes and control the process plasmas at the particle level. Moreover, it is necessary to develop the plasma processes based on not external parameters such as power, pressure, and gas mixture but the internal parameters such as radical densities, their energies, and so on. In our previous studies, we have developed the compact measurement system of the atomic radicals such as H, N, O, and C in the reactive process plasmas. The technique of the system is a vacuum ultraviolet absorption spectroscopy (VUVAS) using an atmospheric pressure microdishcarge hollow cathode lamp (MHCL). The MHCL was 9mm in diameter. So, the system for measuring the atomic radical densities can be easily handled. Using the system, we have carried out the measurements of the densities in various process plasmas and clarified the behaviors of the radicals. However, the two opposite ports are necessary to measure the densities using the system. Moreover, it is difficult to measure the spatial distribution of the atomic radical densities in reactive process plasmas. In this study, we have developed the monitoring probe for the atomic radical density measurements. The probe consisted of the MHCL, the optical part, the probe part, and the VUV monochromator. The size of the probe installed to the plasma was 2.7 mm in diameter. The necessary port for the measurements was only one. Moreover, we can measure the spatial distribution of atomic radical densities by moving the probe along the chamber radius. Using the probe, we carried out the spatial distribution of the H radical densities in the remote H_2 plasmas. The densities drastically decreased from 1.2×10^{12} cm^{-3} to 4.4×10^{11} cm^{-3} near the chamber wall at the pressure of 1.33 Pa, the RF power of 300 W. It was considered that the drastic decrease of the H atom density near the wall was due to the surface loss of the H radical on the chamber wall made of the stainless steel. The atomic radical monitoring probe was the ubiquitous measuring tool because using the probe, anyone can measure the atomic radical densities in any material process plasmas at any time.

2:20pm **PS1-ThA2 Measurement of Absolute Density of Argon Metastables by using Laser Adsorption Spectroscopy**, ***T. Ohba****, T. Makabe*, KEIO University, Japan

Absolute density of Ar metastables($1s_{3,5}$) was measured in a two-frequency capacitively coupled plasma (2f-CCP) in pure Ar by using Laser Adsorption Spectroscopy (LAS) in order to investigate the spatial profile. The axial density distribution of metastables is experimentally characterized as a function of pressure (25 mTorr - 100 mTorr) and bias amplitude (100 V - 400 V). Axial density profile of Ar metastables shows a broad peak in front of the electrode driven at 100 MHz, and gradually decreases toward the opposite electrode biased at 500 kHz. With decreasing pressure, the density approaches to more defusive profile as expected. The typical density of Ar($1s_5$) is 10^{11} cm^{-3}, and the density ratio between Ar($1s_5$) and Ar($1s_3$) changes from 10 to 9.3, when we increase the pressure. Under the present external plasma condition, the bias amplitude has less influence on the axial magnitude and distribution of the metastables. It implies the complete functional separation between the driving and bias power in the 2f-CCP in the present system. The spatiotemporal transport of low energy electrons will be discussed through the fundamental collision process of Ar($1s_5$) by using optical emission and absorption spectroscopy.

2:40pm **PS1-ThA3 Gas Phase Studies of CH3OH Plasmas Using Optical Emission Spectroscopy**, ***K.J. Trevino****, E.R. Fisher*, Colorado State University

Plasmas are traditionally used for deposition, etching, and surface modification of various types of materials, most notably in the semiconductor industry. Plasma systems have recently been utilized in a non-traditional application, water remediation. Three steps are involved in this process; determining which organic molecules can be detected, developing effective detection systems, and establishing the efficacy of abatement. Recent studies of dense medium plasma systems have developed oxidation mechanisms for organic molecules, converted organic contaminants to less toxic species, and examined aromatic compound breakdown with GC/MS. Here, we have investigated the use of an inductively coupled plasma (ICP) system with optical emission spectroscopy (OES) for the purpose of non-intrusive detection as well as abatement of organic molecules in contaminated water. Our data demonstrate that not only is detection of organic molecule breakdown possible for a variety of species, but abatement is also possible. Currently we are able to detect <100 ppm contamination and are exploring this technique for the desired detection limits in the ppb range. OES data for the detection and abatement of CH3OH and larger organic molecules such as urea and methyl tert-butyl ether in aqueous solutions will be presented.

3:00pm **PS1-ThA4 Measurement of the Gas Temperature Distribution in UHF-ECR Dielectric Etching System**, ***H. Kobayashi****, K. Yokogawa, K. Maeda, M. Izawa*, Hitachi, Ltd., Japan

Plasma etching is widely used for the fabrication of semiconductor devices. In this process, particle contamination continue to be an issue. Recently, for the purpose of controlling the particle transport, use of the thermophoretic force, that move the particles toward lower gas temperature region, has been investigated. We measured the particle behavior in plasmas by using UHF-ECR etching apparatus having a laser particle monitor. The laser particle monitor consist of 532nm-YAG laser, lenses to form the laser sheet light passing above the wafer, and CCD camera to detect the laser light scatted by particles. We injected particles into plasmas by gas puffing and we found that particles gathered above the wafer center, when plasma density was decreased at the wafer center. Though, particles moved away from the region above the wafer, when plasma density was increased at the wafer center. We simulated particle transport by considering gas viscous force and thermophoretic force. And, it was predicted that there existed gas temperature gradient of 1000 K/m. In this study, the gas temperature distribution across the wafer was investigated. The gas temperature can be assumed to be equal to the rotational temperature of the nitrogen molecules. Thus, we measured the emission spectra of the second positive system of nitrogen molecules. The rotational temperature was determined by comparison of the measured spectral profiles and theoretical spectral profiles calculated by assuming rotational temperatures. The emission from the plasmas was measured through the top plate. Nitrogen and CHF_3 gases were used for plasma discharge by considering the SiOC damascene etching. When plasma density was increased at the wafer center, the gas temperature at the wafer center and the wafer edge were 450 K and 460 K, respectively. On the contrary, when plasma density was decreased at the wafer center, the gas temperatures at the wafer center and the wafer edge were 410 K and 510 K, respectively. Consequently, we confirmed that the gas temperature distribution across the wafer can be controlled by changing plasma distribution and the gas temperature gradient of 1000 K/m can be made.

3:40pm **PS1-ThA6 Research at CPMI Towards Making EUVL a Success**, ***D.N. Ruzic****, S.N. Srivastava, K.C. Thompson, H. Shin, J.R. Sporre, E.R. Ritz*, University of Illinois at Urbana-Champaign

Center for Plasma Material Interactions (CPMI) at the University of Illinois is currently expanding efforts to solve critical problems for timely implementation of extreme ultraviolet lithography. The research at CPMI is focused on variety of different problems being currently faced in this technology. A commercial extreme ultraviolet light source (XTS 13-35) is investigated to characterize the debris ejecta. A fully calibrated ion diagnostic device (spherical sector ion energy analyzer) is developed, which is used for measuring the ion debris fluxes and their energies in absolute units. Ion debris is measured both from Xe as well as Sn EUV sources. Several mitigation schemes are investigated and tested for their effectiveness in the XTS 13-35 source. Recent work towards debris mitigation includes gas curtain, pulsed foil trap, plasma based mitigation, mixed fuel experiments. In the case of mixed fuel experiments, by adding 5% of H_2 in the main fuel (Xe), the ion energies and fluxes could be reduced by half of the original value. Using pulsed foil trap mitigation, 4 keV Xe^+ ion flux could be reduced about 4 times whereas Xe^{2+} ion flux were dramatically reduced by a factor of about 90. Mirror samples are exposed to the EUV source and erosion due to harsh plasma debris is measured for variety of different EUV compatible materials (C, MLM, Si, Mo, Pd, Mo-Au, Au). For example, the measured erosion on EUV exposed multilayer mirror (MLM) sample is about 13 nm $\pm$ 2 nm. Comparison with theory predicts the major damage from high energy ions itself, but also

indicates the role of neutral particles. To advance the debris diagnostic tool, the detector is further modified to account for neutral debris measurement. Ion and neutral debris measuring capabilities allowed us to perform life time testing. We have also studied the problems with Sn EUV sources and currently developing methods to clean Sn effectively from the mirror surface without actually harming the surface underneath. Reactive ion etching is found to be a viable solution and variety of different samples are tested and processed through the cleaning techniques. Encouraging results in this area has motivated us to do a full blown test in the EUV source and install an integrated cleaning system, which could run in a manufacturing environment.

4:00pm **PS1-ThA7 Inductively Coupled Plasma Radio Frequency Electrical Characteristic Measurement for Deposition of CNTs.**, ***W.-C. Chen,*** Academia Sinica, Taiwan*, C. Mahony,* University of Ulster, UK*, K.-H. Chen,* Academia Sinica, Taiwan*, L.-C. Chen*, National Taiwan University

Here we investigate radio frequency (RF) inductively coupled plasma (ICP) as an in-line sensor for characterizing vertical aligned carbon nanotubes (CNTs) deposition plasma via correlation of the real/imaginary RF current/voltage. The plasma dual directional coupler (PDDC) was used to measure the forward and reflected voltage before the ICP matching network in Ar plasma. Then we introduce a homemade external circuit to give impedance Z, which includes the parasitic inductances of capacitors, parasitic capacitance of inductors and cable resistances. Component values in the circuit model can be determined by analysis of VHF (very high frequency) bridge and spectrum analyzer data. With arising reaction pressure in Ar plasma, the corresponding current & voltage will be change. The maximun current in Ar plasma can be observed at the pressure of 60 mtorr and power of 200 Watt. Indicating much higher electrons density and effective collision frequency in this plasma condition. Measured values of Z with rising RF input power of plasma shows the reactance X to vary from negative to positive values. These correspond with observed E to H transition in this ICP. We will discuss RF harmonics during CNTs deposition condition in Ar & CH4 and relate them to process repeatability and reliability.

4:20pm **PS1-ThA8 Process Control through Diagnostics and Understanding: Multi-frequency Discharges and Atmospheric Pressure Plasmas**, ***T. Gans***, Queen's University Belfast, UK **INVITED**

Despite its technological importance, power coupling and ionisation mechanisms in radio-frequency (rf) discharges are not yet fully understood. Of particular interest are multi-frequency discharges and recently developed non-equilibrium rf discharges at ambient pressure. Insight into the complex dynamics requires close combination of advanced diagnostics and specifically adapted simulations. Phase resolved optical emission spectroscopy (PROES) in combination with particle-in-cell (PIC) simulations reveal details on the dynamics within the rf cycle. Multi-frequency discharges can provide additional process control for technological applications. The electron dynamics exhibits a complex spatio-temporal structure. Excitation and ionisation, and, therefore, plasma sustainment is dominated through directed energetic electrons created through the dynamics of the plasma boundary sheath. These electrons are predominantly produced during contraction of the low frequency sheath. This can be understood in the following picture. During the phase of low-frequency sheath expansion power dissipation is highest which determines plasma heating. This power is, however, deposited into a large number of electrons in the vicinity of maximum sheath expansion. The dissipated power during the collapse of the low-frequency sheath is deposited into a much smaller number of electrons, since the electron density close to the electrode surface is significantly lower. The power dissipation per electron can, therefore, be higher during the sheath collapse, which then creates energetic directed electrons. Recently developed rf discharges at ambient pressure bear enormous potential for future technological applications providing high reaction rates without the need of expensive vacuum systems. Fundamental discharge mechanisms are, however, only rudimentarily understood. The atmospheric pressure plasma jet (APPJ) is a homogeneous non-equilibrium discharge. A specially designed rf μ-APPJ provides excellent optical diagnostic access to the discharge volume and the interface to the effluent region. This allows investigations of the discharge dynamics and energy transport mechanisms from the discharge to the effluent. PROES measurements in the discharge volume show similar excitation and ionisation mechanisms as in capacitively coupled rf discharges at low pressure. An interesting phenomenon is the interaction between the two plasma boundary sheaths.

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