Plasma Science and Technology
Room: Hall 3 - Session PS-ThP

Plasma Science Poster Session

PS-ThP1 3D Numerical Modeling and Experimental Characterization of Internal Antenna Type Inductively Coupled Plasma System for Nitriding of Bipolar Plates for PEMFC(Polymer Electrolyte Membrane Fuel Cell), ***J. Joo**, W. Yang,* Kunsan National University, Republic of Korea, *J. Lee*, Seoul National University, Republic of Korea

Bipolar plates for PEMFC(polymer electrolyte membrane fuel cell) are crucial in determining service life of hydrogen fuel cells. The required anti-corrosion characteristics is very hard to meet with commercial materials, e.g. 316 stainless steels while keeping other requirements, e.g. electrical conductivity, mechanical formability and cost. Thin film coatings could be substitute solution but fairly marginal due to its relatively high cost. Second option is surface nitriding using high density plasma sources with appropriate substrate bias. Plasma nitriding at high temperature upto 800°C is a stable technology for automobile parts and tools. Stainless steels do not allow to go over 500°C due to its microstructural phase transformation. Low temperature, high rate nitriding technology is very crucial technique in this field. Bipolar plate is in a thin sheet form of 300 x 300 mm as thin as 0.5 mm. We used internal antenna type inductively coupled plasma as a source of nitriding species. The mixing ratio of nitrogen and hydrogen was varied to give optimal plasma generation condition. Plasma diagnostic techniques, e.g. Langmuir probe measurement, optical emission spectroscopy, and biasing voltage/current waveform measurements were used to characterize the process. For optimal design of industry scale systems, we used a 3D computational fluid dynamic code (CFD-ACE+). Number of antenna turns, relative positions of antenna and loaded sheets, gas pressure and composition were varied and diagnosed experimentally. In addition, substrate biasing schemes were studied. Final anti-corrosion characteristics showed that pulsed dc bias of 50 kHz with 600 W of ICP was giving best corrosion current density among others; 316 stainless steel, Cr, CrN with dc bias.

PS-ThP2 Multidimensional Plasma Simulations of an SF_6/O_2 Etch, *J. Tennyson,* ***S. Harrison****,* University College London, UK, *J.J. Munro, D. Brown*, Quantemol, UK

Sulfur Hexafluoride (SF_6) is the plasma processing gas that is used industry-wide in a range of processes for the dry etching of silicon. However, the performance and efficiency of different processes and machines can vary widely. Through simulation we can gain significant insight into the optimization problem and provide a low cost means for further development.

SF_6 is also very bad for the environment with a Greenhouse Warming Potential that is 22,000 times that of CO_2. Therefore it is vital that SF_6 is used sparingly and efficiently in every process. Here, simulation can help to find ways of remediating harmful waste gases and optimize the process for typical processing goals (e.g. etch rate, uniformity) as well as improving SF_6 consumption efficiency and other environmental measures.

Here we present an full chamber 2D simulation of an SF_6/O_2 silicon etch process, building upon previous calculations of SF_6 plasma chemistries using Quantemol-P [1]. Etch rate, pressure and power trends along with chamber wide contour plots of gas-phase species concentrations and fundamental plasma properties are considered.

To perform these calculations and build this model a new software tool is being constructed and will be demonstrated. The plasma simulation itself is run using a set of algorithms and codes based on HPEM [2]. The new code will integrate with outputs from Quantemol-N [3], which provides data on molecular processes, and Quantemol-P. It will provide

a set of design and specification tools, along with an expert system for running HPEM and a design of experiments (DOE) type calculation system.

[1] J.J. Munro and J. Tennyson, J. Vacuum Sci. Tech. A, 26, 865 (2008)

[2] R.J. Hoekstra, Michael J. Grapperhaus and M.J. Kushner, J. Vacuum Sci. Tech. A, 15, 1913 (1997).

[3] J. Tennyson, D.B. Brown, J.J. Munro, I. Rozum, H.N. Varambhia and N. Vinci, J. Phys. Conf. Series, 86, 012001 (2007).

PS-ThP3 Semi-analytical Model of Standing Wave and Skin Effect in Large-area RF Discharges, ***M. Klick***, Plasmetrex, Germany

Large area plasma coating becomes more important with increasing diameter of semiconductor wafers and thin film Si solar cells. The layer characteristics depend on the plasma, the uniformity depends mainly on the plasma sheath voltage at the substrate via the ion energy distribution and the corresponding back-etch rate. Therefore the modeling of large-area CCPs is increasingly important. In particular the skin and standing wave effects must be involved, beside the non-homogeneous distribution of chemically active species in plasma these effects are the major root causes of non-uniform interaction plasma and surrounding solid bodies.

A semi-analytic, cylindrical and 2d plasma model based on the full set of the Maxwellian equations was developed. It involves also the non-uniformity and nonlinearity of the plasma sheath as nonlinear boundary condition. It involves dynamic electron effects by a fluid model for the plasma bulk and nonlinear mechanisms by a nonlinear sheath model.

The model includes nonlinear effects and provides so the dependence of the Fourier spectrum of the local RF current on geometry, plasma density, and the electron collision rate. The ratio of the excitation frequency to the resonance frequencies of the spatial mode is found to determine the nonuniformity caused by the standing wave. The collisional skin depth can be also estimated. Thus the mean sheath voltage varying along the grounded electrode through both standing wave and skin effect can be easily calculated and understood by means of a semi-analytical model.

Both a center and edge maxima or even spatial oscillations in the mean sheath voltage at the grounded electrode can be observed. This is in agreement to experimental results of Si deposition used for comparison. It can be also shown that well-known terms as symmetry loose sense for very 'flat' RF discharge systems, they can be symmetric in the center and asymmetric near the edge.

PS-ThP4 U-shaped Internal Inductively Coupled Plasma Source with a Ferrite Module for Roll-to-Roll Processing, ***S.P. Hong****, J.H. Lim, K.N. Kim, G.Y. Yeom*, Sungkyunkwan University, Korea

Flexible display devices are being investigated by many researchers as a potential next-generation display. Roll-to-roll plasma processing is one of the important techniques for flexible display processing. For the fabrication of flexible display devices by the roll-to-roll plasma processing, not only highly uniform plasma processing but also high processing rates are required to increase the throughput of the processing. In particular, for the use of low-temperature substrates such as plastic substrates, the processing at the temperature lower than 100 ℃ is required.

In this work, we present a line-type, high-density plasma source composed of a U-shaped internal antenna for an inductively coupled plasma (ICP) operated at 2 MHz and with a ferrite module installed on the antenna of the ICP source. The 2300 mm long χ 740mm wide ICP source showed the plasma density of about 3.1 χ $10^{11}cm^{-3}$ at 3.5kW with the plasma uniformity less than 11% along the antenna line. The plasma characteristics of the source were measured using a Langmuir probe (Hiden Analytical Inc., ESP), and the electrical properties of the line-type, internal antenna were measured using an impedance analyzer (MKS Inc.).

PS-ThP5 Self-Consistent Electrodynamics of Very High Frequency Plasma Discharge Chambers, ***Z. Chen****, J.A. Kenney, S. Rauf, K. Collins*, Applied Materials, Inc.

Very high frequency (VHF) radio-frequency (RF) sources are used for many plasma processing applications including material etching and thin film deposition. However, when chamber dimensions become commensurate with RF wavelength, electromagnetic effects have a significant influence on plasma behavior. We present a 2/3-dimensional model for self-consistently studying both electrodynamic and plasma dynamic behavior of complete RF plasma discharge chambers. The model is fully self-consistent in the following senses: (1) Maxwell's equations and transport equations for charged and neutral species are coupled and solved explicitly in time domain; (2) The complete RF plasma discharge chamber including the RF power delivery sub-system, electrodes and plasma domain is modeled all together and simultaneously; and (3) The RF source is naturally applied onto the transmission line of the RF feed system in the form of an electromagnetic wave rather than hard imposition of assumed RF sources onto the electrodes or on the boundary of plasma. In the model, Maxwell's equations are discretized using the Finite-Difference Time-Domain (FDTD) method, and plasma discharge is modeled by solving the time-dependent continuity equations for charged and neutral species, drift-diffusion approximation for specie fluxes, and the electron energy conservation equation. Such a systematic approach is equally applicable to both capacitive and inductive discharges. It is useful for understanding not only electrodynamic effects in large-area VHF plasma chambers, but also the impact of asymmetric parts in RF systems and electrodes on the symmetry and uniformity of electric field and plasma in discharge region, which is of significant interest in industrial applications of RF plasma chambers. We first apply the model to study the impact of azimuthally asymmetric dielectric and conducting perturbations in the RF feed system on plasma uniformity. Then we examine the effect of transmission line length and impedance on plasma profile, especially in regimes close to resonance. We also explore the potential application of VHF source in large area (> 5 m^2) capacitively coupled plasmas. Based on the model, we have been able to identify a variety of design approaches for ensuring electric field and plasma symmetry and uniformity in discharge region.

PS-ThP6 Characterization of a Power Splitter for Multi-Tile Plasma Source for VHF/UHF PECVD Film Growth, *A.R. Ellingboe,* Dublin City University, Ireland, ***T. Michna***, Phive Plasma Technologies, Ireland

A novel divide by arbitrary-N power divider for use in the 100-500 MHz frequency range will be introduced. Electrical characterization of the power divider will be reported. The system has been successfully applied to an extensible, multi-tile plasma source operating from below 100 MHz to over 400 MHz. The plasma is found to light uniformly over the electrode surface for electronegative and electropositive gasses; and a 300mm diameter plasma has been sustained at under 15 Watts.

In multi-tile electrode solutions, the plasma load on the power splitter can result in spatial inhomogeneities in plasma creation; this fault is overcome by careful design of the system. A narrow-gap 300mm by 400 mm plasma is found to light uniformly over the electrode surface for electronegative and electropositive gasses at pressures from 10 mTorr to 3 Torr; plasma has been sustained across the full volume at under 25 Watts.

PS-ThP7 Experimental and Numerical Investigations of a Hollow Cathode Plasma Source for Microcrystalline Silicon Deposition, ***F.C. Tung,*** ITRI/MSL, Taiwan, R.O.C., *T.C. Wei,* Chung Yuan University, Taiwan, R.O.C., *S.W. Chau,* National Taiwan University of Science and Technology, R.O.C., *P.S. Wu,* ITRI/MSL, Taiwan, R.O.C, *C.-H. Lin*, Chung Yuan University, Taiwan, R.O.C.

Microcrystalline silicon thin films were grown by plasma enhanced chemical vapor deposition from a mixture of silane and hydrogen gases at low temperature. The effect of process parameters on the velocity, temperature and species concentration profiles are reviewed in this article. Several numerical simulation and in-situ plasma diagnostics on a hollow cathode plasma source and a process chamber are compared, which can be used to characterize the plasma properties. A global plasma model is developed for the plasma source and a CFD model is developed for the process chamber. Diagnostics of the plasma are carried out using a Langmuir probe and optical emission spectroscopy. Based on these investigations, an updated view on the role of the process parameters is presented.

PS-ThP8 Novel Long Linear-Type Microwave Plasma Source, ***C.C. Chang***, Industrial Technology Research Institute, Taiwan

A novel long linear-type microwave plasma source using a variably-reduced-height rectangular wave-guide as the plasma reactor has been developed. Microwave power is fed from the both sides of the wave-guide and is coupled into plasma through a long slot cut on the broad side of the wave-guide. The reduced height of the wave-guide is variable in order to control the coupling between microwave and plasma so that the plasma is able to attain better uniformity when extending the length of the linear-type plasma source.

PS-ThP9 Time Resolved Energy Distributions for Positive Ions in an Inductively-Coupled Plasma Reactor, ***J.A. Rees***, *C.L. Greenwood, D.L. Seymour*, Hiden Analytical, UK

The energy distributions of positive ions created in an inductively–coupled plasma have been examined using a Hiden EQP mass/energy analyzer. Time-averaged distributions were measured with and without the presence of a Faraday shield between the external RF excitation coil and the glass wall of the reactor. With the shield in position, the coupling of power into the plasma was purely inductive, but without it there was a significant capacitive contribution. The time-average distributions were measured both for continuous power applied to the plasma and for the case where the RF supply was pulsed. For this latter series of experiments, time-resolved distributions were also measured, and the decay in the energies of the ions as a function of time in the afterglow of the plasma was examined. The time-resolved data were obtained by gating the operation of the EQP analyzer either at the ion-counting detector of the instrument or, alternatively, by pulsing a grid mounted behind the sampling orifice of the instrument. The measured energy distributions were independent of the gating method. The distributions for the inductively-coupled and inductive/capacitive coupling are compared.

PS-ThP10 Influence of Sheath on Measurement of Electron Density in Frequency Shift Probe and its Application to Measurement of Electron Temperature, ***K. Nakamura***, *Q. Zhang, H. Sugai*, Chubu University, Japan

In advanced materials processing for manufacturing LSI devices, improvement of accuracy and repeatability has been required to achieve high performance plasma processes. In general, temporal variation of plasma components is believed to be one of reasons for the problems, so it is important to develop technologies for accurate plasma control. We have developed a frequency shift probe as a novel in-situ plasma monitoring technology. The probe enables us to measure an electron density from variation of resonance frequency of the probe head, and the density measurement is possible under minimum disturbance to the processing plasma because of its plane structure. Furthermore, the probe is applicable to a reactive plasma such as fluorocarbon plasmas since the deposited polymer has no significant effects on the resonance frequency. When the resonance frequency of the probe varies from f_0 (GHz) to f_r (GHz) by producing the plasma with the electron density of n_e, (10^{10} cm^{-3}), the value of n_e is given by $n_e=(f_r^2-f_0^2)/0.81$. However influences of a sheath formed around the probe have not been considered in the formula. In this work, sheath effects on the frequency shift probe were investigated based on finite difference time domain (FDTD) simulation, and it was examined how much influences on the measured density the sheath has. Furthermore, the frequency shift probe was tried to be applied to measurements of electron temperature using the sheath effects. As the sheath thickness increased, the resonance frequency decreased since effective permittivity of the media around the probe head decreased. Such a decrease of the resonance frequency was observed regardless of the slit width, however its dependence on the sheath width was affected by the slit width, and it became significant as the slit width decreased. The sheath width is proportional to Debye length, so the resonance frequency of the frequency shift probe is a function of electron density n_e and electron temperature T_e. This means that resonance frequencies obtained in two frequency shift probes having different sheath dependence gives an unique solution of n_e and T_e. Actually, in a experiment using a plasma produced with 13.56 MHz RF power up to 400 W at an argon pressure of 3 mTorr, the present method derived 7.5×10^{10} cm^{-3} in n_e and 4.8 eV in T_e which comparatively showed good agreements with values measured by a Langmuir probe.

PS-ThP11 High Performance of Compact Combinatorial Etching Process for Next Generation Plama Nano-Process, ***Ch.S. Moon***, *K. Takeda,* Nagoya University, Japan, *Y. Setsuhara,* Osaka University, Japan, *M. Shiratani,* Kyushu University, Japan, *M. Sekine, M. Hori*, Nagoya University, Japan

Plasma etching technology is one of technologies, which have been in charge of semiconductor device industry. As it is scaled down to several tens of nanometers, nano-leveled precise control has been indispensable to achieve the process requirements. However, up to now, it was an obvious fact that a lot of trials-and-error processes have been carried out in the development of plasma etching processes in which were characterized by external parameters (input power, working pressure, mixture gas ratio), since there has never been any scientific principle based on plasma science. We hereby propose the development of process map, Plasma Nano Science in which the process results are characterized by internal parameters (fluxes and energy distributions of ions, radicals, substrate temperature). For the breakthrough of next generation plasma nano-process guided by Plasma Nano Science, we have developed the combinatorial plasma etching process, in which a variety of results could be acquired by one trial. In this work, the compact combinatorial plasma apparatus was realized in inductively coupled H_2/N_2 plasma driven by two low-inductance (LIA) antennas for etching of organic low-k dielectric films. The spatial distributions of H and N radical densities were measured by vacuum ultraviolet absorption spectroscopy (VUVAS) system and RF-compensated Langmuir Probe (Scientific Systems Smart Probe™) was used to record the spatial distributions of electron densities, temperatures and energy distributions. In this paper, we present high performances of combinatorial etching process. Etching characteristics such as etch rate and profiles were analyzed in terms of internal parameters rather than conventional external parameters by controlling respective LIA antennas independently.

PS-ThP12 Tailoring of Substrate RF Bias Voltage Waveform for Arbitrary Energy Distributions of Bombarding Ions in Plasma Processing: Ion Energy Measurements, ***X.V. Qin***, *Y.-H. Ting, A.E. Wendt*, University of Wisconsin-Madison

In plasma etching of semiconductors for integrated circuit fabrication, positive ions are accelerated by a sheath electric field directed towards the substrate, where, upon impact at normal incidence, they enhance etching to produce anisotropic feature profiles. Varying the amplitude of a sinusoidal bias voltage waveform applied to the substrate electrode may be used to coarsely control the average energy of bombarding ions through its affect on the dc component of the sheath voltage, but the sinusoidal waveform also produces a broad spectrum of ion energies under typical process conditions. A bias voltage waveform with its shape tailored for the purpose of producing ion energy distributions (IED) with one or two groups of ions with a narrow spread around selected energies has been previously utilized to highlight the significant role of the IED in fluorocarbon-based etching. Presented here are direct IED measurements made with an Impedans™ retarding field energy analyzer situated on the biased electrode. Measurements in a 10 mTorr helicon argon plasma in which ion flux and ion energy at the substrate are independently controlled clearly demonstrate the ability to predictably produce arbitrary IEDs at the substrate by tailoring the shape of the bias voltage waveform. Results to be presented for sinusoidal (500 kHz-10 MHz) and tailored (500 kHz) waveforms are compared to predictions based on computation of ion trajectories through the sheath electric field (assumed to instantaneously follow the Child-Langmuir Law), in order to evaluate the accuracy and limitations of this method. For the sinusoidal waveform, the expected broad, bimodal IED is produced, with a reduction in IED width with increasing frequency in agreement with model predictions. Under conditions where the sheath transit time of the ions is short compared to the RF bias period and where ion motion in the sheath is collisionless, tailoring of the waveform produces one or two peaks in the IED, and in the latter case, the energies and relative fluxes of the two peaks can be varied independently through waveform shaping.

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PS-ThP13 Measurement of Electron Energy Probability Function in Dual-Frequency Capacitive Discharges, ***S.K. Ahn***, *H.Y. Chang*, Korea Advanced Institute of Science and Technology

Changes in plasma characteristics depending on low-frequency power in dual-frequency capacitive discharges were found from the measurement of electrical characteristics and electron energy probability functions (EEPFs). It is shown that as the low-frequency (2 MHz) power increases for the fixed high-frequency (27.12 MHz) current, the ion bombardment energy and the ion flux onto the electrode increase simultaneously, and hence independent control of the ion energy and the ion flux is hardly achievable in dual-frequency capacitive discharges. It is also shown that the coupling between the low-frequency power and the ion flux originates from change in electron heating mechanisms when varying the low-frequency power. Depending on the discharge pressure, changes in the collisional electron heating in the bulk plasma and participation of the secondary electron emission in the ionization process are observed.

PS-ThP14 Time-resolved Fast Imaging of the Arcing in RF Discharge, ***Y.H. Kim***, *H.S. Lee, H.Y. Chang*, KAIST, Korea

Arcing have become a fatal problem in TFT-LCD fabrication, semiconductor manufacturing, PECVD, and many other processes using plasma. Although modern plasma processing is using rf power, the arcing in rf plasma isn't well-known. We investigated the arcing in RF plasma. In order to generate the arcing, the dc-grounded rf (13.56 Mhz) power was delivered to argon plasma. The arcs are generated at high plasma potential (over 100 V), irregularly. We measured floating potential, discharge current and voltage during the arcing, and sparks were observed in arcing spots. Floating potential drastically decreased to almost ground potential, and both discharge current and voltage decreased to almost zero, too. As soon as floating potential decreased to ground, floating potential, discharge current and voltage return to steady state slowly more than decrease. These arcing signals show that the arcing perturb the rf plasma and that rf plasma transiently response. The discharge of sheath-capacitor by collective electron emission explain the transient behavior of plasma during the arcing. And, to confirm the collective electron emission, we imaged the arcing by using the ICCD (intensifed charge coupled device, ANDOR Technology Ltd.) camera with the maximum gate speed of 2ns. We checked the three regions in the aring. These are sheath breakdown region, arcing duration region and shaeth rebuilding region.

PS-ThP15 Design of a Kalman Filter for Plasma Process State Estimation and Control, *B.J. Keville,* ***M.M. Turner***, Dublin City University, Ireland

Real time, closed loop control of certain plasma species may potentially improve reproducibility and increase process yields. In order to investigate the feasibility of applying closed loop control to a plasma process, closed loop control of a plasma simulation was studied. This presentation concentrates solely on control issues, since the simulation was described in a companion presentation. The design of real time control algorithms is facilitated by simple, dynamical process models. The derivation of such a model from a much more complex simulation is presented, together with a stability analysis which indicates how the parameters of a real time control algorithm may be determined from such a model (model-based control). Process measurements may be indirect and, in addition, corrupted by process and measurement noise. Simple dynamical models may be used to construct model-based estimators such as the Kalman filter. The construction of such a filter to improve estimates obtained from optical emission spectroscopy is described in this presentation. Finally, the application of adaptive control to maintain closed loop stability despite changes in process parameters such as wall sticking coefficient due to chamber seasoning is presented.

PS-ThP16 Contamination Detection through OES in Conductor Dry Etch Process, ***C. Bevilacqua***, *A. Marchelli, P. Petruzza, G. Fazio*, Numonyx

In a R&D fab, where different processes are performed on the same dry etching hardware, there is a strong need to monitor the status of the chamber, in terms of cross-contamination from the different etching species and their reactions products deposited on chamber walls, which can cause uncontrolled shifts in the processes.

Through this work we validate a new technology method for monitoring and reveal metal elements in dry etch conductor tool.

Changes in chamber wall conditions (e.g., chemical surface composition) are identified as one of the main causes of process drifts leading to changes in the process performance (etch rates, etch profiles, selectivity, uniformity, etc.). This effect is particularly critic when the same chamber is required to sequentially process metals and non-metal elements. Standard control procedures mainly based on XRF technology utilize wafer tests to perform the acquisition measurements with relevant down times and low frequency testing. It is known that different conditions of the chamber walls have great influence upon global system impedance (plasma + equipment hardware), which requires continuous tuning of the RF system in order to maximize the power transfer to the plasma.

The observation of optical emission (performed through a spectrometer directly installed on the tool) from a waferless He plasma allows to detect some variation of impedance due to different chamber conditions.

The choice of He as process gas for this test is mainly due to the fact that it is chemically inert; besides is allows minimum impact on consumable parts inside the equipment. By comparing the test described to standard quantitative technology, we are able to identify a cut off threshold - technology device-dependent - above which the decontamination procedure becomes mandatory.

The new test can be used at the end of each critical process like a waferless autoclean, in order to constantly monitor the status of the chamber and assure a safe and correct lot processing.

PS-ThP17 Spatial Evolution of the Electron Energy Distribution Function in a Microwave Surface-Wave Plasma, ***J.P. Zhao***, *R.V. Bravenec, L. Chen, M. Funk, R. Sundararajan,* Tokyo Electron America, Inc., *C.Z. Tian, K. Ishibashi, T. Nozawa*, Tokyo Electron Technology Development Institute, Japan

Microwave surface-wave discharges operating within a wide power and pressure window can be used to produce large-area plasmas of densities exceeding $10^{11}/cm^3$. Due to its inherent diffusion characteristics, away from the discharge source one can expect a relatively high density, quiescent, uniform, and low-temperature single Maxwellian plasma near the wafer region. That is, one would have a unique plasma tool with totally decoupled source of discharge and wafer process region. These merits are highly desired in large-area microelectronic technologies, such as in plasma-enhanced chemical-vapor deposition and etching processes. Because of these promising features, we are trying to understand the mechanisms of the microwave surface-wave plasma such as electron heating and power absorption in the discharge region and the spatial evolution of plasma parameters in the entire plasma volume. Understanding the evolution of plasma parameters in the entire plasma volume would help the development of tools based on microwave surface-wave plasmas and the design of process recipes. The plasma source used in this work consists of a radial line slot antenna (RLSA) which transmits 2.45 GHz microwaves into a large quartz resonator disk which then couples to the plasma. The plasma parameters of a nitrogen plasma, e.g., electron energy distribution functions (EEDF's) are measured using a cylindrical Langmuir probe. EEDF measurements are carried out from 8 mm below the bottom surface of the resonator disk to the wafer surface, a span of ~140 mm in the vertical direction. A wide pressure-power range has been investigated, i.e., pressures from 20 to 800 mT and powers from 2 to 4 kW. Based on initial global-modal analysis of experimental observations, EEDF's are analyzed using a curve fitting method developed in-house that assumes electrons in the microwave surface-wave plasma consist of two Maxwellian distributions and a drifting Maxwellian that models a beam component.[1] The relative population and magnitude of these electron components vary as a function of vertical location in the plasma volume. High populations of energetic electrons with energies exceeding 20 eV are typically observed near the resonator disk, i.e., the EEDF is dominated by the beam component. Away from the resonator disk, the EEDF transitions to two Maxwellians then thermalizes to a single cold Maxwellian of Te ~1 eV near the wafer surface. Pressure and power are found to have strong effects on the transition of the beam component to Maxwellian component. Particle-in-cell simulations[1] are conducted to understand the experimental observations.

[1]R. V. Bravenec et al., presentation at this conference.

PS-ThP18 Diagnostic Study of an rf-capacitively Coupled Plasma: The Breakdown of the Periphery Gap Regime, ***H.W. Chang***, *C.C. Hsu*, National Taiwan University, Taiwan

A diagnostic study of a radio-frequency capacitively coupled plasma of Ar, O_2, N_2, and He was performed to investigate the mechanism that dominates the breakdown of the periphery gap region. This plasma chamber has a cylindrical glass chamber with annular ring-shaped, powered electrodes with an adjustable height and a planar sample stage that serves as the grounding electrode. A voltage probe and a current probe were used to monitor the electrical characteristics of this plasma, and an optical emission spectrometer was used to monitor the optical emission spectra of the plasma. It is shown that as the (peak-to-peak) voltage at the powered electrode exceeds a critical value, the ignition in the region between the glass chamber wall and the grounding electrode occurs. Such a breakdown potentially leads to unstable and non-uniform discharge. A drop of the current and voltage were found to accompany the periphery region breakdown, and it was found that the pressure, gas type, and gap size are the decisive factors that dominate such a breakdown. The breakdown voltage increases with the decreases of the gap and with the decreases of pressure: in an Ar discharge under 80 mtorr, the breakdown voltage increases from 280 to 972 V as the sample stage-glass chamber wall gap decreases from 7 to 5 mm. Under 5 mm gap and 100 mtorr, the voltage at which the periphery region breakdown occurs for Ar, N_2, and O_2 are 577, 1470, and 2444 V while no breakdown occurs in He plasmas with the voltage up to 2560 V. While such a breakdown seems undesired in materials processing, we will show that a well-controlled transition could potentially be used to obtain a localized high-density region that could be useful for materials processing.

PS-ThP19 Real-Time Feedback Control of Radical Species by OES in a VHF Plasma for Microcrystalline Silicon Thin Film Deposition, ***C.H. Chang***, *C.C. Du, M.W. Liang, J.R. Huang,* Industrial Technology Research Institute, Taiwan, *Y.L. Chang, K.C. Leou*, National Tsing Hua University, Taiwan

Plasma deposition of intrinsic microcrystalline silicon (μc-Si:H) films with high deposition rates is a key process for the fabrication of high efficient thin-film solar cells. Recent studies have shown that the concentration of the radical species in hydrogen diluted silane plasma is time-dependent during the deposition process and results in inhomogeneous film growth that diminishes the solar cell efficiency. In this study, we developed a real-time feedback control system that corrects for the radical species variation in a VHF (40.68 MHz) PECVD reactor, via modulating the chamber pressure and silane dilution for depositing high quality μc-Si:H films. In this control system, trace rare gases-optical emission spectroscopy (TRG-OES) was used to determine the absolute species concentrations (e.q. Si, SiH_x, H) by deriving from their optical emissions. To convert the emission intensities into absolute number densities, a small amount of Ar was fed into the plasma to be as trace gas. Observed real-time variations in species signals were then compensated by using a proportional-integral (PI) feedback control algorithm. The system actuator was either or both of the pressure controller and the silane mass flow controller. The experimental results show that the OES intensities have obvious spikes after plasma is ignited and then decreases to a lower level at the first stage in about 10 seconds. This is because of the pressure unbalance between the throttle valve control and the expanded number density of gas induced by plasma heating and dissociation reaction in the chamber. After the transient of pressure unbalance, the intensity of H_α increases close to 20 % and the SiH^* decreases 10 % during the deposition in 10 minutes. This is believed to be due to the change of chamber wall surface condition. The deposited silicon films on the rf electrode, glass substrate and the other surface surrounds the plasma, grow continuously and affect the conditions for plasma. In the mean while, the closed-loop control can indeed stabilizes the radical species concentration within ± 1.5 % and has a good crystallinity control during the deposition process. Comparisons such as film growth structure and efficiency of solar cells deposited by closed-loop and open-loop controls will also be presented at the conference.

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— N —

Nakamura, K.: PS-ThP10, **2**
Nozawa, T.: PS-ThP17, 3

— P —

Petruzza, P.: PS-ThP16, 3

— Q —

Qin, X.V.: PS-ThP12, **2**

— R —

Rauf, S.: PS-ThP5, 1
Rees, J.A.: PS-ThP9, **2**

— S —

Sekine, M.: PS-ThP11, 2
Setsuhara, Y.: PS-ThP11, 2
Seymour, D.L.: PS-ThP9, 2
Shiratani, M.: PS-ThP11, 2
Sugai, H.: PS-ThP10, 2
Sundararajan, R.: PS-ThP17, 3

— T —

Takeda, K.: PS-ThP11, 2
Tennyson, J.: PS-ThP2, 1
Tian, C.Z.: PS-ThP17, 3
Ting, Y.-H.: PS-ThP12, 2
Tung, F.C.: PS-ThP7, **2**
Turner, M.M.: PS-ThP15, **3**

— W —

Wei, T.C.: PS-ThP7, 2
Wendt, A.E.: PS-ThP12, 2
Wu, P.S.: PS-ThP7, 2

— Y —

Yang, W.: PS-ThP1, 1
Yeom, G.Y.: PS-ThP4, 1

— Z —

Zhang, Q.: PS-ThP10, 2
Zhao, J.P.: PS-ThP17, **3**