Plasma Science and Technology
Room: 25 - Session PS-ThA

Plasma Sources
Moderator: M. Funk, Tokyo Electron America

2:00pm **PS-ThA1 Study on Microwave ECR Plasma Source for 450-mm Wafer Etching**, ***K. Maeda***, Hitachi, Ltd., Japan, *H. Tamura, S. Obama, M. Izawa*, Hitachi High-Technologies Corp., Japan, *G. Miya*, Hitachi, Ltd., Japan **INVITED**

In semiconductor industries, a high level of productivity to reduce the cost of ULSI fabrication has always been required for plasma etching tools, as well as the other tools. According to the International Technology Roadmap for Semiconductors (ITRS) 2010, increasing the size of the wafer improves the productivity, and the diameter of the Si wafer will be 450 mm in 2014. One of the most significant problems for achieving an extremely uniform process for the 450-mm wafer area is precise control of the plasma distribution over a large area. We have developed a newly designed microwave electron cyclotron resonance (M-ECR) plasma reactor for next-generation 450-mm wafer processing. The reactor configuration is based on the previous M-ECR etching reactor for 300-mm wafers. A microwave power of 2.45-GHz in a circular TE11 mode (principal mode) is supplied to the chamber via the circular waveguide, microwave circuit (cavity), and quartz window. The chamber is surrounded by solenoid coils and a yoke, and the position of the ECR plane (87.5 mT magnetic field strength) is controlled by the currents supplied to the coils.

We present the measurement of two-dimensional (radial and vertical) distribution of ion saturation currents in the reactor, which was measured by a movable single probe system in halogen gas mixture at 0.4 Pa for poly-Si etching. The ring-shaped high density region was observed at the ECR plane in the optimized microwave circuit type, in which we could obtain uniform plasma distribution just above the wafer. This plasma distribution could be controlled by changing the position of the ECR plane. On the other hand, strongly convex-shaped plasma distribution was observed in an inappropriately designed microwave circuit. A plasma generating distribution is also estimated by comparing the result of plasma-diffusion analysis in magnetized plasma to that of a probe experiment. We confirmed that the plasma seemed to be generated in a very thin (1-2 cm) region at the ECR position. In addition to the result of plasma characteristics, the etching results, i.e., radial distribution of poly-Si etching rate, with a uniformity of 1.5%, and critical dimension control of the line and space pattern by controlling the temperature of the wafer are also presented.

2:40pm **PS-ThA3 A Grid Reactor with Low Ion Energy Bombardment for Large Area PECVD of Thin Film Silicon Solar Cells**, ***M. Chesaux***, *A.A. Howling*, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland, *U. Kroll, D. Dominé,* Oerlikon Solar-Lab SA, Switzerland, *Ch. Hollenstein*, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

This study presents a PECVD reactor using localized remote plasma in a grid electrode. The aim is to reduce the ion energy bombardment inherent in RF capacitively-coupled parallel plate reactors conventionally used to deposit large area thin film silicon solar cells. This bombardment could cause defects in silicon layers and deteriorate electrical interfaces. Here, low ion bombardment energy is obtained by inserting a grounded grid close to the RF electrode of a parallel plate reactor. The plasma is then localized in the grid holes and remote from the substrate. This grid also increases the negative self-bias by increasing the effective area of grounded electrode in contact with the plasma while retaining the lateral uniformity required for large area deposition. The self-bias reduces the ion energy bombardment, but retarding field energy analyzer measurements show that the ion energy is even lower than expected from the self-bias effect alone. This reduced ion energy could be caused by a non sinusoidal RF cycle of the plasma potential as was measured with a capacitive probe and supported by phase resolved optical emission spectroscopy. Measurements were done in hydrogen at 0.5 mbar and 13.56 MHz.

3:00pm **PS-ThA4 Plasma Generation and Delivery from a VHF Remote Source**, ***D. Carter***, *D. Hoffman, K. Peterson, R. Grilley*, Advanced Energy Industries Inc.

A new remote plasma source (RPS) driven by capacitively coupled VHF power has been defined for use in chamber cleaning or other processes where ex-situ plasma generation is desired. The combination of VHF drive, compact size and unique geometry results in a plasma source capable of very high plasma densities and a resulting field structure offering some interesting characteristics. The device is shown to allow operation in a conventional "remote" mode where the plasma is largely confined within the primary volume of the source or alternatively in a "projecting" mode where the plasma extends well beyond the output of the device reaching to and even filling a downstream chamber with active plasma. This study evaluates behaviors of the VHF RPS in both remote and projected modes as well as in a hybrid mix of both modes. We report on operating characteristics and plasma parameters including density, potential and electron temperatures at the source and downstream and additionally look at ion energy distributions at various points in the system. Results are compared with alternative remote source technologies to illustrate the differences and potential advantages offered by this new RPS topology.

3:40pm **PS-ThA6 Mechanical Optimization of a Plasma Source Device**, ***S. Polak***, *M. Thornton, D. Hoffman, D. Carter*, Advanced Energy Industries Inc.

A new, remote plasma source device (RPS) is being developed. From a mechanical standpoint, there are a number of unique challenges and areas for optimization. The RPS features high plasma density in a compact, mechanical envelope, resulting in high heat-flux and therefore requiring robust cooling solutions. Also, because the RPS has the ability to confine plasma within the chamber or project the plasma downstream, the locations and magnitudes of heat flux are dynamic, depending on the process. High and variable-density heat fluxes result in high temperatures and high thermal gradients, both of which lead to thermal-mechanical strain and stress within the components. Numerical models and finite-element simulations have been developed to predict the thermal and structural responses within the critical components in the RPS assembly and to mitigate structural failure of these components. Furthermore, because the RPS features high gas flow rates through a relatively small-volume chamber, optimization of the fluid flow becomes paramount to the ignition, stability, and efficiency of the plasma. Finite-volume, computational fluid dynamics (CFD) models were developed to characterize and optimize the gas flow into the chamber. We report on the development of these thermal-mechanical and fluid dynamics analysis tools, including correlation of the analytical models to empirical data. Also, we will discuss the parameters and techniques of optimization.

4:20pm **PS-ThA8 Impact of Reactor Design on Plasma Polymerization Processes - An International Round-Robin Study**, ***J.D. Whittle***, *A. Michelmore, D.A. Steele, R.D. Short*, University of South Australia

Plasma polymerization is capable of producing adherent pinhole-free thin films with a diverse range of chemical functional groups and physical properties. These materials are used widely in applications ranging from composites, electronics, solar cells and biomaterials. Although a number of plasma processes have been scaled up very successfully and have used sophisticated diagnostics, the majority of researchers utilize lab-built reactor systems with very little in the way of plasma diagnostics, relying on control of external parameters to achieve reproducibility and to guide materials design. Often the focus is on retaining chemical function from the precursor compounds, and these processes are typically described by a limited number of variables, for example, rf power, reactor pressure, monomer flow rate. While these parameters often give reasonable control within a given system, it is not clear to what extent these parameters correlate between systems.This becomes a problem when comparing plasma polymerisation experiments with those in the literature - generally the only practical way to repeat a treatment is to re-engineer the process on ones own system by a trial and error process.

In this paper we report the results of an international round-robin exercise which sought to explore the differences resulting from plasma polymerization using 14 different reactor designs spread across seven countries.

We have explored two separate processes; argon plasma treatment of spin-cast polystyrene films and deposition of plasma polymerized acrylic acid at different discharge powers. In all experiments the monomer or gas flow rate was kept the same, and treatments were carried out at the same nominal power. Surfaces were characterized using atomic force microscopy (AFM) and X-ray photoelectron spectroscopy (XPS), and the effect of reactor geometry, and other uncontrolled variables on the resulting surface properties was examined.

Whilst we did expect significant differences between these systems, the magnitude of these variations was surprising - for many of the surface properties, the coefficient of variation was in excess of 100%. We speculate on the key factors which influence the observed differences in the resulting surface treatment, and how these differences could be reduced in the future.

4:40pm **PS-ThA9 A Mini Plasma Source for *In Situ* Sample Cleaning**, ***N.B. Koster***, *F.T. Molkenboer, R.J. Bolt, T.J. Versloot, J.P.B. Janssen*, TNO Technical Sciences, The Netherlands

Energetic photons, ions and electrons can induce carbon growth on surfaces due to residual hydrocarbons present on the sample surface or in the vacuum system. This effect is well known and has been a major obstacle for the successful introduction of EUV Lithography. This has been overcome by introducing a very clean vacuum system in combination with surface cleaning technologies. For EUVL we have developed a plasma cleaning process for the mirrors that has a relatively high efficiency for carbon removal and causes no surface damage[1]. In high resolution imaging applications like SEM, TEM or Helium Ion Microscopy (HIM) this problem is also present and more difficult to counteract due to the delicate nature of samples or that the sample itself is the source of contaminants. We have applied our cleaning process and successfully and non-intrusively cleaned samples for electron microscopes. As a result, and on request of several microscopy users, we have developed a miniature microwave-induced plasma source to be used on various types of imaging systems for sample and chamber cleaning. The miniature source is to be mounted on the load lock of the imaging system or on the microscope chamber by means of a standardized vacuum flange.

We will report on the design, manufacturing and realization of such a miniature source and discuss the results that were obtained on our own HIM as well as other microscopes. This plasma process has already successfully been used to clean samples with graphene, EUV reticle materials or asbestos. Part of the experiments presented include characterization of the plasma with Langmuir probes and Optical Emission Spectroscopy (OES).

[1] N.B. Koster et al, Towards defect free EUVL reticles: carbon and particle removal by single dry cleaning process, and pattern repair by HIM , Proc. of SPIE Vol. 7969 79690X-1, 2011

5:00pm **PS-ThA10 Magnetic Neutral Loop Discharge Reactor for Low-k Dielectric Plasma Processing**, ***W.Y. Li***, *Z. Ling, H.-Z. Zhang, J.A. Bray, T.M. Griffin, M.T. Nichols*, University of Wisconsin-Madison, *B.N. Moon, Y.M. Sung*, Kyungsung University, Korea, *S. Banna*, Applied Materials, Inc., *Y. Nishi*, Stanford University, *J.L. Shohet*, University of Wisconsin-Madison

Since the magnetic Neutral-Loop Discharge (NLD) plasma was first proposed by Uchida *et al.* [1], its properties and usage have been investigated by a number of researchers. In this work, we design an NLD reactor to investigate the response of low-k dielectric materials to plasma exposure. Moreover, the NLD reactor will be used to compare the properties of its plasma to that of conventional inductively and capacitively coupled plasma reactors. The NLD reactor is located inside of a set of cylindrical magnet coils which at first glance appears to be a simple solenoid. However, the magnet current in the center of the solenoid is reversed from that near the ends of the solenoid which causes the field in the central solenoid to reverse from that in the outer solenoids. By carefully adjusting the coil currents, a circular region of zero magnetic field can be generated underneath the center solenoid—the neutral loop. The shape of the NLD magnetic fields was numerically evaluated and experimentally confirmed. Numerical calculations of particle orbits show the effect of the neutral-loop zero-field region. A region of electron cyclotron resonance appears around the neutral loop. By adjusting the currents, the radius of the neutral loop can be controlled to move closer or farther from the central axis of the reactor.

This work has been supported by Semiconductor Research Corporation under Contract No. 2008-KJ-1781 and by the National Science Foundation under Grant CBET-1066231.

[1] T. Uchida, "Application of radio-frequency discharged plasma produced in closed magnetic neutral line for plasma processing," 33, L43-L44 (1994).

5:20pm **PS-ThA11 High Efficiency ICP Source for Plasma Dry Clean Processing**, ***V. Nagorny***, *O. Todor, V. Surla, A. Kadavanich*, Mattson Technology, Inc.

Inductively coupled plasma (ICP) sources are widely used in the semiconductor industry for plasma processing. They can easily produce high density plasma and provide good plasma control. For photoresist strip (dry clean) processes, direct plasma interaction with a wafer is undesirable and plasma is used as an intermediate for modification of a gas composition and creating chemically active radicals for processing the wafers. As strip rate directly relates to the flux of radicals to the surface of the wafer this process usually uses high gas flows (5-20slm), high RF power (3-5kW) and high gas pressure (~1000mTorr). Obviously, when the gas and energy consumption is that high, the efficiency of the source becomes very important, since it affects both capital and operational costs, and with newer and more restrictive regulations, efficiency may become determining characteristic of the source.

There are a few factors that strongly affect source efficiency, as well as the process, the most important of which are the gas flow and electron heating efficiency. If only small fraction of gas molecules participate in collisions with hot electrons then most of the gas simply flows through the system without dissociation. In this case most of the gas is simply wasted. So it is important to make the gas flow in such a way that most (if not all) gas molecules have a high probability of collision with hot electrons. To increase efficiency of generating hot electrons one has to improve electron confinement in the region where the induced electric field is high.

We accomplished both goals by modifying Mattson Technology Inc.'s production-proven ICP strip source. By modifying the gas injection system into the plasma generating volume and optimizing the vessel, we simultaneously achieved significantly increased photoresist removal rate at reduced input of process gas and a much larger operational window for the source, with concomitant process benefits.

Our implementation is scalable for processing 450mm wafer sizes and the underlying concepts are generalizable for optimizing other types of ICP sources, as will be discussed in the presentation.

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