Plasma Science and Technology

Room: 607 - Session PS2-ThM

Plasma Diagnostics I

Moderator: V.M. Donnelly, University of Houston

8:00am **PS2-ThM1 Ion Flux Measurements in an Ar/NH_3/SiH_4 - Remote Plasma using a Pulse Shaped Double-Side Capacitive Probe**, ***M.C. Petcu**, A.C. Bronneberg, M.A. Creatore, M.C.M. van de Sanden,* Eindhoven University of Technology, The Netherlands

In this work the investigation of an Ar - fed remote expanding thermal plasma (ETP) where NH_3/SiH_4 mixtures are injected downstream, is reported. Our interest is mainly focused on ion flux and ion densities measurements at different gas phase compositions. The ion and electron densities measurements using various methods and different plasma conditions have been previously reported in literature. For example, double and single cylindrical Langmuir probes have been successfully used to measure the ion density in non - depositing Ar/NH_3 ETP. A limitation of Langmuir probe measurements is to determine the ion densities in depositing plasmas, e.g. Ar/NH_3/SiH_4 mixtures, due to the formation of a resistive layer on the probe. An alternative approach is to use a single-side electrostatic probe, as already proposed in literature. This technique is compatible with the presence of insulating layers, showing the potential for absolute ion flux determination. The method is based on the discharging of an RF-biased capacitance in series with the probe. An alternative method, based on the use of pulse shaped double-side capacitive probe to measure ion flux in Ar/NH_3 and Ar/NH_3/SiH_4 plasma mixtures is here proposed. Our approach allows an accurate ion flux determination from the linear discharging of the capacitor connected in series with the collecting surface. Such approach could be easily implemented in a sensor for ion flux control in various discharges, e.g, in the case of a biased substrate to induce ion bombardment during film growth. When Ar/NH_3 mixtures are investigated, a decrease of the ion flux from 10^{18} to 10^{16} $cm^{-2}s^{-1}$ as a function of the NH_3 flow rate is measured and attributed to the consumption of Ar ions due to the charge exchange reaction between Ar ions and NH_3 molecules, followed by the dissociative recombination with low energy electrons. These results are also confirmed by Langmuir probe measurements. Furthermore, the addition of SiH_4 is showing an interesting behavior, i.e., a local increasing of the ion flux presently attributed to the formation of lighter ions, in conditions of high Ar ion depletion due to the high molecular gas flow rates. These measurements, together with mass spectrometry analysis, will be presented and commented in terms of plasma chemistry channels developed in an Ar/NH_3/SiH_4 plasma.

8:20am **PS2-ThM2 In Situ Plasma Analysis and Sheath Modeling of Silicon Deep Trench Etching in Capacitively Coupled Dual Frequency HBr/NF3 Plasmas**, ***M. Reinicke***, Dresden University of Technology, Germany, *S. Wege, S. Barth, A. Steinbach,* Qimonda Dresden, Germany, *G. Wenig, A. Kersch,* Qimonda Munich, Germany, *J.W. Bartha*, Dresden University of Technology, Germany

Facing critical dimensions below 50nm requires significantly improved knowledge about complex process mechanisms for DRAM technology development. To extend the knowledge of physical and chemical interactions during high aspect ratio (HAR) silicon etching using HBr/NF3/O2 plasmas, in situ plasma analysis has been performed at the latest generation of multi frequency capacitively coupled MERIE plasma reactors. Focus of this presentation is a detailed investigation of ion angular and energy distribution functions (IAEDFs) since these distributions are considered to be most essential for characterization of plasma-induced silicon deep trench etching using reactive plasma chemistries. Ion distribution functions (IDFs) were measured for basic Ar, HBr, NF3, as well as complex HBr/NF3/O2 plasma chemistries at the ground electrode of the plasma reactor using an in situ Hiden Analytical EQP500 combined energy and mass analyzer. Measured IDFs are compared to calculations using the Hybrid Plasma Sheath Model (HPSM) simulator. Difficulties in measuring IDFs are minimized by simulation of ion trajectories and a careful determination of the relevant transmission functions specific for the plasma monitor used. The hybrid-fluid simulator was additionally modified by implementation of differential cross sections resulting from ab-initio calculations for relevant ion-atom collisions. Finally, combination of measurement and simulation for investigation of the complex nature of multi frequency high voltage rf plasma boundary sheaths is shown to yield valuable information on the IAEDF for ions impacting the substrate and hence influencing etch process results.

8:40am **PS2-ThM3 Noninvasive Monitoring of Ion Current and Ion Energy during Plasma Processing**, ***M.A. Sobolewski***, National Institute of Standards and Technology **INVITED**

The bombardment of substrate surfaces by energetic ions plays an important role in plasma etching and other plasma processing applications. To obtain optimal results, ion current and ion kinetic energy must be carefully controlled. Unfortunately, directly measuring ion current or energy in situ, at a wafer surface during plasma processing, is difficult or impossible. To solve this problem, a technique for indirectly monitoring ion current and energy has been developed. It relies on measurements of the waveforms of rf current and voltage applied to the wafer electrode, which are interpreted by fundamental physical models of the plasma and its sheaths. The technique is noninvasive, i.e., there is no need to insert any probe into the plasma reactor, and it is suitable for use during actual processing in industrial equipment. This talk will describe the technique, the models it uses, and validation tests performed in an rf-biased, inductively coupled plasma reactor. It will also present results from experiments that demonstate the use of the technique to monitor ion current and ion energy during fluorocarbon etch processes and argon sputtering processes, including processes that were perturbed by reactor drift and equipment "faults." I will also discuss the present limitations of the technique and potential extensions of the technique to make it applicable to other plasma processes and other types of plasma reactors.

9:20am **PS2-ThM5 Application of an RF Biased Langmuir Probe to Etch Reactor Chamber Matching, Fault Detection and Process Control**, ***D.L. Keil**, J.-P. Booth, N. Benjamin, C. Thorgrimsson,* Lam Research Corporation, *M. Brooks,* San Jose State University / Lam Research Co., *G. Curley,* Ecole Polytechnique / Lam Research Co., *L. Albarede, D. Cooperberg,* Lam Research Corporation

As feature size shrinks below 45 nm the demand for precision plasma etch process monitoring has increased. The final etched profile is determined by physical processes occurring at the wafer-plasma interface which are typically driven by neutral flux, ion flux and ion energy. However, typically only the RF delivery, gas flow, and chamber temperature are monitored. These measurements are too far removed from the actual physical processes of interest to be of value in tool matching, fault detection and advanced process control. This work examines the usefulness of an RF -biased planar Langmuir probe approach.[1] This method delivers precise real-time (10 Hz) measurements of the ion flux and tail weighted electron temperature and is insensitive to contamination and deposition on the probe. Data was taken during wafer processing, and indicates the utility of this approach for tool matching, process diagnosis, tool fault detection and advanced process control.

[1] J.P. Booth, N. St. J. Braithwaite, A. Goodyear, and P. Barroy, Rev. Sci. Inst., Vol. 71, No 7, July 2000, pgs. 2722-2727.

9:40am **PS2-ThM6 A New Diagnostic Method of Very High-Frequency Plasmas Produced in Insulated Vessels**, ***H. Shindo**, K. Kusaba*, Tokai University, Japan

A new method to measure electron energy by an emissive probe has been proposed. The method is based on measurement of the functional relationship of the floating potential and the heating voltage of emissive probe. From the measured data of the floating potential change as a function of the heating voltage, the curve of the probe collection current-voltage can be analytically obtained. The present method has several important advantages of the following: (1) it is even applicable to radio-frequency plasma in which the potentials are usually fluctuating, (2) also applicable to plasmas which are produced in non-conductive containers. One of key issues in the method is to achieve a perfect floating condition for radio-frequency. To ensure this condition, the probe circuit was optically connected into the measurement circuit. In the experiment, the emissive probe 30 micrometer diameter tungsten was heated by 40 kHz pulse voltage, and the floating potential at the heating voltage off period and the floating potential difference between the heating off and on period were measured by digital oscilloscope in argon plasma. The measurements were made in plasmas, produced by a variety of frequencies of 2 MHz to 60 MHz, and these plasmas are both the capacitively coupled and inductively coupled. It was shown that the plasma electron energy probability function could be obtained without any RF compensating circuit even in capacitively coupled plasmas. In particular at the frequency of 60 MHz, since the method is very sensitive near the plasma potential, the clear indication for the depletion of the low energy electron could be obtained. This low energy electron depletion is due to high plasma potential. Therefore, in the inductively coupled plasma at the frequencies below 27 MHz this low energy electron depletion was obtained near the induction antenna, but at the further positions from the antenna the energy distribution became Maxwellian. This change in the electron energy distribution found in ICP was very systematic with the frequency, the gas pressures and the distances from the antenna. Thus the present method is quite innovative in that it is applicable to the potential fluctuating RF plasma and measurements are all done in a floating condition of probe.

10:00am **PS2-ThM7 On-wafer Real Time Monitoring of Charge-Build-up Voltages during Plasma Etching in Production Equipment**, ***J. Hashimoto***, *Y. Yatagai, T. Tatsumi, S. Kawada, M. Konishi, I. Kurachi*, Miyagi Oki Electric Co.,Ltd., Japan, *Y. Ishikawa, S. Samukawa*, Tohoku University, Japan

For requirements of high performance and large scale integration to semiconductor devices, transistor size has been shrunk down to nano-scale regime. Recently, 32nm gate length has been already developed and even 22nm gate length is under studying. As a result, gate insulator thickness of MOSFETs must be thin as less than 1nm in 22nm technology. Consequently, gate oxide breakdown caused by the plasma damage is a significant concern. In addition, extraordinary shape of via hole and etching stop caused by the electron shading effect must be solved to realize high aspect ratio via holes.These issues are attributed to charge-up during plasma etching processes. It is absolutely necessary for solution of them to monitor charge-up phenomena precisely. There are two typical methods to monitor them so far. One is measurement of electrical charge on the blank wafer after processing. The other is charge monitoring by using NVM(Nonvolatile memory). However, both methods dose not function for monitoring them in real time or on the actual patterned wafer. Consequently, the charge-up phenomena during device fabrication plasma etching can not be understood in detail.We succeed to monitor real time charge-up phenomena on the actual patterned wafer by using On-Wafer Monitoring Sensor newly proposed by Dr. Samukawa. In this study, an etcher for production was employed. From data of charge-up quantity under various etching conditions such as gas chemistry, RF power and pressure with various types of On-Wafer Monitoring Sensors, the charge-up phenomena can be revealed and will be reported in the presentation.

10:20am **PS2-ThM8 In-Situ Wafer-Based Plasma Sensor Analysis in Inductively Coupled Plasmas**, ***M.J. Titus***, *D.B. Graves*, University of California, Berkeley

In-situ, wafer-based plasma sensors are currently being explored to attack plasma process control and process development challenges. One such commercially available sensor tool is the PlasmaTemp^{TM} sensor wafer, developed by KLA-Tencor. PlasmaTemp^{TM} includes an on-board electronics module, coupled with wireless communication, which allows data storage of 30 temperature sensors embedded onto the wafer at different radial positions. In the present work, we focus on molecular gas (e.g. O_2) inductively coupled plasmas (ICPs). Wafer heating mechanisms in molecular gas plasmas can involve effects in addition to those identified in atomic gas plasmas (i.e. ion bombardment and ion-electron recombination). These mechanisms include thermal conduction from the neutral gas, when bulk temperatures are in excess of ~1000K, and atom recombination on the wafer surface. We report a combination of plasma diagnostics and modeling, sensor wafer modeling, and experimental measurements for a variety of conditions in an Ar/O_2 inductively coupled plasma for wafer temperature measurements as well as for other plasma characteristics such as plasma density, ion flux and optical emission intensity.

10:40am **PS2-ThM9 Plasma Process Development and Control with Real-Time Critical Process Parameter Detection at the Wafer Surface**, ***M.R. Tesauro***, *R. Koepe, T. Remus,* Qimonda Dresden GmbH & Co. OHG, Germany, *G.A. Roche, P. MacDonald*, KLA-Tencor

Improved semiconductor manufacturing equipment / process diagnostics and control are ever more critical as the push toward ever smaller microelectronics device geometries continues. This is especially true for the fabrication process of controlled destruction: plasma etch. Improved plasma etch process diagnostics can be advantageous for initial development of stable processes to enable fast and profitable manufacturing ramp-up as well as assuring well-matched process results from the multiple plasma processing chambers required for volume manufacturing. Traditionally the focus of diagnostics and control has been on monitoring process chamber inputs (e.g. RF Power, pressure, gas flows, etc.) and outputs (e.g. product critical dimensions, etch rates, particle tests, etc.). Sensors which monitor the average plasma environment (e.g. plasma emission monitoring, advanced RF sensors, etc.) have further improved equipment and process control. Improved technologies now make possible process variable measurement directly at the wafer surface by incorporating sensors into an autonomous data collection sensor wafer. We present the results of such a wireless sensor wafer containing an array of temperature sensors to address issues of process stability and chamber matching. We will show how the unique properties of the thermal â?ofingerprintâ? of the actual plasma process measured near the wafer surface can be used to detect and correct differences between chambers and control for shifts following critical hardware replacement. In addition an example of the potential for process instability detection by thermal fingerprint on the wafer during development instead of during product ramp-up will be presented, showing the advantages and increasing necessity for time-resolved critical process parameter detection at the wafer surface.

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