Plasma Science and Technology
Room 310 - Session PS1+MS-WeA
Sensors and Control in Plasma Processing
Moderator: I.P. Herman, Columbia University

2:00pm **PS1+MS-WeA1 Supervision of Plasma Processes using Multiway Principal Component Analysis**, ***D. Knobloch***, *F.H. Bell,* Infineon Technologies AG, Germany*; K. Voigtlaender, J. Zimpel,* Fraunhofer Institute IVI, Germany

In modern IC-manufacturing lines, plasma processing is still one of the most complex single process steps. The trend towards even smaller feature sizes and greater wafer diameters results in the need of better process and equipment control. In previous studies@footnote 1,2@, we have shown that an OES-system, based on a multiband CCD-spectrometer and operated with a home built software, can be used for run-to-run and real time process control. In this work, we show how we extended our software tool in order to improve data analysis. A MPCA (Multiway Principal Component Analysis) has been implemented that allows extraction of key numbers from spectral data simultaneously in time and wavelength. Key numbers are extracted for single processes as well as for run-to-run variations. As an example, the chamber conditions as a function of rf-hours and process mix is characterized by MPCA key numbers. It is shown, that the key numbers represent the cleanliness of the plasma chamber that depends on the process mix. Consequently, the key numbers can be used to establish an optimum product flow in the chamber in order to optimize wet clean cycles and control particle generation. Furthermore, we demonstrate, how fault detection, such as determination of gas flow variations or chamber leaks, can be achieved. The MPCA key numbers of misprocessed wafers show variations to processing of good wafers and can be correlated to certain equipment or process faults. However, the establishment of a catalogue with spectral pattern of fault classifications, such as chamber leaks, is needed. Consequently, preventive maintenance is triggered in order to fix the observed equipment faults as soon as possible. @FootnoteText@ @footnote 1@ D. Knobloch et al, November 1998, AVS 45th International Symposium, Baltimore @footnote 2@ D. Knobloch et al, October 1999, AVS 46th International Symposium, Seattle

2:20pm **PS1+MS-WeA2 Sensors and Control in Plasma Processing**, ***J.C. Arnold***, *M.J. Hartig, C.F. Pfeiffer, J.A. Rivers, M.L. Johnson,* Motorola Semiconductor Products Sector **INVITED**

Even with the entrance of such processes as CMP and electrochemical deposition into the mainstream of semiconductor manufacturing, plasma processes remain among the most complex processes in the fab as well as among the most difficult to sustain. Furthermore, plasma deposition, etching, and cleaning processes are so numerous in typical product flows that the potential economic impact of plasma tool or process breakdowns is tremendous. The impetus for application of advanced sensors and automatic controls to these processes has been clear for years; however, widespread deployment of these devices and techniques in high volume manufacturing has been elusive. In this presentation, we will examine reasons for the apparent weakness in the pace at which sensors and controls have been adopted. We will begin with consideration of the terms "sensor" and "control" as related to the current state of the art in plasma processing. We will evaluate some of the sensor and control industry's current offerings in the context of the sensor and factory CIM system's ability to provide the "Acquisition - Analysis - Action" chain of three characteristics which we believe to be essential for adding value in the manufacturing environment. Finally, we will offer some end user perspectives on how changes in the business relationships between sensor and software vendors, capital equipment suppliers, and device manufacturers would facilitate more rapid and effective transfer of new techniques from the research lab to the production floor.

3:00pm **PS1+MS-WeA4 Run-to-Run and Real Time Process Control of Plasma Processes using an Inductive Antenna with Microsecond Resolution**, ***J. Mathuni***, *F.H. Bell, D. Knobloch,* Infineon Technologies AG, Germany

Equipment and process stability during the fabrication process of integrated circuits is one of the main issues in current and future production lines. This is particularly mandatory for plasma processes. Intelligent run-to-run and real time control using plasma sensors help to prevent wafer scratches or misprocessing and to monitor chamber drifts, e.g. caused by damaged reactor walls or polymer coating on chamber walls during wet cleans. We have implemented the real time control of plasma processes using an in house developed antenna that measures the electric field of the plasma with microsecond resolution. Introduction of this sensor in our fabrication lines was challenged by two factors, namely, the development of robust and low cost hardware and easy to use software including process and equipment related control algorithm. The latter needs special attention, since the time resolution in the range of microseconds results in a very high amount of data making intelligent data reduction techniques mandatory. The measurement technique requires a dielectric material between plasma and sensor that can be easily realized using the quartz endpoint window of the plasma chamber. The benefit of this sensor is demonstrated for applications such as arcing detection, a phenomenon that may occur during microseconds and results in yield killing particle generation, and process parameter dependencies, such as B-field and power analysis. As a result, preventive maintenance is automatically triggered by sensor data. Since the sensor allows electric field measurements with nanosecond resolution, analysis of pulsed plasmas could be a further application.

3:20pm **PS1+MS-WeA5 Improved Utility of Microwave Energy for Semiconductor Plasma Processing through RF System Stability Analysis and Enhancement**, ***P.W. Rummel***, *T. Grotjohn,* Michigan State University, US

The bulk of today's semiconductor plasma processing equipment utilizes RF energies at frequencies from 50 KHz to 60 MHz for deposition, etching, cleaning and various other processes. One of the impediments to utilizing microwave energy for these processes is the inherent instability often encountered with systems operating at frequencies of .5 to 2.45 GHz. Systems with plasma loads excited by resonant antennas, impedance matched by resonant circuits or cavities, and powered by generators of various source impedances are invariably unstable over some operating conditions. For microwave systems, this instability typically manifests itself as a propensity for the plasma to extinguish or rapidly change to a lower density as the impedance matching device is adjusted to minimize reflected power to the microwave generator. This paper shows why this instability exists and how a microwave driven plasma system can be modified to achieve better stabilization. A Matlab Simulink model and a state-model control analysis are used to identify system parameters that affect system stability and to predict the results of modifying those parameters towards the goal of improving stability. A plasma system utilizing a microwave cavity plasma reactor operating at 2.45 GHz. is first characterized to develop the models, and then modified to improve stability and illustrate the models' predictions. A high correlation between predicted and measured system stability validates the method of using a control analysis to model plasma system stability.

3:40pm **PS1+MS-WeA6 Modeling and Real-time Control of RF Diode Sputtering for GMR Thin Film Deposition**, ***S. Ghosal***, *R.L. Kosut, J.L. Ebert, L. Porter,* SC Solutions, Inc.*; D.J. Brownell,* Nonvolatile Electronics, Inc.*; H.N.G. Wadley,* University of Virginia, usa

This presentation describes the development and implementation of real-time control of rf diode sputter deposition resulting in significantly reduced wafer-to-wafer variation in device properties. Giant magnetoresistive (GMR) materials have very important applications which include technologies such as hard disk read-heads, computer memory, and sensors. One common configuration for thin-film sensors made by NVE is the GMR multi-layer consisting of sixteen metallic layers with individual layer thickness ranging from 15 to 40 @Ao@. For maximum GMR, the acceptable variation in layer thickness from one deposition cycle to another is very small (0.5 @Ao@ for the critical CuAgAu conducting layer). Before this work, there was considerable variation in GMR properties from wafer to wafer, despite no change in the nominal values of layer thickness. Sensitivity studies using a steady-state physical model (integrating plasma, sputter and atom transport processes) showed deposition thickness falling out of acceptable range with relatively small changes in rf power, chamber temperature, pressure, and electrode spacing. Careful experiments showed that while three of the four variables were controlled relatively well, there was significant variation (>1%) in total rf power delivered due to transients at the onset of the plasma. A controller was designed to compensate for transient fluctuations by turning off the plasma based on the time-integrated DC bias voltage at the target. This approach keeps the total rf energy input into the plasma constant for individual layers deposited. As a result of implementing this controller, the standard deviation (wafer-to-wafer) in average GMR % and in sheet resistance were both reduced by more than half. Additionally, guided by the integrated physical model, within-wafer uniformity was considerably improved by optimal electrode spacing and target shaping.

4:00pm **PS1+MS-WeA7 Productivity Solutions for Eliminating Within-Wafer and Wafer-to-Wafer Variability in a Silicon Etch Process through Plasma and Surface Diagnostics***, **E.A. Edelberg**, L.B. Braly, V. Vahedi, J. Daugherty,* Lam Research Corporation*; S.J. Ullal, A.R. Godfrey, E.S. Aydil,* University of California, Santa Barbara*; H.K. Chiu, H.J. Tao,* Taiwan Semiconductor Manufacturing Corp.

Various plasma and surface diagnostics were used to understand the root causes that lead to within-wafer and wafer-to-wafer variability in critical dimension (CD) loss in Si etch applications. It is found that the conditions of the reactor walls can play a significant role in determining the plasma properties and therefore the figures of merit of the etching process. Etch products from the wafer can adsorb and build up on the walls of the chamber leading to changes in the wall properties. These changes can lead to drifts in the plasma properties and cause wafer-to-wafer variability of the etch process. It is demonstrated that such drifts can be avoided by cleaning the walls of the reactor using Fluorine-containing plasmas in between wafers. We demonstrate that a fundamental understanding of the chemistry and composition of the deposited materials on the walls of the chamber and their relation to the gas phase species can be used to develop and optimize appropriate reactor wall cleaning processes. A multiple pass downstream Fourier transform infrared (FTIR) spectrometer is used to quantitatively measure the concentration of gas phase species such as SiCl@sub 4@ and SiF@sub 4@ in the reactor exhaust. In addition, a novel diagnostic technique based on the principles of multiple total internal reflection FTIR spectroscopy is used to measure, in situ, the presence and composition of material deposited or removed from the walls of the chamber. In particular, during Si etching processes with Cl@sub 2@/O@sub 2@ plasmas, the deposited films were found to be the byproducts of the etching reactions and contain Si, O and Cl. We show that performing a short plasma chamber clean with the appropriate chemistry between each wafer can reduce the wafer-to-wafer variability of both etch rate and CD bias. By performing an in situ clean after every wafer during a 0.13 micron gate etching process the wafer-to-wafer repeatability is reduced to 2nm (at 3 sigma).

4:20pm **PS1+MS-WeA8 Source Optimization for Magnetron Sputter-Deposition of NbTiN Tuning Elements for SIS THz Detectors***, **N.N. Iosad**,* Delft University of Technology, The Netherlands*; B.D. Jackson, J.R. Gao,* Space Research Organization of the Netherlands*; S.N. Polyakov,* Moscow State University*; P.N. Dmitriev,* Russian Academy of Sciences*; T.M. Klapwijk,* Delft University of Technology, The Netherlands

NbTiN is one of the most promising materials for use in the tuning circuits of Nb-based superconductor-isolator-superconductor (SIS) mixers for operating frequencies above the gap frequency of Nb (about 700 GHz). Device development requires stable and reproducible film properties. In this manuscript we compare the properties of NbTiN and NbN films obtained with a DC magnetron sputtering source using balanced and unbalanced magnetic trap configurations. This experiment shows that reducing the effectiveness of the magnetic trap by changing the magnet configuration is equivalent to reducing the sputtering pressure from the prospective of the film properties. We find that the properties of the films are not stable throughout the target life-time. Sputtering source with balanced configuration shows degradation of the NbN film properties as the target gets grooved for the fixed applied power and sputtering pressure. In contrast unbalanced sputtering source shows opposite behavior for the NbTiN films. We also show that it is possible to optimize the configuration of the magnetron magnets to produce stable and reproducible NbTiN films under the same gas pressure and applied power throughout the target lifetime.

4:40pm **PS1+MS-WeA9 Multiwavelength In-Situ Ellipsometry for Optical Coatings Fabrication: Optimal Control Strategies and Results***, **A. Hofrichter**, D. Kouznetsov, P. Bulkin, B. Drevillon,* Ecole Polytechnique, France

There is an increasing interest in adopting ellipsometric control for the manufacturing of optical filters. Ellipsometry does not relay on the amplitude of reflected signal, has very high sensitivity to both, thickness and complex refractive index, and can be used directly to probe growing surface, thus it is neither limited to transparent films nor depends on stability of light source. In comparison with such traditional techniques, as quartz crystal monitor and transmission/reflection spectrometer or laser interferometer, it is free of most their problems. However, interpretation of ellipsometric data is much more complicated and usually prevents application of ellipsometers for real-time process control in industrial environment. We present a robust algorithm for feed-back control of the PECVD deposition, based comparison of pre-computed ellipsometric trajectories with real-time data stream. Such approach allows to stop growth of each layer with high accuracy without performing complicated real-time inversion of ellipsometric data. Using our Integrated Distributed Electron Cyclotron Resonance (IDECR) PECVD reactor we performed depositions of multilayer and gradient optical coatings with good agreement with design. The next step will be inclusion of dinamic corrections of gas flows based on real-time determination of refractive index profile.

5:00pm **PS1+MS-WeA10 Low Open Area Endpoint Detection of Plasma Etching Processes - Limitations and Signal to Noise Characterization***, **B.E. Goodlin**, D.S. Boning, H.H. Sawin,* MIT*; M. Yang,* Texas Instruments, Inc.

In low open area contact and via etches, endpoint detection has proven very challenging in manufacturing, despite apparent successes in research and development. In our current studies, we are looking into critical issues preventing successful implementation of endpoint detection in a manufacturing environment. In particular, we have characterized two major limitations to endpoint detection inherent in many oxide etching processes. 1) Wafer Edge Limitations - Depending on processing conditions, the wafer edge contributes between 1% to 6% open area to the etch, and thus cannot be neglected in the endpoint detection scheme for etches where the patterned area is <10% open area. 2) Interferometry Limitations - When using optical emission spectroscopy, reflections from the wafer surface and the top electrode can lead to a significant source of noise that is very difficult to remove and can easily lead to false identification of endpoint. In addition to looking at limitations inherent in typical processes, we have also quantitatively compared performance of various sensors that have been proposed for endpoint detection. S/N was characterized for 4 different levels of open area (100%, 20%, 0.7%, 0.14%) for optical emission spectroscopy (OES), residual gas analysis (RGA), and RF Impedance sensors. Our findings indicated that the RGA had the best S/N capability at 0.14% open area, but the simple monochromator OES system was a close second, with good capability at 0.7%. Lastly, we have compared performance of multivariate OES systems with single wavelength monochromator systems and found that the monochromator showed greater capability for low open area endpoint detection. After revisiting some of the multivariate algorithms, it was discovered that the S/N improvements previously claimed for multivariate algorithms have been overstated. In some cases multivariate algorithms can actually decrease S/N.

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