Manufacturing Science and Technology Group
Room 317 - Session MS-ThM

Sensors and Support Technology

Moderator: B. Van Eck, SEMATECH

9:00am **MS-ThM3 RF Monitoring of PECVD Tools in a Manufacturing Environment*, M.B. Freiler,*** IBM

The use of RF monitoring systems for plasma enhanced chemical vapor deposition (PECVD) tools in an advanced microelectronics production environment is discussed. Data obtained from the measurement of RF current and voltage at the input to the process chamber provides valuable process information that is unavailable from data recorded using traditional process control techniques, such as RF forward and reflected power. RF current and voltage data is presented for silicon oxide and nitride films deposited in commercial PECVD reactors. The application of this data to improvement of the periodic chamber cleaning process with the goal of reducing gas emissions and chamber contamination will be shown. In - film wafer contamination measurements showed an improvement of 10 X in number of particles when the improved clean was implemented. RF measurements have also been used to improve the effectiveness of post - clean chamber seasoning, by giving an indication of the completion of the seasoning. Inadequate seasoning will result in increased variability of film thickness and stress. Changes in RF current and voltage during the deposition process give an indication of this increase in variability. Finally, the application of RF measurements to reactor matching will be discussed; RF signal strength of different reactors running the same process can be compared in order to understand and control performance differences between the reactors.

9:20am **MS-ThM4 Advances in Broadband RF Sensing for Real-time Control of Plasma-Based Semiconductor Processing*, C. Garvin,*** *D.S. Grimard, J.W. Grizzle,* The University of Michigan

Ever shrinking geometries are putting heavy pressure on sensor systems to provide adequate process knowledge for control and diagnostics. Plasma processing specialists in industry and academia have recognized that a substantial amount of information about the plasma state should be contained in the RF signal (13.56 MHz) and its harmonics. On the surface, making measurements for control purposes should be straightforward, and the real work should lie in making the connections (mathematical models) between measurements and key plasma quantities. Unfortunately, this is not the case. Work reported in this area from major University and Government research facilities, as well both US and Japanese chip manufacturers, has shown disappointing results and revealed that the RF sensing problem itself is non-trivial. An approach which has shown promise is `broadband sensing', a novel sening method based on the Resonance Probe used in ionospheric physics. The goal of the broad band RF work is to create a diagnostic with much greater signal to noise ratio, and much higher sensitivity to the plasma state and its environment than standard RF sensing. The idea is to scan the plasma with a very low wattage, broad band RF signal from 100 MHz to 1 GHz, measuring the reflected signal. In a typical scan, the large amount of data taken over a wide range of frequencies provides redundancy and enhances the signal to noise ratio of the sensor. Preliminary work has shown this sensor to have favorable performance when compared to standard RF sensing. We will present novel results of a non-intrusive implementation of the sensor.

9:40am **MS-ThM5 NOVA In-Line CMP Metrology and Its Use for Lot-to-Lot Process Control*, T.H. Smith,*** Massachusetts Institute of Technology*; S.J. Fang, J.A. Stefani, G.B. Shinn,* Texas Instruments*; D. Boning,* Massachusetts Institute of Technology*; S.W. Butler,* Texas Instruments

The use of in-line metrology with run by run (RbR) process control is becoming a means to meet the future demands on improved processing quality without sacrificing throughput. This control will become critical for large variation processes such as chemicalmechanical polishing (CMP). In response to this, other works have described the use of the NOVA in-line CMP metrology system for use in RbR process control. This work describes a similar system, but focuses on quantifying 1) the quality of measurements obtained from the NOVA system, 2) improvements gained by simple RbR control of post-polish patterned wafer thickness over fixed-time polishing and pilot wafer control, and 3) the increases in throughput using an in-line measurement and control system. The results of a gauge study of the NOVA system and a 600 wafer RbR control experiment performed at Texas Instruments, Inc. are discussed. The variability of the system is shown to be well within standard requirements. The reliability of the system over the 600 wafer experiment was very good. The NOVA measurements are shown to correlate well with ex-situ measurements. The 600 wafer RbR control experiment indicates that even a simple control approach provides a 25% improvement over the fixed-time approach. The results demonstrate that controlling directly on patterned wafers provides a 23% improvement over control using pilot wafers. The experiment shows a 25-40% improvement in throughput using the system. The number of cleans were reduced by 0-66% (depending the number of look-aheads and amount of re-work) and ex-situ measurements were eliminated, indicating significant cost of ownership reductions.

10:00am **MS-ThM6 In Situ CD Measurement during Post Exposure Bake*, R.H. Krukar,*** Bio-Rad Semiconductor*; N.T. Sullivan,* Digital Semiconductor*; S.L. Prins, J.R. McNeil,* Bio-Rad Semiconductor

As critical dimensions are reduced below 0.18 micron, post exposure bake is emerging as a critical and controllable process. Direct correlations between bake times and line width have been reported. We built an in-situ post exposure bake sensor and monitored the critical dimensions of a SRAM pattern as it baked. The data indicates that production of an accurate in-situ PEB monitor is possible.

10:20am **MS-ThM7 Process Environment Monitoring of Plasma Etching for Advanced Process Control*, H. Enami,*** *A. Kagoshima,* Hitachi, Ltd., Japan **INVITED**

The development of 0.18um process is our current target. Some equipment, at present, cannot meet the requirements from the process (e.g. Selectivity, uniformity, aspect ratio, etc., in dry etching). Considering the facts: (1) Physical limitation against the countermeasures in equipment (2) Decrease of Overall Equipment Effectiveness due to increasing QC time, we suggest quick installation of advanced process control (APC) system such as In-Situ control. To make the best use of In-Situ Control, following 3 steps are necessary. (1) To find useful methods and instruments for process condition analysis. (2) To make digital network among instruments for analysis and to reduce sampling period (less than 1 sec./time) and the prices of those instruments. (3) To find a correlation between monitoring data and process condition or results. Firstly, In-Situ data comparison between Plasma Probe Data and RF Impedance (RFIM) Data shows that RFIM is more useful monitoring method than Plasma Probe for unstable plasma discharge and fluctuating process condition. Secondly, Plasma diagnostics by Plasma Optical Emission Spectroscopy (OES) per sub-micro-sec shows that Pulsed-Plasma-Discharge contributes to improve etching uniformity and control the quantity of etchant. Quadrupole Mass Spectrometry (QMS) is also useful for the same purpose. Comparing OES and QMS, OES is useful for short life species in plasma, on the other hand OMS is for reacted species or products. Both are necessary as In-Situ-Monitoring. In dry etching (SiO@sub 2@ film) process, for example, the combination of OES and RFIM for Gas flow rate and RF Power control contributes to reduce the dispersion of Selectivity among wafer to wafer in a batch to 25% of it without control. This data shows the advantage of In-Situ Control by simple, convenient and high-speed sensor. Then we have began the development of process control system using RFIM, OMS, OES allowing more than one time feedback per second.

11:00am **MS-ThM9 Improvement of Process and Equipment Performance Using Online and Real Time Optical Emission Spectroscopy*, D. Knobloch,*** Siemens Microelectronics Center GmbH & Co. OHG, Germany*; F.H. Bell,* Siemens AG, Germany*; J. Zimpel,* Fraunhofer Institute, Germany*; A. Steinbach,* Siemens Microelectronics Center GmbH & Co. OHG, Germany

The semiconductor industry is continually driven towards the use of larger wafers (200 mm and larger) and smaller device dimensions (0.18 mm). More and more sophisticated technologies are necessary to improve overall production performance and reduce manufacturing costs. Intelligent process and equipment control applied to plasma processing is an excellent candidate to improve productivity, and thus profitability. We use optical emission spectroscopy to characterise etching processes for 64Mbit DRAM fabrication by in-situ analysis of plasma conditions. Parameters to be optimised include: increased wafer throughput and wafer yield, reliable processes, reduction of monitor wafers, optimisation of cleaning procedures. Four MxP@super +@ oxide etch chambers mounted on a Centura platform are equipped with optical multichannel analysers (200 - 950nm). The dynamic evolution of the spectra can be recorded every 20msec during wafer processing. The spectrometers are coupled to the etch chambers via the fab host computer allowing in-situ and real time process and equipment control. Intelligent data reduction techniques, such as principal component analysis (PCA), are used to extract process and equipment related wavelength ranges. Every process parameter, such as pressure, power and gas flows, shows a typical optical signature. Therefore, the cause of process variations can be determined. Furthermore, even without variation in the external parameters, the plasma processes are plagued by process drift phenomena: the process performance (e.g. etch rate, uniformity, selectivity) varies continually as a function of time. These phenomena are linked to the chemistry occuring at the reactor walls and the influence of thin films deposited by the plasma. These drifts can be correlated to changes of certain wavelength ranges in the optical emission spectra. Major benefits of this technique are early process fault detection and optimisation of chamber cleaning cycles. @FootnoteText@ The presented work was part of a project funded by the saxonian department of economy (SMWA), project number: PT2648.

11:20am **MS-ThM10 Multivariate Spectral Analysis of Optical Emission Spectroscopy for use in Low-Open Area Endpoint Detection**, *D. White, **B. Goodlin**, A. Gower, D. Boning, H. Sawin,* Massachusetts Institute of Technology*; T. Dalton,* Digital Equipment Corporation

As device dimensions continue to shrink, the need for tighter control of semiconductor processes is increasing. In particular, accurate determination of endpoint in plasma etching processes is essential to decrease defects due to both incomplete clearing of the etched material and excessive overetch of the underlying material, leading to a loss of dimension control. This is particularly challenging for low open area etches (<1%), where traditional sensors are at the limits of their sensitivities in determining endpoint. Many sensors have been utilized for the purposes of determining endpoint including optical emission spectroscopy(OES), laser interferometry, optical emission interferometry, mass spectrometry, and rf impedance monitoring, but OES is the most widely used sensor. Traditional endpoint algorithms using OES observe only a few selected wavelengths corresponding to major product and reactant species, thus utilizing only a small fraction of the data provided by OES. For instance in an oxide etch process, using C@sub 2@F@sub 6@, we might follow the emission lines corresponding to a reactant species C@sub 2@ (e.g. 516 nm) and a product species SiF (e.g. 440 nm) during an etch process. Endpoint would be indicated by an increase in the ratio of the C@sub 2@ line intensity to the SiF line intensity. Since both lines are changing in intensity at endpoint we say that these lines are correlated or covarying. The OES spectrum, however, consists of a number of other emission lines which also correspond to reactant and product species, including many more lines corresponding to the many different excitations of C@sub 2@ and SiF. All of these lines have correlated changes that occur at endpoint, so by throwing away all of the spectra except a few spectral lines, the traditional endpointing algorithms do not take full advantage of all of the information available, resulting in a lower signal to noise ratio than that resulting if all of the lines were kept. In this paper, we examine the use of a multivariate technique called principal component analysis (PCA) which utilizes the entire OES spectrum and thus demonstrates superior signal to noise over the traditional univariate methods. We then demonstrate the technique for real-time endpoint detection in an industrial oxide contact etching process with low open areas (~1%). Lastly, implementation issues such as adjusting for process drift due to window fogging and PCA model validation are discussed.

11:40am **MS-ThM11 Simulations of the Performance of Novel Ion Current Sensors**, ***M.A. Sobolewski,*** National Institute of Standards and Technology

To obtain optimal results from plasma processing, the properties of ions and neutrals incident on the substrate must be carefully controlled. If sensors for the relevant properties of the ions and neutrals were available, they could be used to detect process drift and equipment malfunctions, diagnose their origin, and take correction action, if needed. One particularly important parameter to monitor is the total ion current at the substrate. Recently, a method has been demonstrated for using external, radio-frequency (rf) electrical measurements to monitor the ion current at an electrically insulating or conducting wafer during processing by a high-density plasma.@footnote 1@ The rf signals are generated by the rf bias power which is normally applied to wafers. There is no need for any probe to be inserted into the reactor or for any additional power supplies which might perturb the plasma. At low rf bias frequencies (0.1-1 MHz) ion currents measured by this technique agree well with dc measurements of the ion current, but they agree less well at higher frequencies.@footnote 1@ In this work, this disagreement was investigated using a fluid model of the sheath region of high-density plasmas. Simulations show that, as the rf frequency approaches the ion plasma frequency at the edge of the sheath, the ion current at the electrode varies strongly with time during each rf period. Under these conditions, the rf measurement of ion current differs from the time-averaged value of the ion current. The simulations are used to characterize the error in the rf measurement technique and to suggest new rf methods which more accurately determine the time-averaged ion current. @FootnoteText@ @footnote 1@M. A. Sobolewski, Appl. Phys. Lett. 72, 1146 (1998).

Author Index

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