Plasma Science and Technology
Room: 304 - Session PS-MoA

Invited Highlights on Plasma-Surface Interactions - Honoring the Distinguished Career of Herbert H. Sawin
Moderator: J.P. Chang, University of California, Los Angeles

2:00pm **PS-MoA1 Plasma Etching - The Early Days**, ***J.W. Coburn***, University of California at Berkeley

Remarkable progress has been made in the implementation and understanding of the pattern transfer capabilities of plasma etching in the 30 or so years this technique has been used in microelectronics manufacturing. Where did it all begin? One perspective of some of the early highlights introduced in the mid-1970s will be presented. The importance of studies supporting physical sputtering (both sputter-etching and sputter-deposition) using Ar glow discharges will be emphasized. A select few pioneering advances in processing chemistries will also be described.

2:20pm **PS-MoA2 Following Moore's Law – How Many Knobs are Enough?**, ***R.A. Gottscho***, *K. Smekalin*, Lam Research **INVITED**

With the introduction of 3x technology, more new materials are introduced into semiconductor devices and their manufacture. Yet, the basic etch challenges do not change qualitatively: selectivity, profile, uniformity, damage, line edge roughness and more. Quantitatively, of course, virtually everything changes: with each shrink, the difficulty in meeting the tolerances increases along with cost. The tightening of tolerances on the die, the wafer, and the system places un-precedented demands on system and sub-system variability reduction – active and passive. For repeatable, high yield, high output manufacturing, minimizing variability is essential. Yet the requirements to shrink stimulate increased demands for more control "knobs." Some knobs are provided to compensate for asymmetric limitations in design or inherent non-uniformities. Other knobs are provided to expand process flexibility in the hope of facilitating recipe optimization. The irony is that more control knobs means increased variance in the control parameter vector leading directly to more difficulty in matching chambers and narrower process windows, leading to more manufacturing excursions and downtime. More control knobs also means more recipe complexity. Despite impressive advances in simulation capability, plasma process development remains an empirical endeavor. With the most recent advances in etch production equipment, the number of recipes that have a measurable impact on the wafer are already more than 1 trillion. Can any production recipe be said to be truly optimal? Do more control variables help or hinder our ability to meet next-generation technology challenges? And do they save cost or add cost?

3:00pm **PS-MoA4 Real Time and 3D Characterization Techniques to Control Plasma Etch Processeses at the Nanometer Scale**, ***O. Joubert***, CEA/LETI-Minatec, France

As the industry approaches the ability to create microcircuit structures on the order of 20 nm, this technology faces fresh challenges. To make progress, we need to go back to the basic science of how plasmas interact with surfaces. Several trends are at work: First, circuit patterns need to be accurate to within 1 nm and below, within a single wafer and across several wafers. Second, plasma etching is becoming an integral part of pattern generation (using lateral erosion of the lithographic photoresist to improve resolution, for example). Third, aspect ratios of the final structures (that is, the ratio of length to width) are increasing dramatically. Finally, the number of potential new material candidates and their possible combinations in future structures is exploding. In this context, understanding the fundamentals of the etch mechanisms and their correlations to key process parameters is crucial. Each etch step must be characterized not only by etch rate and uniformity, but also by more fundamental properties such as the composition, thickness, and line-edge roughness of the sidewall layers of the structure, the chemical nature of etch by-products deposited on the chamber walls (which affects process stability and reproducibility), the thickness of the etch-front mixing layer (correlated to etch rate and selectivities between layers), and the impact of aspect ratio–dependent etching phenomena. In this talk, we will describe in details the latest development in scatterometry that can be used to monitor in real time resist trimming processes or more complex processes. We will also discuss the latest results obtained using the 3D AFM technique to characterize the transfer of photoresist line edge roughness in complex stacks. Finally we will also discus the importance of monitoring passivation layers formed on the feature sidewalls as well as the coatings formed on chamber walls during plasma processes since both impact directly the critical dimension of patterned structures.

3:20pm **PS-MoA5 Investigations of Plasma-Polymer Interactions For Nanoscale Patterning of Materials[1,2]**, ***G.S. Oehrlein***, University of Maryland

The combination of photolithographic patterning of organic materials followed by plasma-based transfer of photoresist patterns into electronic materials enables the production of nanometer scale devices required in information technology products. Despite the success of these thin film and substrate patterning approaches in what is possibly the most important example of nanoscale manufacturing, important gaps in our scientific understanding of relevant plasma-polymer interactions remain. In this talk we will review chemical and morphological changes induced in selected model polymers and advanced photoresist materials as a result of interaction with fluorocarbon/Ar plasmas. Of special interest are the changes of the materials that take place at the beginning of the plasma-polymer interaction period. We will evaluate the respective roles of a) polymer structure/chemistry and b) plasma process parameters on the consequences of the plasma-polymer interactions. The impact of plasma-induced polymer alterations on changes of polymer-defined nanoscale features will also be discussed.

[1] Based on collaborations with S. Engelmann, R. L. Bruce, F. Weilnboeck, T. Kwon, T.C. Lin, R. Phaneuf, Y. C. Bae, C. Andes, D. Wang, D. Graves, D. Nest, J. Vegh, E. A. Hudson, B. Long, G. Willson, P. Lazzeri, E. Iacob and M. Anderle

[2] We gratefully acknowledge financial support of this work by the National Science Foundation under awards Nos. DMR-0406120, DMR-0705953 and NIRT CTS-0506988.

4:00pm **PS-MoA7 Will Recombination Reaction Probabilities at Plasma Chamber Walls Ever Be Non-Adjustable Parameters?**, ***V.M. Donnelly***, University of Houston

Reactions of neutral species on surfaces immersed in plasmas have been recognized for many years to be an important class of processes that plays a major role in determining the make-up of species in the plasma. The association of radicals on the surfaces of chamber walls and substrates represents a sink for radicals and a source of larger product species. Chemistry-rich models have been developed in recent years for plasmas such as those used to etch silicon and dielectric materials. Heterogeneous reactions are an essential part of these models. With the exception of a few atom recombination reactions, the reaction probabilities for these processes are completely unknown; hence they are usually treated as adjustable parameters, or are guessed at and left constant. Experimental measurements of these reactions are usually carried out in one of two ways, neither is ideal. First, in-situ measurements can made in the plasma. This approach has the advantage of studying the surface that exists during plasma operation - one that is often coated with amorphous deposits of sputtered or etched substrate and reactor materials, and receives high fluxes of neutrals, ions, electrons and photons. This complexity makes it difficult to isolate individual reactions. Consequently, a second approach has been practiced in which the complex plasma environment can be avoided by studying reactions in high vacuum with selected molecular beam impingement. While this approach can provide accurate measurements of reaction probabilities, product identification and surface characterization, it can also lead to misleading predictions when extended to real plasma conditions. This talk will briefly review a few selected studies that highlight the complexity and lack of consensus in this field, and offer prospects for system-non-specific rate parameters for this class of heterogeneous reactions.

4:20pm **PS-MoA8 Ion-Surface Interactions Beyond Etching**, ***K.P. Giapis***, California Institute of Technology

Plasma etching has been conceptually distinguished into physical and chemical etching, in reference to the way material is removed from the surface under ion bombardment. There are other ion-surface interactions at play, which have received little attention although they may substantially alter the outcome of the etching process—especially when patterning wafers. We will present evidence from ion beam experiments for the following mechanisms: 1) Eley-Rideal (abstraction) reactions, 2) Electronic excitation as a result of inelastic collisions, 3) Pre-dissociation of molecular ions before collision with the surface, and 4) Coulomb explosion of adsorbed electronegative atoms. The importance of these processes in plasma etching will be discussed.

4:40pm **PS-MoA9 Can Plasma Modeling Be a Predictive Tool in Process Development?: Etching of Very High Aspect Ratio Features and Gate Stacks***, *M. Wang, Y. Yang, J. Shoeb,* ***M.J. Kushner***, Iowa State University

The use of modeling in the development of plasma tools has achieved a significant degree of success. Optimizing the uniformity and energies of reactant fluxes with results of modeling prior to prototyping by varying, for example, the aspect ratio of the reactor or frequency of excitation is now accepted practice. The assist of modeling to develop plasma processes has provided a less clear return on investment. This is due, in part, to the complexity of the reaction mechanism and the lack of fundamental data. The rate of technology development will likely outstrip our ability to generate the required fundamental data, at least in the near term. As such, what are the realistic expectations for modeling to provide high value to the development of plasma processes? In this talk, the general status and the potential success of plasma modeling in the development of processes will be discussed with results from two case studies using reactor and feature scale modeling platforms. In the first, sporadically occurring twisting of via-like features in extremely high aspect ratio etching has been attributed to the stochastic nature of fluxes entering the feature as the size of the opening shrinks. This is an effect exacerbated by charging. Here the reaction mechanism, fluorocarbon plasma etching of Si and SiO_2, is relatively well known. So modeling has assisted in developing a dc-augmented strategy for the capacitively coupled tools that addresses the contribution of charging to twisting. In the second, high-k dielectric HfO_2 gate stack etching, the reaction mechanism is at best poorly known. Here, the contribution of modeling has been to refine that reaction mechanism based on the existing but fragmentary database and so narrow the now broad range of operating conditions that might be considered in process development.

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5:00pm **PS-MoA10 Predictive Etch Profile under Competition Among Deposition, Etching, and Charging on Dielectrics in a Low Temperature Plasma**, ***T. Makabe***, Keio University, Japan

A dielectric surface exposed to plasma irradiation keeps competitive, physical and chemical processes among etching, deposition, and charging on the local pattern.[1] Top down plasma nano-etching is a technology assisted by a directional and energetic positive ion onto a surface saturated by adsorbed chemical molecules. The ion flux to the wafer has a magnitude of $10^{15}cm^{-2}s^{-1}$. It means that the ion incident on the surface transfers the kinetic energy to the lattice with a relaxation time shorter than the surface collision interval. We have no way to protect the surface from the charging damage, particularly on the dielectric, in a periodically steady state radio frequency (rf) plasma, which always forms the positive ion sheath in front of the biased wafer to be etched. We have demonstrated a technique to inject negative charges having a relatively high energy in a synchronized mode between an rf plasma source with on/off period and a LF bias pulse in order to develop a charging free plasma etching. It is realized by an artificial formation of a double layer close to the wafer.[2,3] The synchronized pulsed operation will enable us to develop a charging free plasma etching. The time constant of local charging, caused by the great difference in the velocity distribution between ions and electrons incident on a topographical surface, is approximately two orders of magnitude shorter than the time for the effective monolayer etching in SiO_2. This difference enables us to estimate the etching profile by the two-step evaluation, i.e., surface charging followed by etching. Even in a controlled wafer exposed to a plasma etching, the surface is the competitive processes between etching and deposition, where two-layer model will be efficient in order to predict the feature profile evolution by using Level set method[3]. Predictive images are shown and discussed for the feature profile evolution of dielectric.

[1] T. Makabe and Z. Petrovic, "Plasma Electronics: Applications in Microelectronic Device Fabrication", Taylor & Francis (2006).

[2] T. Ohmori, T. Goto, T. Kitajima, and T. Makabe, Appl. Phys. Lett. 83, 4637-9 (2003); T. Ohmori and T. Makabe, Appl. Surf. Sci. 254, 3696-3709 (2008).

[3] T. Shimada, T. Yagisawa, and T. Makabe, Japan J. Appl. Phys. 45, L132-4 (2006); Ibid. 45, 8876-82 (2006); T. Makabe, T. Shimada, and T. Yagisawa, Comp. Phys. Commun. 177, 64-7 (2007).

5:20pm **PS-MoA11 Silicon Processing Technologies in Adjacent Spaces: Applications Beyond Information Technology**, ***T. Dalton***, IBM

Over the course of the last fifty years, the microelectronics industry has made tremendous strides in the development and manufacturing of ever more complex integrated circuits (IC). These circuits have typically been applied to the information technology (IT) industry and have driven improvements in the computational power per dollar of many orders of magnitude. Part of the "toolbox" of skills acquired to produce integrated circuits is the ability to form desired patterns at ever decreasing sizes. The minimum controllable feature size has been reduced by six orders of magnitude (from millimeters to nanometers) during the last fifty years. With feature sizes rapidly approaching 10nm, the conventional silicon IC industry is nearing a threshold with the end of conventional silicon scaling approaching. Research today focuses on new device structure to replace the CMOSFET as the engine of the IT industry. Another very active research area is the concept of taking the skill-set acquired from IC research, development, and manufacturing, and to apply those skills into new area – "adjacent spaces" where the ability to machine patterns at very small sizes may open up new areas of research and development, and to form the basis for future industries.

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