Plasma Science and Technology
Room: 104 C - Session PS-WeA

PSTD at AVS60: Looking Back and Moving Forward
Moderator: C.A. Wolden, Colorado School of Mines

2:00pm **PS-WeA1 The Origins of the AVS Plasma Science and Technology Division**, ***H.F. Dylla***, American Institute of Physics **INVITED**

The AVS Plasma Science and Technology Division (PSTD), from its origins the mid 1980's through the present, has been a significant international forum for both the science and technology associated with the interaction of low temperature plasmas with materials. This talk will trace the origins of the PSTD from the formation of the Fusion Technology Division (FTD) in the late 1970's. The FTD's topical interests concerned both magnetic and inertial fusion devices that were undergoing rapid development at the time. Initial interests included the important plasma surface interactions that influenced the behavior of boundary plasmas and were used to condition the vacuum vessels of magnetic fusion devices or to prepare the multi-layer targets used in inertial fusion experiments. This concentration on plasma surface interactions laid the groundwork for broadening the FTD to the wider interests of the application of low temperature plasma for materials processing, and for rebranding the division to reflect its expanded focus.

2:40pm **PS-WeA3 The Emergence of Plasma Processing**, ***M.A. Lieberman***, University of California, Berkeley **INVITED**

Plasma processing is a crucial technology for fabricating trillions of nanometer-size transistors on a silicon wafer [1]. It evolved from humble beginnings in the early 1900's: the silver-coating of mirrors by physical sputtering in dc glow discharges. The late 1950's - early 1960's saw extensive studies of physical and reactive sputtering in capacitive rf reactors. Isotropic plasma etching, mainly for photoresist stripping, was developed in the late 1960's - early 1970's, and etching of many other important materials was demonstrated. Three key advances in the late 1970's made plasma processing technology indispensable: (a) the discovery of ion-enhanced (anisotropic) etching [2]; (b) the development of SiO_2 etching with high SiO_2/Si selectivity [3]; and (c) the controlled etching of passivating films, e.g., Al_2O_3 over Al [4]. Etching discharges evolved from a first generation of "low density" reactors capacitively driven by a single source, to a second generation of "high density" reactors having two power sources, such as ICP's (rf inductive-driven) and ECR's (microwave-driven), in order to control independently the ion flux and ion bombarding energy to the substrate. A third generation of "moderate density" reactors, driven capacitively by multiple frequency sources, is now used, and there is increasing use of pulsed discharges to further control processing characteristics. The inductive reactors were invented 129 years ago [5], while the ECR's and the pulsed technology emerged in the aftermath of World War II [6]. Amazing challenges lie ahead as scale-down of transistor critical dimensions proceeds.

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[2] N. Hosokawa, R. Matsuzaki and T. Asamaki, "RF Sputter-Etching by Fluoro-Chloro-Hydrocarbon Gases," Jpn. J. Appl. Phys. Suppl. 2, Pt. 1, 435 (1974).

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[4] S.I.J. Ingrey, H.J. Nentwich, and R.G. Poulsen, "Gaseous Plasma Etching of Al and Al2O3," USP 4,030,967 (filed 1976).

[5] W. Hittorf, "About the Conduction of Electricity Through Gases," Wiedemanns Ann. Phys. **21**, 90 (1884).

[6] H. Margenau, F.L. McMillan Jr, I.H. Dearnley, C.S Pearsall and C.G. Montgomery, "Physical Processes in the Recovery of TR Tubes," Phys. Rev. **70**, 349 (1946).

4:00pm **PS-WeA7 The Virtual World of Modeling Plasma Processing**, ***M.J. Kushner***, University of Michigan **INVITED**

Modeling of plasma processes has significantly advanced during the tenure of the AVS with benefits to investigating fundamental science issues and to technology development. Modeling's contributions to plasma processing science have been facilitated by a series of milestone contributions, including development of accessible particle-in-cell simulations, use of molecular dynamics for investigation of surface processes, hybrid techniques which have expanded the variety of plasmas investigated, multi-phase models for dusty plasmas, technology relevant profile simulation, on-demand computation of cross sections, and now state-of-the-art algorithms embedded in commercially available modeling platforms. Although model development has been closely tied to applications, a collaborative development of fundamental theories has been exceedingly important to formulating proper and relevant technology focused models. The variety and dynamic range of plasma processing applications, from low pressure magnetrons to atmospheric pressure jets and now to liquids, has both challenged and benefited modeling. In other fields of applied physics, and other sub-fields of plasmas, the dynamic range of interest is markedly smaller and so resources have been concentrated on advancing modeling in more focused areas. Plasma processing, with its greater dynamic range, has been less focused with the unexpected benefit of finding more common ground between what appears to be quite different sub-fields of plasma processing. With this virtual capability, the plasma processing community has embraced computational experimentation as a necessary and beneficial tool. In this talk, a perspective will be provided of modeling's impact on science and technology development in plasma processing, and on future opportunities.

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4:40pm **PS-WeA9 Innovations in Diagnsotics for Non-Thermal Plasma**, ***N.St.J. Braithwaite***, The Open University, UK **INVITED**

Internal electrical diagnostics of plasmas date back to the early days of plasma physics. The first innovation was the realisation that drawing currents between wires placed in a plasma does not measure conductivity - the current depends mainly on the non-neutral space charge sheaths around the wires. In 1926 Langmuir and Mott-Smith reported this in a systematic analysis. Langmuir and coworkers were then able to link the form of collected currents to the density of charged species and to the mean energy of the electrons. Their equipment was inexpensive and uncomplicated; their analysis was state of the art for the 1930s and could take up to an hour between measurement and quantitative result. Since then electrostatic (Langmuir) probes have been a standard tool for investigating low-temperature plasmas. The chief innovations in the Langmuir probe method have come from incremental improvements in the analysis of probe data and refinements of the method. Self-consistent analysis of particle collection, the inclusion of collisional factors and the Druyvesteyn method that yields electron energy distributions have now been truly popularized by the digital revolution, enabling sophisticated data acquisition and rapid processing: quantitative sub-ms plasma parameters in real time. Nevertheless, autonomous systems still have not mastered the insight of real experts. Less obvious, but equally important in opening up access to probe methods, was the development of vacuum compatible, ceramic epoxies. Many imaginative variations of electrostatic probes now deliver data on potentials, densities, energies and fluxes. These innovations were awaiting 'need' more than 'technology'. For instance, probes for plasma environments involving RF or electronegative gases were slow to evolve until the semiconductor manufacturing industry found both scenarios to be indispensible. The simplicity of Langmuir's probe is both an advantage (anyone can make one) and a disadvantage (the models for analysis are contentious and restrictive). A similar challenge has been faced by electromagnetic probes based on resonances and transmissions of microwave signals in and around low temperature plasmas with ns resolution, in real time. Microwave methods also owe a great deal to advances in materials and data acquisition, driven by the technological need for robust, minimally intrusive probing of plasmas as a dielectrics. Thus, C21, user-friendly, finite element methods have opened up microwave techniques for probing low pressure plasmas , long after fast oscilloscopes and programmable microwave sources had made them attractive options to the electrically minded plasma diagnostician.

5:20pm **PS-WeA11 Plasma Surface Interactions and How They Limit Semiconductor Plasma Processing**, ***R.A. Gottscho***, *K.J. Kanarik, S. Sriraman*, Lam Research Corp **INVITED**

Semiconductor growth continues at a brisk pace, driven by consumer electronics. Meanwhile, t he semiconductor industry is evolving and facing unprecedented technology and economic hurdles. Limits imposed by planar technology and a stalled lithographic roadmap threaten to slow down the rate at which density, cost, and speed improvements can be made. More intricate device designs hold the promise of extending Moore's Law, but they increasingly rely on high-precision plasma processes of deposition and etching. This means that deposited films must be conformal and atomically smooth; and formation of the FinFET structure requires atomic-scale etch precision across not only the wafer but also from wafer to wafer and fab to fab. Precision process solutions are already known but making them cost-effective is difficult as they are prone to inefficiencies in plasma surface interactions. In this paper, we will review fundamental plasma surface interactions such as the kinetics and dynamics of transport, adsorption, and desorption. These interactions will be discussed in relation to the performance of processing equipment, and how the resulting limitations can be overcome with clever process solutions.

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