ALD & ALE Tutorial Speakers and Schedule

Sunday, July 29, 2018

1:00-1:05	Tutorial Welcome
1:05-1:50	**“Challenges of ALD Applications in Memory Semiconductor Devices,”** Choon Hwan Kim (SK Hynix, South Korea)
1:50-2:35	**“Overview of ALD Precursors for Semiconductor Manufacturing and Its Development Challenges,”** Wonyong Koh, (UP Chemical, South Korea)
2:35-3:20	**“*In situ* Studies of ALD Processes and Reaction Mechanisms,”** Erwin Kessels (Eindhoven University of Technology, The Netherlands)
3:20-3:40	Break
3:40-4:25	**“Overview of Area Selective Atomica Layer Deposition,”** Gregory N. Parsons (North Carolina State University, USA)
4:25-5:10	**“Impact of ALE on Process Tool Design – a Tutorial,”** Mike Cooke (Oxford Instruments, USA)
5:10-5:55	**“Modeling and Simulation Approaches to Atomistic Control in Etch and Deposition Processes,”** Peter L.G. Ventzek (TEL, USA)

ALD & ALE Tutorial Speaker Abstracts

“Challenges of ALD Applications in Memory Semiconductor Devices,”

Choon Hwan Kim (SK Hynix, South Korea)

In memory devices, as the minimum feature size is smaller than 18nm and three dimensional structures (3D) is introduced, patterning and thin film properties are getting important in order to acquire the excellent electrical performance. Currently, high performance ALD (Atomic Layer Deposition) technology has been widely used in memory devices. However, in order to acquire ALD films with the conformal high-quality and high throughput properties, the process development for new materials is strongly needed. This talk will review the requirement and challenges for ALD process in memory devices. In first part, DPT (Double Pattern Technology), BG (Buried Gate) electrode, capacitor electrode and materials in DRAM will be covered. The second part will deal with the gap-fill ALD oxide materials and gate electrode in 3D NAND devices.

“Overview of ALD Precursors for Semiconductor Manufacturing and Its Development Challenges,”

Wonyong Koh, (UP Chemical, South Korea)

ALD was first used for semiconductor manufacturing to form DRAM capacitor dielectric and later for high-k gate dielectric more than a decade ago. Since then ALD became essential to control the thickness and composition of films needed for semiconductor manufacturing. ALD enabled pattern doubling and quadrupling using the same 193nm wavelength photolithograph and helped Moore’s Law alive until today. Advanced finFET and 3D-NAND flash memory devices became manufacturable only because ALD can deposit films on complex 3D structures of finFET and 3D NAND.

Many precursors have been developed since 1990s initially for CVD and later specifically for ALD. CVD precursors can be repurposed for ALD, especially to form oxide films. However, finding a suitable precursor with ALD process conditions to meet the film properties required by semiconductor manufacturing is not straight forward. It demands close co-operation among precursor manufacturers, ALD tool manufacturers, and the semiconductor device manufacturers. Volatile silicon- and other metal-containing molecules are screened by precursor manufactures for reactivity and thermal stability. Then precursors are used by ALD tool manufactures to develop ALD processes to form films useful for semiconductor manufacturing. Finally a semiconductor device manufacturer, the end-user of the precursors and ALD tools, decides whether or not to adapt the ALD process, the ALD tool and the precursor for high-volume manufacturing.   After such screening, process development, and final evaluation, only handful of precursors has been put into high-volume manufacturing.

ALD is expected to do critical role continuously to manufacture 7nm, 5nm devices and beyond. The challenges to develop ALD precursors/processes will be discussed.

“*In situ* Studies of ALD Processes and Reaction Mechanisms,”

Erwin Kessels (Eindhoven University of Technology, The Netherlands)

In situ studies by dedicated analytical probes have been crucial for the understanding and development of ALD processes and have therefore contributed largely to advancement of the field of ALD. Such studies can provide critical feedback and information on several features related to the deposition of the thin films:

- they can aid in efficient design of ALD processes, for example, in fast scanning of the ALD saturation conditions and temperature window;
- they can give immediate insight into the material properties obtained under certain conditions and, for example, reveal how material properties change with film thickness;
- they can be used to probe surface species and reaction products and provide detailed understanding on the underlying reaction mechanisms of the ALD process;
- they can be used for process monitoring and process control to warrant the correctness and precision of the process.

In this tutorial, an overview of analytical probes and *in situ* studies will be presented with respect to the aforementioned features. The analytical probes covered will range from relatively easy-to-implement (elllipsometry, quartz crystal microbalance, mass spectrometry, optical emission spectroscopy) to more advanced (infrared spectroscopy, x-ray photon spectroscopy) to very sophisticated (advanced x-ray investigations, nonlinear spectroscopy, calorimetry) methods. The type of insights obtained will be illustrated by several examples reported in the literature, especially with respect to the well-known ALD processes of Al_2O_3 but also for selected ALD processes of other materials.

“Overview of Area Selective Atomic Layer Deposition,”

Gregory N. Parsons (North Carolina State University, USA)

This tutorial will introduce approaches to substrate- or area-selective thin film formation, with focus on recent advances in area-selective atomic layer deposition, AS-ALD. We will give a basic description of some key application areas where AS-ALD is desired, particularly related to advanced sub-10 nm electronic devices. To address AS-ALD mechanisms, we briefly overview reactions and energetics of thin film nucleation, and puts known nucleation models in context with conditions and constraints driving the need for improved low-temperature ALD.The presentation also examines approaches known for CVD-based area-selective growth and how these and new methods have transitioned into current AS-ALD research. To highlight recent advances in AS-ALD, a few representative metal oxide and metal materials are selected as examples to describe what is known about controlling nucleation to achieve area-selective deposition. Finally, we discuss the current limitations of area-selective ALD, including material flexibility and overall process rates, and describe the need for new advanced atomic level processing schemes, including integrated ALD and Atomic Layer Etching, that may circumvent or otherwise master these and other emerging challenges.

“Impact of ALE on Process Tool Design – a Tutorial,”

Mike Cooke (Oxford Instruments, USA)

Atomic layer deposition equipment began by adapting existing PECVD or CVD hardware, but quickly developed into a dedicated hardware. Atomic layer etching (ALE) has begun in the same way, using existing plasma etching tools. Will ALE follow the same path?

Process characterization for ALE and its likely development path are described, with reference to the gas residence time, chamber memory effects, and control of ion bombardment energy. The prospects for combining thermal and plasma ALE chemistries in a single chamber will be considered.

“Modeling and Simulation Approaches to Atomistic Control in Etch and Deposition Processes,”

Peter L.G. Ventzek (TEL, USA)

To achieve atomic layer and even sub-atomic layer control of materials’ topography and properties, state-of-the-art processing techniques have evolved to plasma processes that are cyclic in nature comprising two or more individual steps. They may be deposition, etch or surface conditioning steps in any order. The need for these complex processes is driven not only by the process requirements for silicon and titanium oxide/nitride materials but also “hard-to-etch” or compound materials. Sub-atomic layer materials processing is motivating the development of model based simulators/process emulators that may or may not be linked to advanced metrology. Decades of effort have resulted in simulation tools that can be integrated from chamber scale to the feature/sub-surface scale to describe wide ranges of plasma and non-plasma processes for materials modification. Helped along by increasing computation capacity and concurrent methods, process simulation tools contributed in an environment of increasing fidelity requirements. This despite the burden that they have to chase sub-angstrom fidelity requirements.

This tutorial will survey integrated modeling and simulation methodologies and their underlying principles. Keeping in mind the focus of the meeting is on precision etch, we will begin with a background discussion of the fidelity requirements for simulations/emulators. The first segment of the tutorial will focus on state-of-the-art equipment-feature scale model coupling including input data requirements. These kinds of models are well known now and include fluid, particle based and hybrid models in combination with models for electromagnetic power coupling, plasma chemistry and feature scale evolution models (e.g., cellular, string…). Historically, we could think of feature surfaces in the steady-state. Beam experiment derived, calibrated or anecdotal etch yields or sticking coefficients would make due for describing a well characterized experiment. In contrast to etch processes of old, every surface is special at each instant during a cyclic or pulsed plasma process. Sub-angstrom control means controlling plasma surface interactions at every surface all the time.

The second segment of the tutorial will focus on approaches to modeling surface chemistry during plasma surface interactions. We will look at examples of important precursor – organic surface, silicon and nitride/oxide interactions to name a few. In this segment, different methods (e.g., fundamentals-based DFT) and the physics needed to capture relevant surface interactions will be explored. Highlighted will be the importance of establishing good models of realistic surfaces and understanding the limits of idealized surface models. First principles models will be used to explore how surface conditions change during ALE and will be used to test simplified assumptions around ALE (and ALD).

We will round out this segment by introducing different microkinetic models. In the final segment, the tutorial will discuss the problem of process integration simulation in the ALE and post-ALE era. Circling back to the question of fidelity requirements, how accurate do all these models actually need to be? How do these efforts fit into the usual empirical approaches? All these modeling and simulation approaches involve enormous amounts of detail, effort and raw data. “Keeping it real,” we will discuss how models can be packaged as reduced models for process aware correction purposes.