IVS TECHNICAL WORKSHOP - ATOMIC LAYER DEPOSITION - 2010

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Abstracts

Topics for Atomic Layer Deposition Short Course

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- 1. ALD Introduction: History & ALD Overview
- 2. Al₂O₃ as Ideal Model System.
- 3. Relationship between ALD & CVD and ALD Survey
- 4. Reactors for ALD
- 5. Metal ALD Using Thermal Chemistry
- 6. ALD on Polymers
- 7. Molecular Layer Deposition of Polymers
- 8. ALD on Particles
- 9. ALD on High Aspect Ratio Structures
- 10. ALD for Engineering Materials Properties

ALD Applications for Research and Development and Implementation through to Production

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Atomic Layer Deposition (ALD) enables the fabrication of highly uniform and conformal thin films, and as such, has been adopted in a number of leading edge technologies. Due to the unique deposition process, ALD films can overcome challenges faced by traditional deposition techniques, such as conformaly depositing films less than 10nm, functionalizing difficult materials (such as plastics and graphene), and coating high-aspect ratio structures (such as DRAM trenches or porous materials). In this talk, an overview of the challenges associated with scaling ALD from R&D lab scale samples to production level systems will be outlined. Particular examples will include the coating of "high-aspect" ratio structures, ALD precursor selection and delivery and considerations for improving throughput of ALD systems. As well, examples of leading edge ALD technologies including plasma-enabled atomic layer deposition will be highlighted.

ALD from R&D to Industrial Production: Selected Examples Beyond IC Technology

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ALD has gained increased interest as a versatile coating technology in research community for various applications. This is setting a solid ground for industrial applications where highquality conformal thin films are needed. At the moment, most of the industrial ALD coating activities are still close to the semiconductor market but very recently ALD has also been applied to various non-IC technologies.

Quite often ALD processes are first developed on R&D size substrates and due to surface controlled chemistry it makes possible the scaling of the processes to bigger surface areas. Different ALD tool approaches can be designed depending on the coating thickness and speed needed in various applications. Travelling-wave batch type reactors are most common but also alternative approaches based on continuous roll-to-roll ALD as well as inline ALD can be used. When batch sizes are scaled up

to several square meters even small variations in the growth rate or slight thermal decomposition of the precursors can be detrimental. Therefore process tuning is often needed to fix the small deviations of the processes. Successful implementation of ALD from R&D scale studies to high throughput production requires solid knowhow.

Atomic Layer Deposition has many unique features, which make it an attractive thin film preparation technique for many industrial applications. Its possibility to produce pin-hole free and highly conformal thin film coatings even on complex shaped objects is often highly appreciated. The material selection is very wide, including numerous oxide and nitride materials as well as combinations and multi-layer structures of these materials. Industrial production often needs also interface modification before and

after active layers as well as integration to other process steps. More and more applications can be 'enabled by ALD' in the future. In addition to silicon substrates applications based on metal, glass and plastic substrates are emerging. Different substrates will affect also the ALD deposition mechanism and film quality. In this presentation we discuss emerging application areas where ALD has been recently utilized. Examples of these new applications outside semiconductor industry include photovoltaics, diffusion barriers, biomedical, wear resistant materials and optical coatings aiming to improve competitiveness of existing products and creating new opportunities for ALD.

Bridging Between Research and Production with ALD Technology: Selected Design Considerations

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As ALD technology has been successfully implemented into high volume manufacturing, it has been found increasingly indispensable for a wide variety of applications, thanks to the results of ever increasing research activities worldwide. More than often, however, the difficulties are found in interpreting and converting the research results into high volume production processes. This is particularly true for enterprises that depend upon the successful implementation of research results into manufacturing with minimum complications. At the beginning of research, it is characteristic to compromise reactor features for budgetary reasons. Within the academic community, obtaining a low cost tool must not compromise research flexibility, and also importantly, the validation of research results due to suboptimal tool configuration. On the other hand, for small and medium scale production, it is highly desirable to provide ALD users a flexible tool that can be used for proof of concept in the initial research and development stage and later convert into production without significantly modify the core features of their ALD equipment.

This presentation considers some of the key features that are necessary for bridging the research and production of ALD technology from the reactor design and module integration point of view. One example of a frequently encountered situation is the conversion of an existing tool from a typical R&D lab setup into a cleanroom compatible system for pilot or production use. The selection of an ALD tool must include consideration for adequate reactor design already at the initial stage to ensure particle and contamination free depositions. Some obvious requirements must be taken into consideration, including minimization of cross talk of reactants, reduction of gas turbulence and flow restrictions, and the elimination of dead pockets, among others. Developing a novel ALD process often involves the critical activity of chemical precursor evaluation. While it is relatively straightforward when using high vapor pressure chemicals, it can be particularly challenging to deliver low vapor pressure solid or liquid precursors in vapor form into the reaction chamber. Chemical clogging, source depletion, and long term stability are a few of the commonly encountered issues when transferring the process from R&D to production. A few solutions for handling small to large batch chemical precursors are discussed. Substrate handling becomes a critical requirement when transferring from R&D to production, not only for minimizing contamination, but also to ensure high productivity. The addition of wafer handling modules is a common solution. On the other hand, the ability to integrate a reactor platform with popular commercial modules can provide much easier user experience with high adaptability. Implementing industry standards, such as the SEMI standards for reactor design, is necessary to ensure the smooth integration.

In conclusion, it is highly desired to provide industry and academy with versatile ALD equipment, which can be used for both R&D and production. Careful consideration of reactor design and module integration enables viable solutions for bridging R&D results into production while maintaining low costs.

High-k Dielectric Layers for Low Power Microelectronics and Nonvolatile Memory Device

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Atomic layer deposition (ALD) enables high quality well controlled dielectric film deposition. Its use is particular important for high-k dielectric films which are crucial for low power small scale VLSI technology. Using several high k films, most noticeable HfO_2 , we have demonstrated a unique low power non volatile memory capacitor based on a stack of high k films in which we embedded Au nano particles.

The memory exhibits a superb hysteresis in its C-V characteristic, good retention properties at room temperature as well as at 80° C and interesting optical responses. Both single layer and double layer structures have been developed.

Heteroepitaxial Si/ZnO Hierarchical Nanostructures for Future Optoelectronic Devices

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The synthesis of highly-ordered ultra-dense heteroepitaxial Si/ZnO hierarchical nanostructures by a simple ALD-based approach is demonstrated. We also show, based on the same approach, the synthesis of ZnO nanoparticle-decorated Si nanowire cores and Si/ZnO conformal core-shell hetero-nanostructures. The as-synthesized ZnO nanobranches on Si nanowire cores exhibit an epitaxial relationship as (111)Si/(100) ZnO. Excellent control over the composition, dimensions, and density of ZnO branches on Si cores has been achieved. Thus, in future, this family of well-controlled, high-quality Si/ZnO hierarchical hetero-nanostructures could play a role as multifunctional candidates in the fabrication of optoelectronic devices, particularly for the development of a new generation of solar-cell devices.