Controlling Atomic Layer Deposition for Advanced Semiconductor Manufacturing

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Given the increased attention on advanced semiconductor manufacturing, interest in atomic layer deposition (ALD) as a method for fabricating structures with atomic-level control is intensifying. Based on sequential, self-limiting gas-surface reactions, ALD provides excellent capabilities for depositing thin solid films and other nanoscale materials while offering exceptional conformality, thickness control at the angstrom level, and tunable film composition. Yet despite the powerful film growth capabilities already attained with ALD, there is a compelling need to push the technique even further and control atomic placement not just in the direction of film growth, but also laterally. Area selective deposition, a bottom-up growth strategy in which deposition is directed only to desired regions of a patterned substrate, is a way of controlling atomic placement for advanced device technologies. Area selective atomic layer deposition (AS-ALD) is gaining attention for pattern features at the sub-10 nm length scale and as a way to fabricate complex 3D device structures. AS-ALD provides advantages in reduced process complexity and improved pattern fidelity. Selective deposition is also being explored for applications within fields as diverse as catalysis and optoelectronics.

Because ALD relies on self-saturating, layer-by-layer, gas-surface reactions to deposit conformal thin film materials, it is a good choice for selective deposition since its chemical specificity provides a means to achieve selectivity on a spatially patterned substrate. Moreover, inhibitory layers such as self-assembled monolayers (SAMs) can alter the native surface reactivity, further enhancing ALD selectivity. Selectivity is defined as a function of deposition on the growth surface relative to that on the non-growth surface. Our results have shown that a SAM-based process provides excellent selectivity in the deposition of thin films on a variety of substrate materials, including dielectrics and metals such as Cu, Co, W and Ru. Moreover, we have shown that small molecule inhibitors (SMIs) can also serve to achieve AS-ALD with proper selection of SMI and process parameters (Fig. 1). Several materials systems will be presented to demonstrate the capabilities of the AS-ALD approach. The important role of ALD precursor design on the selectivity will also be discussed using Al_2O_3 AS-ALD as a model. Results will show that bulkier Al precursors such as triethylaluminum are easier to block than smaller ones (e.g., the commonly used trimethylaluminum) and lead to higher selectivity.

Strategies to achieve even higher selectivity are also being developed, including repairing the inhibitory layer between ALD cycles, adding a selective etching step, or enhancing nucleation on the growth surface. We will also overview challenges that still need to be overcome in order to achieve atomic-scale precision on nanoscale patterns for advanced semiconductor devices.

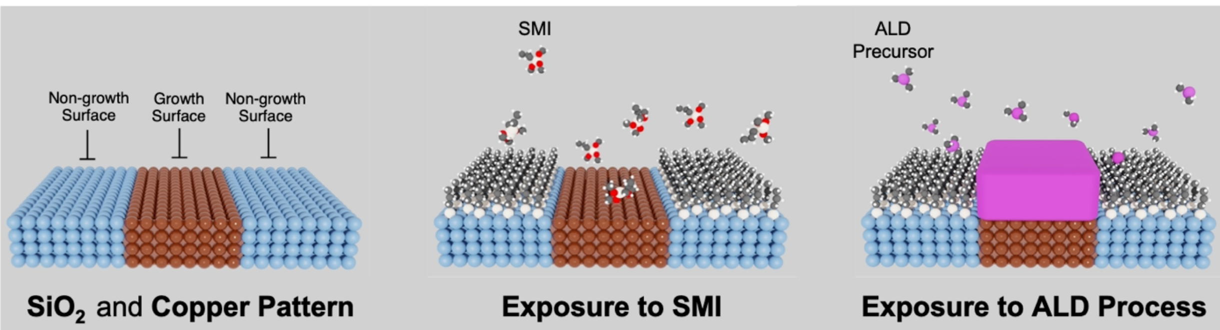

Fig. 1. Illustration of the area selective ALD processing using small molecule inhibitors (SMIs)