Conformality analysis of the archetype aluminium oxide ALD process in 3rd-generation silicon-based lateral high-aspect-ratio test structures

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Abstract

Atomic layer deposition (ALD) is the choice of the method when processing films in atomic-scale thicknesses for the most structurally demanding electronic devices as well as increasingly for catalysis and energy applications [1-3]. ALD's conformality, referring to uniform thickness and properties in three-dimensional structures, is the main reason for the growing interest in this thin film growth method.

This work expands on an earlier work on conformality analysis, where the 1st-generation microscopic lateral-high-aspect-ratio (LHAR) structures (PillarHall™) have been designed, fabricated and applied for conformality analysis [4-8]. The LHAR structures consist of a lateral gap of most typically 500 nm (targeted height) under a polysilicon membrane supported by pillars. The 3rd-generation PillarHall LHAR3 is an improved design with a lower density of support pillars, now made of silicon. In LHAR3, the lateral gap length varies from 1 to 5000 μm, giving aspect ratios (length vs height) for the typical ~500 nm gap of 2:1 to 10,000:1. The lower density of support pillars enables the removal of the polysilicon membrane e.g. by adhesive tape to expose the bottom for planar analysis; the removal of the top membrane was difficult in LHAR1. The conformality results obtained on LHAR3 have already been for kinetic modeling of the alumina and titania ALD processes [7]. This work reports further on the LHAR3 design and presents experimental data for the archetype Me3Al-H2O alumina ALD process obtained in a Picosun R-150 reactor at 300°C for various LHAR3 design splits (gap heights 100-500-2000 nm) and ALD process conditions (no. of ALD cycles and purge times) [2]. The film saturation profile was analyzed after removal of the top membrane by spectroscopic reflectometry line scans.

The saturation profile of 500 cycles of alumina in different targeted LHAR3 gap heights was obtained. As expected, the film penetrated deeper in the LHAR3 structures in the order 2000 nm > 500 nm > 100 nm gap height. Expressed as 50% penetration depth (PD50%), the dimensionless distance used, the differences almost vanished for larger-gap structures (Dimensionless distance refers to the physical measurement length x divided by the LHAR structure's gap height). The alumina saturation profile for the films of different thickness in LHAR3 of 500 nm gap was obtained. The leading front of the saturation profiles nicely overlapped. The PD50% decreased somewhat with increasing film thickness (PD50% is 230, 216, 192 for cycle numbers of 250, 500, and 1000, respectively, unpublished data). This is explained by narrowing of the gap by the film and a thereby higher aspect ratio experienced by the process [7]. The slope of the saturation profile at PD50%, analyzed against the dimensionless distance, is somewhat steeper for a thinner film.

The LHAR3 design presents a quick means to characterize the saturation profile of ALD processes and extract experimental process metrics such as the PD50% analyzed in this work. The LHAR3 design also allows one to experimentally extract slope at PD50%, which is related to the fundamental kinetics of the ALD growth process.

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