Atomic Layer Deposition of High-k Metal Oxides For Gate and Capacitor Dielectrics

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Abstract

As the integrated circuit device scale approaches a 65nm node, the need for high-k gate dielectrics to replace SiO_2 is rapidly increasing. Conventional SiO_2 gate dielectrics suffer from leakage and reliability deficiencies as the silicon oxide thickness decreases below 20Å. There is a growing need for high-k gate dielectric materials that are thermally stable with Si and provide good electrical properties.

We have developed atomic layer deposition (ALD) processes for Al_2O_3, HfO_2, TiO_2, Hf-Si-O, and nanolaminate films to replace SiO_2 for gate and/or capacitor dielectric applications. The precursors used in this study are all volatile liquids. The use of ozone allows us to process at temperatures below 300°C and provides good electrical properties.

In this paper, the ALD process conditions and resulting film properties will be discussed. Characterization of both as-deposited and annealed films will be compared, including data on the amorphous nature of the dielectric and its thermal stability. The structure of the high-k dielectric layer(s) and presence of interfacial oxide are investigated by transmission electron microscopy (TEM). Basic electrical properties are also presented on the different high-k dielectric films. The capacitance-voltage and leakage current density-voltage characteristics are examined to show the suitability of the different films compared to conventional SiO_2 gate dielectrics.

Thickness control of the thin deposited layers is critical to ensure good performance for these applications. The dependence of the growth rate on the substrate temperature and ALD cycle time parameters was observed. For the hafnium silicate film, the composition of the film can be adjusted by varying the deposition parameters as well. The effect of the film composition on electrical behavior is described.

Using a multi-chamber cluster ALD platform in our lab, aluminum and hafnium oxide-based nanolaminate films were also formed by stacking multiple layers of different film composition. Preliminary results on the dielectric properties of such nanolaminate films will be reported.

Film growth for Al_2O_3, HfO_2, and TiO_2 materials was studied by plotting the film thickness as a function of the number of precursor/oxidizer cycles. All results show excellent linearity. Conformality of film growth on non-planar surfaces was also explored.

The formation of interfacial layers in the stacked and single films was investigated using TEM measurements. Film surface morphology is investigated using atomic force microscopy.

Production capability of these processes is also demonstrated. All processes have excellent thickness repeatability, and stable low film thickness non-uniformity. Particles were controlled at low levels. The tool is capable of depositing on both 200 mm and 300 mm diameter wafers.

In summary, our studies indicate that the ozone-based ALD process is a viable approach for creating high-k dielectrics.