Nucleation, Growth and Post Deposition Annealing of Atomic Layer Deposited (ALD) High-κ Gate Dielectric Layers

M. L. Green, G. D. Wilk, B. Busch and M.-Y. Ho[1]
Agere Systems
Murray Hill, New Jersey 07974 USA
[1]National University of Singapore
Singapore 119260

High-κ gate dielectrics will be required when the SiO_2 gate dielectric thickness decreases to ~1.3 nm, if CMOS scaling is to continue, since leakage currents will be excessively high. Low leakage, low power applications, such as for portable devices, might necessitate high-κ implementation for thicker EOT's, perhaps ≤ 2.0 nm.

Table 1 is a list of criteria for the high-κ layers. Many metal oxides, silicates and aluminates, where M = Al, Zr, Hf, or Rare Earths, have been identified, which are stable on Si and have the proper dielectric constants. However, most of these candidates readily form the crystalline phase, which might be disadvantageous due to mass and electrical transport along grain boundaries. Al_2O_3, and metal aluminates or silicates with sufficient Al_2O_3 or SiO_2 content, can have an amorphous phase that is stable even after commercially important thermal budgets such as gate implant activation anneals. Fig. 1 illustrates control of Al composition in Hf-Al-O layers, enabling one to make such an amorphous gate dielectric.

The remaining major challenges that must be addressed before implementation of high-κ films can begin are the growth of thin, dense and smooth two-dimensionally continuous layers, and the control of fixed charge in these layers. This talk will address the nucleation, growth and post-deposition anneal processing required to fulfill these goals.

Although the talk will review important background work, it will focus on the atomic layer deposition (ALD) growth of HfO_2 and Hf-Al-O. The effect of various underlayers on film nucleation and growth, as measured by RBS, AFM, TOFSIMS and ellipsometry, will be presented. Underlayers may be thermally grown oxides or oxynitrides, whose ultrathin (~0.5 nm) growth may be hard to control. Chemical oxides may be thinner, but perhaps not as good electrically.

Since ALD is inherently a low temperature process, not likely to result in an uncontaminated, defect-free ceramic thin film, higher temperature anneals, in a variety of atmospheres, might be required to optimize the electrical properties of the high-κ layers. Such experimental results will also be featured in this talk.

Table 1

- Thermodynamic stability on Si with respect to formation of SiO_2 and MSi_x
- Amorphous
- $9 \leq \kappa \leq 25$
- Deposition technique should be capable of ultrathin growth control
- Conformal, two-dimensionally continuous growth
- Lower leakage current than SiO_2 at t_{ox}(eq)
- Low fixed charge ($\leq 10^{11}$ cm^{-2})
- Low D_{it} ($\leq 5x10^{10}$ $eV^{-1}cm^{-2}$)
- Many other considerations (etchability, diffusion resistance to oxygen, dopants and impurities, oxide defects, etc.)

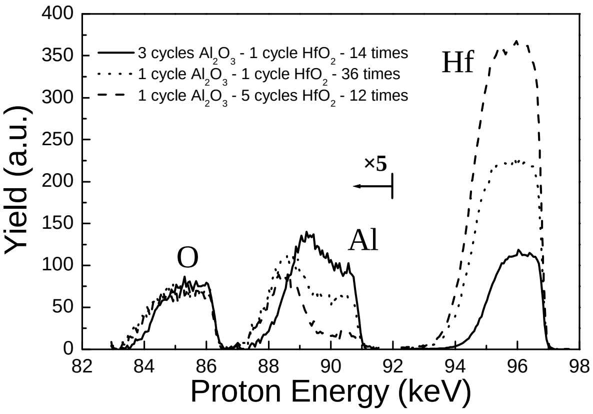

Fig. 1. MEIS spectra for ALD Hf-Al-O layers grown by varying the Al_2O_3/HfO_2 cycle ratio from 3/1 to 1/1 to 1/5, illustrating the compositional control available.