

Interfaces in Nanoelectronics

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The properties of alternative dielectrics, metal electrodes and semiconductors are under intense scrutiny because of their potential to offer greatly increased performance in nanoscale CMOS devices. To enable the rational selection of these new components, the ultrathin film and interface properties of adjoining materials must be understood at the atomic scale. There remain a variety of issues whose elucidation would greatly facilitate the integration of novel materials and structures. We will present selected results on structural, compositional, electrical, electronic band alignment and thermal stability properties of several classes of alternative (post-Si) materials. Although most results will be for planar CMOS structures, selected results for nanowires will also be presented.

In the first part of the presentation we will present results from medium energy ion scattering (MEIS). MEIS is a high-resolution, low energy version of Rutherford Backscattering (RBS). We will discuss the behavior of amorphous and polycrystalline films of materials such as HfO_2 , ZrO_2 , Y_2O_3 , etc. We will present data on their thermal stability and reactivity to adjoining semiconducting channel and gate electrode materials. We will next present recent results on the use of isotopically labeled oxygen to learn how oxygen reacts with and exchanges in the films, as oxygen chemistry appears critical to understanding defects in these systems. The third class of systems that we will discuss is epitaxial crystalline oxide thin films such as SrTiO_3/Si and $\text{Sc}_2\text{O}_3/\text{Si}$. Finally, the stability of dielectrics on alternative channel materials (Ge and GaAs) will be presented.

In the second part we will focus on band alignment at individual interfaces as well as across multilayer stacks to ensure proper device performance, including low leakage currents and appropriate threshold voltages. An understanding of the relevant energies, particularly the role played by interface dipoles, may enable the tuning of band offsets and effective work functions at interfaces. Band offset and DOS results of studies using direct, inverse and internal photoemission will be presented for a series of structures comprised of different metals (Ru, Al, Ti, Ni), dielectrics (HfO_2 , SiO_2 and $\text{Hf}_x\text{Si}_{1-x}\text{O}_2$) and semiconductors (Si, Ge and GaAs). The band offsets we measure for the metal/oxide and oxide/semiconductor interfaces are, to first order, in agreement with a modified Schottky-Mott model. But as expected, the results reveal more complicated interfaces, and in particular strong chemical effects in some cases on the entire stacks after metal deposition. Both Ru and Al induce an energy shift of the core, valence and conduction band levels of an adjoining material: Ru stays metallic upon deposition on the oxide, whereas Al is shown to become oxidized. We also present complimentary analysis using electrical methods, electron and scanning probe microscopy, and theory.

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