Nano- and Micro-Electronic Materials Characterization

As the scale of electronic devices is reduced, tools for characterizing materials properties and behavior at the nano- and micro-scale are required. We are developing and characterizing techniques to measure local properties, e.g., texture, strain, chemical homogeneity, and phase evolution, in materials used in nano- and micro-electronic systems.

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The characterization of nano- and micro-electronic materials requires different techniques than those used for bulk electronic materials. For example, optimizing the properties of multilayer systems requires knowledge of the structure and composition of interfaces at nearly atomic resolution. In ferroelectric thin films for ferroelectric random access memory (FRAM), local texture is known to have a significant effect on fatigue and imprint. The origin of strains at phase interfaces that cause microcracking can be determined from the structure of the surface near the crack. Examples of our research addressing these issues are highlighted below.

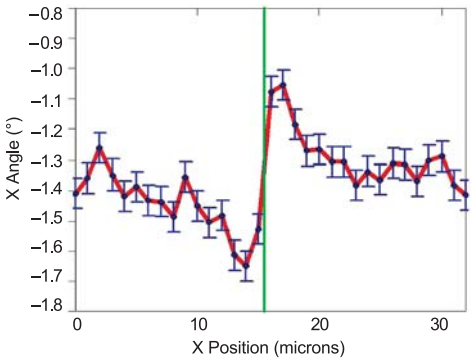

Figure 1: *Average tilt angle of lattice planes of $Al_xGa_{1-x}N$ thin films versus distance from a crack.*

A road block in the application of $Al_xGa_{1-x}N$ as light sources and detectors is the development of cracks during deposition of the films. Electron back-scatter diffraction (EBSD) was used to characterize the misorientation around individual cracks in 0.25 µm – 1.2 µm thick AlGaN films on (111) silicon substrates. EBSD showed that the orientation of the AlGaN in the vicinity of each crack changed so that lattice planes in the film tilted away from the crack causing uplift of the specimen surface, which was also seen by atomic force microscopy (AFM). The basal plane orientation change across the cracks was typically 0.6° (Figure 1) with a measurement accuracy of the order of 0.05°. The width of the strain field varied from 2 µm to 15 µm in different specimens.

The presence of impurities or an intergranular liquid phase can significantly alter properties by affecting the motion of grain boundaries and transport or conductivity between grains. We have studied the influence of boundary misorientation and chemistry on the velocity of interfaces in $SrTiO_3$ single crystals of varying orientations. Crystals were bonded to dense textured polycrystalline $SrTiO_3$ ceramics; upon heating, the interface migrates into the ceramic. This experiment allows the isolation of key variables including crystallographic misorientation, impurity content, curvature, and boundary energy, leading to control over the nature of the grain boundaries, and the potential for improved properties.

Piezo-force microscopy (PFM) is used for characterizing individual domain orientations and the piezoelectric coefficient of ferroelectric thin films. Interpretation of results is complicated by highly localized, short-range interactions acting at the tip, as well as long-range interactions acting along the lever. The resulting distributed loads change the load applied at the tip by a factor of ≈ 3/8. Of greater importance is the impact of distributed loading on the angle along the lever. PFM measurements of piezoactuation can differ substantially from the true piezoactuation under conditions that have been modeled. Model calculations are supported by AFM measurements performed with interferometric lever detection and by PFM measurements on lead zirconate titanate thin films and triglycine sulfate crystals.

Silicon oxide-nitride-oxide multilayers are potential materials for charge storage structures in non-volatile memory devices; individual layers are 5 nm to 10 nm thick. Thorough microscopic examination of multilayers using electron energy loss spectroscopy, secondary ion mass spectrometry, and x-ray absorption spectroscopy revealed numerous details of the interface structure as a function of processing. There is a broadening of the nitrogen distribution across the nitride/oxide interfaces and reduction of the hydrogen content with increasing thermal budget in processing the top oxide. Also, radial-distribution functions are similar for differently processed silicon oxide layers.

Contributors and Collaborators

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