Correlations Between Structure and Physical Properties in Metallic Superlattices

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Many of the physical properties of superlattices are strongly affected by subtle structural and chemical changes as a function of layer thickness. Examples of these type of changes are correlations between elastic anomalies and lattice expansions, changes in the giant magnetoresistance due to interfacial roughness and the effect of interdiffusion on the decrease in superconducting transition temperature in high Tc superconductors. It is therefore of great importance to determine the structure of thin films and superlattices quantitatively, with high accuracy, at atomic length scales. We have developed a structural refinement method which allows the quantitative determination of structural disorder in superlattices. We present first a number of model calculations which give counterintuitive results. One such model calculation implies that structural disorder broadens diffraction line widths contrary to naive expectation. This then forms the basis for structural refinement in which the detailed line shapes are fit to obtain a quantitative determination of a variety of disorder parameters. The parameters obtained from the refinement were found to be in good quantitative agreement with other independent determinations.

We have been dedicated for a number of years to exhaustive studies connecting structural and physical properties using the principal growth techniques (MBE and sputtering), quantitative characterization techniques (ex-situ X-ray and electron diffraction, transmission and scanning electron microscopy, and in-situ surface analytical techniques and scanning tunneling microscopy) combined with transport, optical and magnetic measurements. Recent highlights of this work include; 1) studies of the connection between structure and transport in MBE and sputtered magnetic/normal superlattices, 2) observation of superlattice effects in the transport of magnetic/magnetic superlattices, 3) development of a widely used refinement technique for structure of superlattices using X-ray diffraction, and 4) growth of antiferromagnetic-ferromagnetic bilayers with the highest exchange bias observed in thin films.

I will describe several examples of current research in which the structure and physical properties in metallic superlattices are intimately related; i.e. magnetism and superconductivity. A structural refinement technique was used to determine quantitatively interfacial strains and interdiffusion in superconducting thin films and superlattices. Films with roughness smaller than one unit cell were prepared using an improvement of the on-axis magnetron sputtering techniques. A novel technique was developed and used to prepare oxygen deficient ceramic films with sharp transition temperatures. These films were used to study the changes in the superconducting transition temperature as a function of thickness and to study the superconducting coupling across a nonsuperconducting material. The magnetism and magnetotransport in magnetic multilayers is strongly affected by the structural properties of the interface. Structural aspects which strongly influence these properties include the roughness, crystallinity and crystallographic orientation. I will describe a series of experiments in which we have observed large changes in the magnetotransport and magnetism of multilayers involving magnetic-normal, magnetic antiferromagnetic and magnetic-magnetic interfaces.

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