"Nanoscale Mechanical Characterization of Graphene–Polymer Nanocomposites using Atomic Force Microscopy"

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Abstract

This thesis focuses on the study of the static and dynamic magnetic interactions in ferromagnetic/nonmagnetic heterostructures using interface-specific and time-resolved optical techniques. The goal of this thesis is to elucidate the interface exchange coupling, magnetic anisotropy, and coherent spin dynamics in these advanced material systems, crucial to the realization of high performance spintronic devices.

First, the ferromagnet/oxide interface of Fe/MgO is studied using magnetic second harmonic generation. We identify an exchange bias (EB) phenomenon manifested in the interface spin system – the hysteresis loop is shifted entirely to one side of the zero magnetic field axis. The bulk magnetization does not, in marked contrast to typical systems where EB is manifested only in the net magnetization. This reveals existence of antiferromagnetic (AF) magnetizations at the interface. We control the EB magnitude by varying the interface oxygen concentration and Fe-O bonding. Thus, we identify FeO nanoclusters as the origin of AF pinning sites that exist even for a nominally "clean" interface. These results demonstrate that atomic moments at the interface are non- collinear with the bulk magnetization, and can serve as spin scattering sites to reduce the tunneling magnetoresistance. Temperature and strain dependent studies show that the lattice mismatch between MgO and Fe enhances the blocking temperature above room temperature. Our results have broad implications for understanding ferromagnet/oxide heterostructures, and provide new insights into the interface spin system and exchange bias.

Second, the magnetization reversal process within the first two iron layers at the Fe/GaAs(001) interface is found to be different and independent from the Fe bulk, as measured by magnetic second-harmonic generation and magneto-optical Kerr effect, respectively. The interface magnetization is largely noncollinear from the bulk with an abrupt magnetic boundary and an anisotropic exchange coupling stiffness, weak inter-layer coupling but relatively strong intra-layer stiffness. In contrast, Fe/GaAs(110) exhibits a rigid coupling between interface and bulk magnetization suggesting that the interfacial bonding structure can dramatically change the nature of the exchange coupling. Moreover, the uniaxial magnetic anisotropy in Fe/GaAs(001) extends from the interface to the first 5 nm in the Fe bulk and is induced by stress. These results are consistent with the observation of noncollinear alignment of interface and bulk magnetization in Fe/MgO(001), and also relevant to other magnetic/non-magnetic interfaces with abrupt chemical bond structures.

Last, the relaxation mechanism of coherent spin precession is investigated in single crystalline Fe/CoO/MgO(001) heterostructure by time-resolved magneto-optical Kerr effect. At 78K, the intrinsic damping property is enhanced by frozen AF spins in CoO layer for thicknesses of 2.5 nm and 4 nm. In contrast, at room temperature or for thicknesses of 1 nm and 1.5 nm, the damping process is dominated by a dephasing effect caused by disordered AF spin clusters which show a strong dependence on the magnetic field.