Electronic Structure of Single Crystal Magnetostrictive $Fe_{1-x}Ga_x$ Films

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Bulk $Fe_{1-x}Ga_x$ alloys have generated recent interest because of their unique magnetostrictive properties. Of particular appeal is the large and anisotropic behavior of the magnetostriction constant $(3/2)\lambda_{100}$ as a function of Ga concentration, where a double peak with values exceeding 400 ppm are measured. The first peak near x = 0.19 is due to a maximum in the magnetoelastic coupling constant, B_1, while the second peak near x = 0.27 is related to the softening of the elastic shear constant, $(c_{11} - c_{12})/2$, as a result of the crystal undergoing a bcc to bct transition. In thin film form, the atomic pinning of a highly magnetostrictive material to a substrate, along with the subsequent application of a magnetic field, will impart an anisotropic stress in the film that will modify the magnetic properties of the film including the magnetic anisotropy and magnetization dynamics (damping coefficient). Furthermore, these properties should be externally controllable with a small field or by deposition on a suitable piezoelectric substrate.

Single crystal $Fe_{1-x}Ga_x$ thin films (~20 nm) of various Ga concentrations were prepared on GaAs(001) and MgO(001) substrates by molecular beam epitaxy (MBE), with and without ZnSe buffer layers, respectively. X-ray magnetic circular dichroism (XMCD) measurements performed at the Fe $L_{2,3}$-edges reveal a very gradual decrease (10%) in the elemental Fe moment as the Ga concentration approaches 20% followed by a precipitous drop in moment for higher concentrations, while X-ray absorption spectroscopy (XAS) and XMCD measurements performed on the Ga $L_{2,3}$-edges show an evolution in the local Ga electronic structure and establishes an induced moment in the gallium of 0.1 μ_B anti-aligned to the Fe moment, in remarkably strong agreement with *ab-initio* density functional (GGA) calculations. Angle-dependent ferromagnetic resonance (FMR), rotational magneto-optic Kerr effect (ROTMOKE), and magnetometry measurements on both sets of samples show that the films deposited on MgO exhibit a purely cubic anisotropy, while those films deposited on GaAs show the presence of a strong uniaxial anisotropy in addition to the cubic term. More importantly, we find that the anisotropy coefficients for these pinned thin films are dependent on the magnitude and direction of the applied magnetic field. The differences in the magnetic responses of $Fe_{1-x}Ga_x$ thin films from their bulk properties, namely the uniaxial anisotropy for depositions on GaAs and the reduced concentration at which K_1 switches sign for depositions on MgO, will be explained from the differences in evaluating thin film and bulk magnetostriction.