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Authors

McClure, A.

Cao, J.

Wu, R.

et al.

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Magnetostrictive Effect in Single Crystal Fe_{1-x}Ga_x Thin Films

*A. McClure*¹; *J. Cao*²; *R. Wu*²; *E. Arenholz*³; *Y. Idzerda*¹

1. Physics, Montana State University, Bozeman, MT, USA.
2. Physics and Astronomy, UC Irvine, Irvine, CA, USA.
3. Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Bulk Fe_{1-x}Ga_x alloys have generated recent interest because of their large and anisotropic behavior of the magnetostriction as a function of Ga concentration, where $(3/2)\lambda_{100}$ features a double peak with values exceeding 400 ppm [1,2] under a small applied field [3]. 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, controllable by the magnetic field, which may modify the magnetic properties of the film including the magnetic anisotropy and magnetization dynamics.

Single crystal Fe_{1-x}Ga_x thin films (~20 nm) of various Ga concentrations were prepared on GaAs(001), with a ZnSe buffer layer, and MgO(001) substrates by molecular beam epitaxy (MBE). For the depositions on GaAs, reflection high energy electron diffraction (RHEED) measurements, performed in-situ during the growth, show single crystal epitaxial growth of the bcc structure for alloy compositions up to at least $x = 0.6$, while RHEED and vibrating sample magnetometry (VSM) measurements reveal a stability limit of about $x = 0.45$ for the depositions on the MgO substrates. Both substrates stabilize the bcc structure well beyond the bulk limit of about 27% Ga. As shown in Figure 1, VSM measurements on samples deposited on both substrates show a similar reduction in the saturation magnetization with the incorporation of Ga, however the samples' magnetic hysteresis loops demonstrate very different responses to the applied magnetic field. From the top two panels of Figure 1, it is clear that the films grown on MgO(001) have a purely cubic anisotropy, whereas the films deposited on the directionally bonded ZnSe(001) buffer layer feature a strong uniaxial anisotropy. As can be seen in the left two panels, the easy axis of magnetization has switched from [100] for Fe_{0.85}Ga_{0.15} to [110] for Fe_{0.825}Ga_{0.175} samples deposited on the MgO substrates. This signals that the cubic anisotropy constant, K_1 , has become negative by 17.5% Ga, in contrast to bulk Fe_{1-x}Ga_x alloys where K_1 switches sign near 20% Ga [4]. The reduction in the saturation magnetization with Ga concentration for the Fe_{1-x}Ga_x samples (lower right panel) closely follows a simple dilution model up to a concentration of 20% Ga where the total moment falls more abruptly than simple dilution would allow. X-ray magnetic circular dichroism (XMCD) performed at the Fe L_{2,3}-edges reveals 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 (a narrowing of 1.6 eV in the L₃ peak position) 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 calculations.

The reasons for the differences in the magnetic properties of Fe_{1-x}Ga_x thin films from

their bulk properties, namely the single peak in the $(3/2)\lambda_{100}$ for thin films, the greatly reduced peak value for $(3/2)\lambda_{100}$ due to substrate pinning, the uniaxial anisotropy for depositions on GaAs and the reduced concentration at which K_1 switches sign for depositions on MgO, will be discussed.

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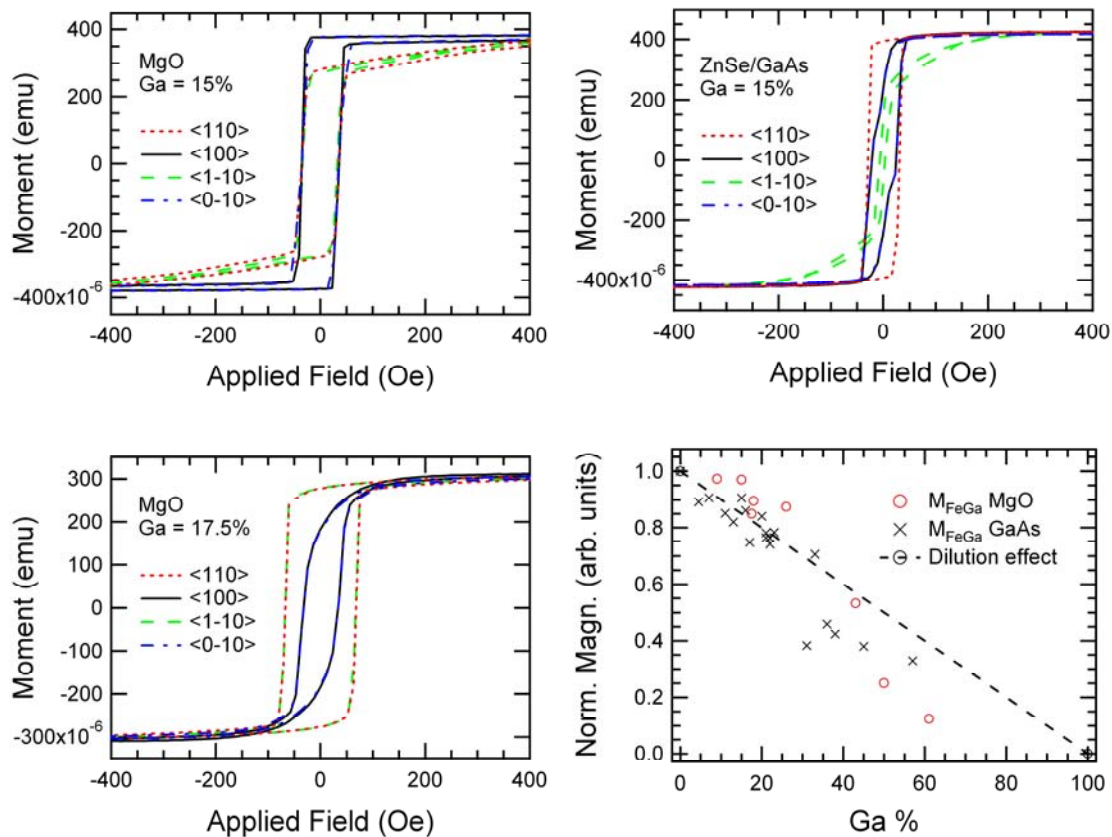


Figure 1: (Lower right panel) The magnetization values for $Fe_{1-x}Ga_x$ single crystal thin films deposited on ZnSe/GaAs(001) and MgO(001) substrates. The dotted line represents the expected decrease in magnetization if the Ga substitution simply diluted the Fe matrix. (Upper Panels) Hysteresis loops for $Fe_{0.85}Ga_{0.15}$ thin films deposited on (Upper left) MgO and (Upper right) ZnSe/GaAs substrates. The MgO depositions result in a purely cubic anisotropy, while the GaAs depositions show the presence of an additional uniaxial anisotropy as indicated by the inequivalence between the $\langle 110 \rangle$ and $\langle 1-10 \rangle$ axes. (Lower left panel) Hysteresis loops for $Fe_{0.825}Ga_{0.175}$ thin films deposited on MgO demonstrating the change in the easy axis direction (change in sign of K_1).