Research Highlight

Unusual In-plane Anisotropies in Fe/GaAs (001)

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Ferromagnetic Fe/GaAs (001) thin films are among the most promising heterostructures for potential ‘spintronics’ applications, and a large number of studies have been devoted to this system in recent years. Fe grows epitaxially on GaAs (001) with a cube-on-cube orientation due to a relatively small mismatch of -1.4% in lattice parameters between Fe (a_{Fe}= 0.28664 nm) and GaAs (a_{GaAs} = 0.56537 nm) as long as half the lattice constant of GaAs is considered. When the film thickness is less than about 60 monolayers or 9 nm, Fe/GaAs (001) exhibits a remarkable and unexpected in-plane uniaxial magnetic anisotropy (UMA) with a [110] easy axis [1]. This is dramatically different from the cubic magnetic anisotropy of bulk bcc Fe with <100> easy axes, and its origin has remained one of the unanswered fundamental questions in ferromagnetic thin film studies over the past fifteen years.

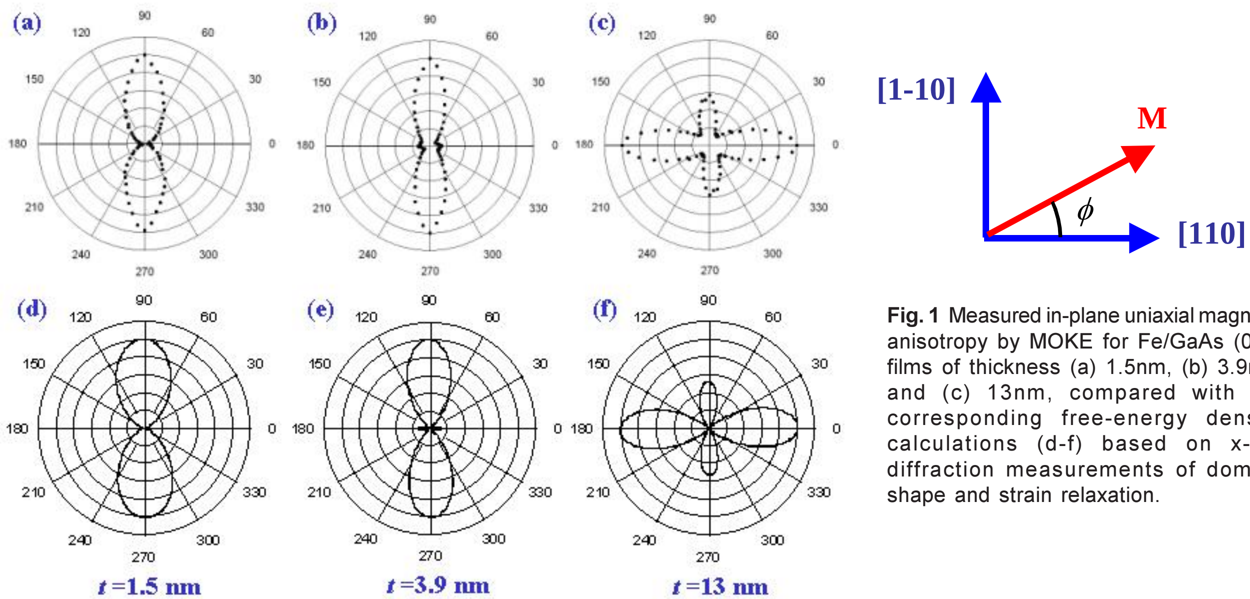

Fig. 1 Measured in-plane uniaxial magnetic anisotropy by MOKE for Fe/GaAs (001) films of thickness (a) 1.5nm, (b) 3.9nm, and (c) 13nm, compared with the corresponding free-energy density calculations (d-f) based on x-ray diffraction measurements of domain shape and strain relaxation.

Magnetic anisotropy represents the orientational dependence of free energy density with respect to magnetization direction, and can be measured by magneto-optic Kerr effect (MOKE) as shown in Fig.1(a-c) for the Fe/GaAs system. Different contributions to the total energy may include magneto-crystalline anisotropy, demagnetizing field energy (shape anisotropy), magneto-elastic coupling energy, plus additional surface and interface terms in order to take into account deviations from the bulk behavior. However, none of these terms provide quantitative and definitive results for the Fe/GaAs (001) system.

In a grazing-incidence x-ray diffraction experiment [2] performed by Olivier Thomas (Université Aix-Marseille, France) et al. at CHESS F3 station, an unusual anisotropy in in-plane domain shape and elastic strain relaxation has been observed in Fe/GaAs (001) thin films, which has led to an unambiguous explanation of the UMA in this important system. As shown in Fig.2, the in-plane reciprocal space maps around the (220) and the (2-20) reflections for Fe thickness of 1.5 nm and 13 nm indicate that for thinner films the Fe domains or islands are elongated along the [1-10] direction and are pseudomorphous with the GaAs substrate. For thicker films, not only is the Fe film relaxed, which is well-known in all epitaxy thin films, but also the strain relaxation is anisotropic, with a greater relaxation along [110]. Furthermore, as shown in Fig. 3, the domain shape anisotropy is reversed from elongation along the [1-10] to along the [110] in the thicker films. Given the possibility of plastic deformation mediated by misfit dislocations, the domain sizes observed here can be interpreted as the average spacings between the dislocations.

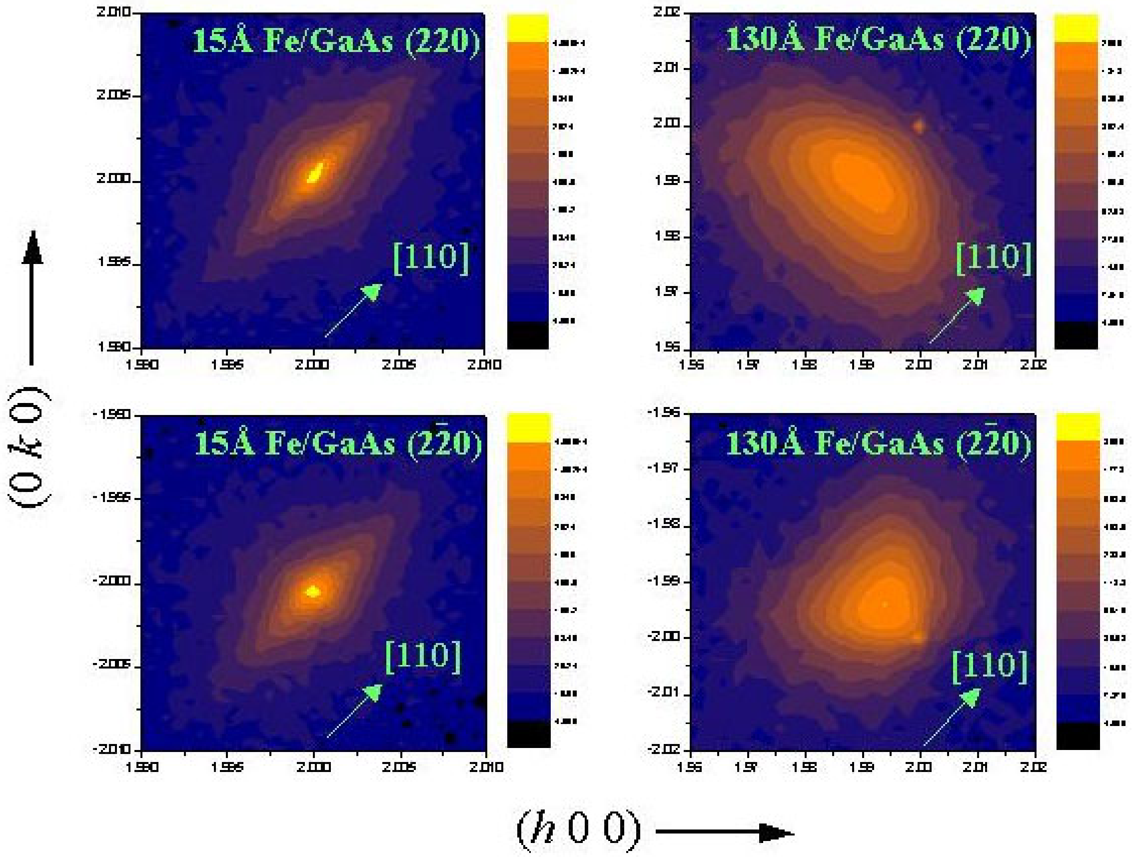

Fig. 2 In-plane reciprocal space maps of (220) and (2-20) reflections measured by grazing incidence x-ray diffraction on Fe/GaAs(001) thin films of 1.5nm and 13nm thick. For convenience, GaAs reciprocal space units are used. The sharp peaks at (220) and (2-20) are from the substrate GaAs. These maps show clear anisotropies in domain/island size and strain relaxation in the Fe films.

With these and additional measurements for Fe films of intermediate thickness, Thomas et al. conclude that considerable strain and shape anisotropies do exist in these Fe thin films that should affect the in-plane magnetic anisotropy. However, these structural anisotropies are more pronounced for the thicker films investigated, and therefore cannot be the principal causes for the UMA in the thinner films. Using the x-ray measured domain sizes and strain tensors through magneto-elastic coupling, a careful free-energy analysis involving all possible effects indicates that (1) the interfacial effect, with interface uniaxial coefficient $K_u = 1\times10^{-4}$ J m^{-2}, is the principal contributor to the observed UMA for thin Fe films, and (2) the measured anisotropic strain tensor with [110] and [1-10] being the principal axes is responsible for the reversal of UMA in thicker Fe films. These results, as illustrated in Fig.1(d-f), show excellent agreements with the in-plane magnetization-energy integrals measured using MOKE and provide a clear overall picture of how different contributions affect the in-plane uniaxial magnetic anisotropy in the Fe/GaAs (001) system.

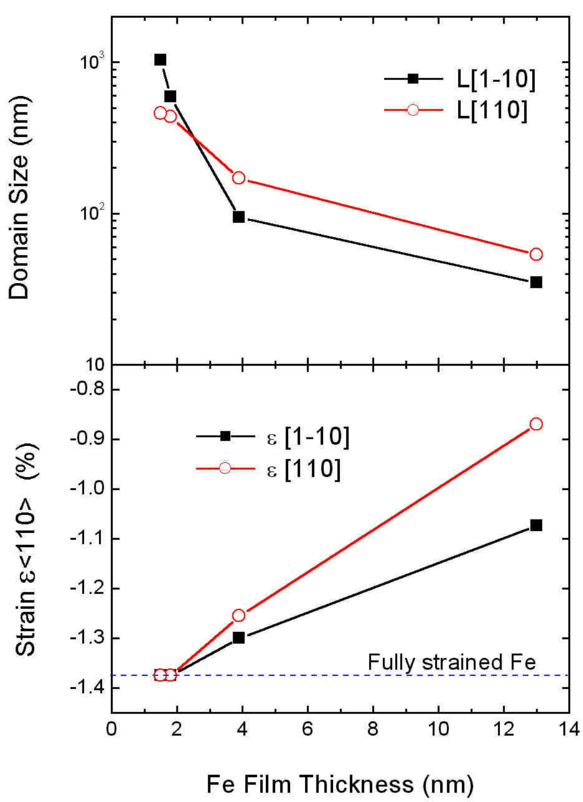

Fig. 3 Domain shape and strain anisotropies observed by grazing incidence x-ray diffraction on Fe/GaAs as a function of Fe film thickness.

References

[1] J. Krebs, B. Jonker, G. Prinz, J. Appl. Phys. 61, 2596 (1987).
[2] O. Thomas, Q. Shen, P. Schieffer, N. Tournerie, B. Lépine, Phys. Rev. Lett., in press (2002).