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Effect of Magnetic and Material Structure on Epitaxial Garnet Coercivity

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Abstract. The stress dependent magnetic parameters of epitaxial garnet films were measured. Lattice distortion was found to have a significant effect on the uniaxial anisotropy constant and on the domain wall parameters. Although coercive properties are also expected to be sensitive to mechanical stress, this effect was not revealed because of the different individual properties of the samples. A method is suggested for determining the stress dependence of coercivity, measured on the same sample. Present results show the primary effect of material structure on the domain wall coercive field. The effect of modifying magnetic parameters is weaker, though it also leads to a change in coercivity.

Epitaxial magnetic garnet films play an important role in the study of basic magnetization processes. The stress dependent magnetic parameters of epitaxial garnet films were previously measured as a function of lattice mismatch in a series of samples [1]. Lattice distortion - due to the different sizes of the substituting ions in the crystal lattice - was found to have a significant effect on the uniaxial anisotropy constant and on the domain wall parameters. Although coercivity - a very important parameter in any application of magnetic materials - was also expected to be sensitive to mechanical stress through the domain wall parameters, this effect was not revealed. A possible explanation is that the measurements were performed on a series of samples with different individual properties (originating in the slightly different growth conditions), which blurred the effect.

The aim of this work is to find a direct, empirical correlation between the mechanical distortion of the lattice - due to lattice mismatch - and the coercive properties of the material.

For the measurements epitaxial garnet films with the nominal composition $(\text{YSmCa})_3(\text{FeGe})_5\text{O}_{12}$ were used. The films were grown by liquid phase epitaxy, (LPE) on (111) oriented $\text{Gd}_3\text{Ga}_5\text{O}_{12}$ (GGG) substrates [2]. The thickness of the films, h , was $5 \pm 0.5 \mu\text{m}$; the saturation magnetic polarisation, $J_s (= \mu_0 M_s)$, was $20 \pm 2 \text{ mT}$. The lattice mismatch, Δa , was measured by X-ray diffraction [3], with an accuracy of $3 \times 10^{-5} \text{ nm}$; anisotropy, K_u , was measured by a magneto-optical method [4], with an accuracy of 15 J/m^3 . H_{CW} , the domain wall coercive field of the samples was measured by low frequency domain wall oscillation [5], with an accuracy of 4 A/m .

H_{CW} and K_u were measured on a series of samples, as a function of Δa ; K_u increases linearly with increasing Δa . A knowledge of the exchange constant, A and of K_u enables us to calculate the domain wall energy density γ_w and the thickness of the domain wall δ_w , based on the expressions $\gamma_w = 4(AK_u)^{1/2}$ and $\delta_w = \pi(A/K_u)^{1/2}$. Taking the values of K_u from the measurement, as a function of Δa , and supposing that A is not a function of the stresses, the dependence of domain wall energy and domain wall width on the lattice mismatch is obtained. The value of A is taken from the literature [6]. These correlations are shown in Fig. 1. It is seen that the domain wall energy definitely increases, whereas domain wall width decreases with increasing lattice mismatch.

The parameters of the domain walls are very closely correlated with the coercive properties of the samples. Consequently, an increase of coercivity should have been found with increasing lattice mismatch. But measurements did not reveal any correlation between coercive field and Δa . The scatter of H_{CW} values is too high to observe any dependence. The cause of the above mentioned discrepancy is the very strong influence of the growth conditions on the structural properties of the samples. This effect is significantly stronger than the modification of magnetic parameters because of the mechanical stress, in view of which the weaker dependence of the coercivity on the lattice mismatch is not seen.

To reveal the direct correlation between coercive field and mechanical stress, the magnetic parameters should be measured in the same sample, having different lattice distortion. Relaxation of the mechanical stress, without modifying the crystal structure and other magnetic parameters of the film, was performed by thinning the substrate from the rear.

Figure 1: Domain wall energy, γ_w , and domain wall density, δ_w , as a function of the lattice mismatch, Δa

Figure 2: Coercive field, H_{cw} , of samples A-C as a function of substrate thickness T

This procedure was carried out on three different garnet films (samples A-C). The substrate was removed in three successive steps, after each of which all magnetic parameters were remeasured. Figs. 2 and 3 show the dependence of H_{cw} and K_u on the substrate thickness. The previously found $K_u(\Delta a)$ dependence and the results shown in Figs. 2 and 3 make it possible to obtain the wanted $H_{cw}(\Delta a)$ correlation for the three thinned samples (see Fig. 4).

Figure 3: Uniaxial anisotropy constant, K_u , of samples A-C, as a function of substrate thickness T

Figure 4: Coercive field, H_{cw} , of samples A-C as a function of lattice mismatch, Δa

In this way a quantitative, empirical correlation was found between the lattice mismatch and the domain wall coercive field, H_{cw} . As expected, H_{cw} increases with increasing lattice mismatch. The slope is nearly the same for all the investigated samples. The results show the primary effect of the material structure on the domain wall coercive field. The effect of modifying the magnetic parameters is weaker, though it also leads to a change in the coercivity; however, this is measurable only by appropriate processing on the same sample.

The measurements support the idea that coercivity is the parameter which is most dependent on the individual properties of different, although similarly grown samples. Such measurements also provide a useful means of showing how the influence of the two different sources of coercivity (material imperfections and domain wall parameters) can be distinguished.

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