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Magnetization processes and magnetic domain structure in weakly coupled GdCo/Si/Co trilayers

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ABSTRACT

The magnetization reversal in weakly coupled GdCo(13 nm)/Si(0.8 – 2 nm)/Co(8 nm) trilayers has been studied by conventional magnetometry and layer-selective Kerr microscopy. In a very weakly coupled trilayer system the Co layer reverses by the propagation of 180°-walls and the GdCo layer remagnetises by the nucleation and growth of patch-like domains nucleating at 360°-walls. A decrease of the non-magnetic separating layer thickness results in the magnetization reversal of both layers as a whole at low fields. Further field increase induces a magnetization reversal of the GdCo layer by the nucleation and growth of domains acting against the interlayer coupling.

1. Introduction

Exchange coupled bilayers, consisting of two magnetic films of different magnetic hardness can be regarded as model materials for nanostructured composites containing exchange coupled hard and soft magnetic phases. Such magnetic materials can be used as permanent magnets with giant magnetic energy production [1]. In bilayer systems where one or both layers are heavy rare earth (RE)–3*d* transition metal (TM) amorphous ferrimagnetic alloys, interesting phenomena have been observed. In particular, it has been demonstrated that for bilayer structures exhibiting an antiferromagnetic interface exchange coupling both positive and negative exchange bias field values can be obtained [2–4].

The magnetic properties of the ferrimagnetic layers can easily be tuned by changing the composition, allowing for a variety of magnetic configurations in bilayers. For example, in the case of RE-rich composition the resultant magnetization is dominated by the RE element over a large temperature range [5] and the magnetization of the RE–TM layer is parallel to the magnetic moments of RE. If a TM layer or a TM-rich RE–TM layer is chosen as the second layer in the bilayer structure, an antiparallel alignment is present between the two layers' net magnetizations because the interlayer exchange coupling is dominated by the TM–TM ferromagnetic interaction [4,6,7]. In large applied fields, the magnetizations of the two layers are forced to align parallel to each other and a parallel-to-plane domain wall forms at the interface between the two layers as a result of the competition between TM–TM interfacial exchange and Zeeman energy [6,8]. However, if both the soft and the hard layers are thin, the magnetic moments in both layers reverse simultaneously under an external field due to the strong direct exchange interaction at the hard/soft magnetic layer interface [9]. In turn, the interfacial exchange coupling can be modulated by inserting a very thin nonmagnetic spacer between the two magnetic layers [10,11]. The spacer strongly reduces the coupling strength and allows a successive magnetization reversal of the layers [12].

A similar situation occurs, when ferrimagnetic/nonmagnetic spacer/ferromagnetic trilayers with thin layer thicknesses are used, for example, in spin-valve structures and magnetic tunnel junctions [13–15]. In these devices the thickness of the nonmagnetic spacer is such that there is a weak ferromagnetic coupling between the magnetic layers, which continues to influence to a certain degree the magnetization processes of the layers [16]. In order to understand the features of the magnetization reversal mechanisms in these devices the domain structures were studied by transition electron microscopy and optical Kerr microscopy [16–19]. However, in these works only structures with weakly ferromagnetically coupled layers of the same composition (FeNi) were examined.

In the present work the magnetization processes and domain structures in a sputtered GdCo/Si/Co trilayer were comparatively analysed using the data of conventional magnetometry and layer-selective Kerr microscopy and magnetometry [20].

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2. Experimental

The GdCo(13 nm)/Si/Co(8 nm) layered films were deposited onto glass substrates at room temperature using three-target RF sputtering. A mosaic Gd–Co target was used for the preparation of GdCo layers of different compositions. The background pressure was 3×10^{-7} mbar and the deposition was performed in Ar atmosphere with a partial pressure of 3×10^{-3} mbar. The thickness of the Si spacer ranged from 0.8 to 2 nm. Finally, an additional 3 nm Si layer was deposited on the top of the samples as protective layer. The nonmagnetic Si spacer was chosen because it reduces the interlayer coupling more effectively than nonmagnetic metal spacers [21]. At the same time its effect on the penetration of light into the sample is smaller. A magnetic field of 7.9 kA/m was applied during deposition to induce an in-plane uniaxial magnetic anisotropy. X-ray diffraction patterns indicated that the Co layer exhibited a hcp (0 0 2) crystalline texture with grain size in the order of 10 nm and the GdCo layer was amorphous. The surface root-mean-square roughness of the sample was measured by atomic force microscopy and its value was aprox. 0.5 nm. The magnetization hysteresis loops were measured along the easy axis direction by a vibrating sample magnetometer (VSM) and a conventional magneto-optical Kerr (MOKE) magnetometer operated in the longitudinal mode. Moreover, the hysteresis loops were also measured in a Kerr microscope by plotting the average image intensity as a function of magnetic field. Layer-selective domain imaging and magnetometry was achieved by adjusting the phase of the magneto-optical Kerr amplitude by means of a rotatable compensator [20].

3. Results and discussion

Fig. 1 shows magnetization curves and magnetic domains obtained for a GdCo(13 nm)/Si(2 nm)/Co(8 nm) sample. The GdCo layer composition in this case is very close to the "compensation" composition (~20 at.% Gd), but it is Gd-rich, i.e. the magnetic moment of the Gd-sublattice dominates over that of the Co-sublattice. The direction of the Gd-sublattice moment is thus in the same direction as the total moment of the GdCo-film. This GdCo/Si/Co trilayer is characterized by a peculiar magneto-optical magnetization curve (Fig. 1a). The estimated penetration depth of the employed visible white light is about 30–40 nm [7], resulting in an information depth of half that range (the light has to travel back to surface for detection). Therefore, in this figure both, the GdCo and Co layers contribute to the Kerr signal. When we follow the hysteresis curve in accordance with the indicated arrows, the following order of macrospin configuration is observed:

(i) In positive field the magnetic moments of the Gd-sublattice and that of the Co-layer are parallel to the external field. Consequently, the cobalt moments in the Co-layer and GdCo-layer are opposite. As the Kerr signal is generated solely by the cobalt moment (not gadolinium), a weak overall signal is measured.

(ii) At a small negative field of about 1 kA/m, the Co layer is remagnetized abruptly. The cobalt moments of both layers are now parallel, leading to a strong Kerr signal.

(iii) In stronger negative field the total moment of the GdCo-layer finally follows the external field direction as well. This leads to a reversal of both, the Co- and Gd-sublattices in the GdCo-film. The cobalt moments of the layers are then antiparallel again, resulting in a weak Kerr signal. On the backward branch the process is analogous.

Fig. 1b shows the VSM-loop for this sample. Considering the ratio of the layer thicknesses and magnetizations (~1400 kA/m and

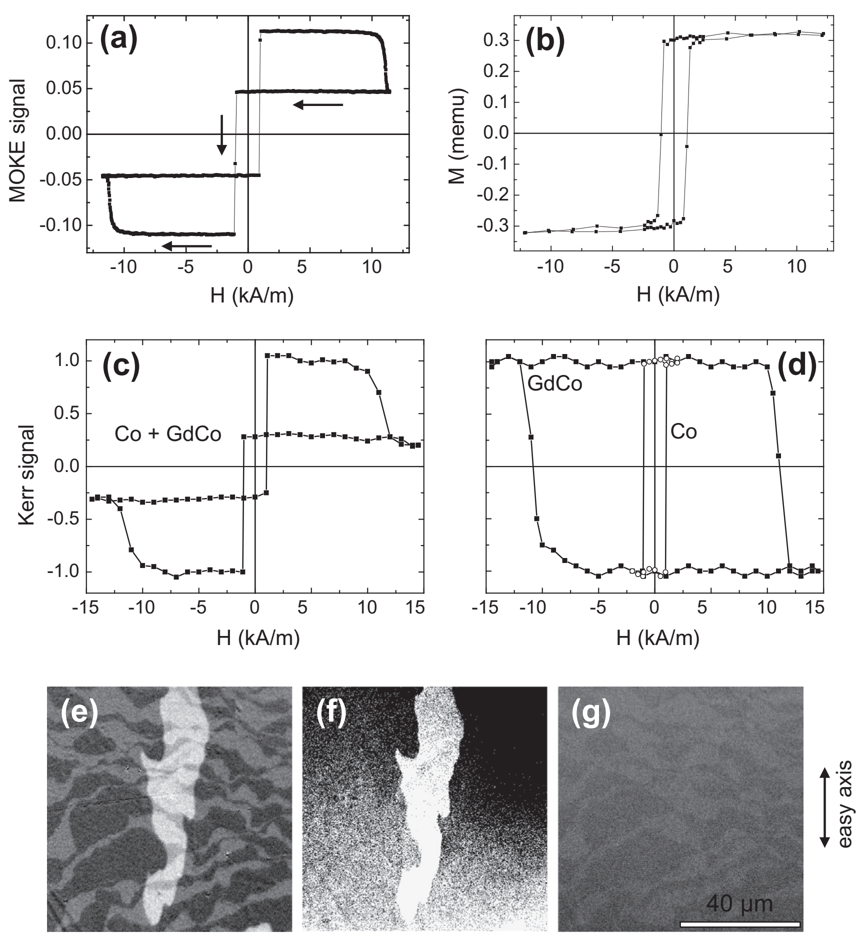

Fig. 1. Easy axis magnetization curves measured by laser-MOKE (a), VSM (b), and Kerr microscopy (c, d) for a GdCo(13 nm)/Si(2 nm)/Co(8 nm) sample. The composition of the GdCo layer is Gd-rich. The domain images in (e–g), showing an identical domain state, were obtained after ac-demagnetization along the hard magnetization axis. Image (e) was recorded for arbitrary compensator setting, revealing domains in both, Co and GdCo layers. Layer-selective images of the Co and GdCo films are shown in (f) and (g), respectively. They were obtained for the same microscope settings as the layer-selective Kerr loops in (d).

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