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Supersaturation of antiferromagnetically coupled multilayers: A comparative polarised neutron reflectometry study

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Abstract

Reflectometric methods like polarised neutron reflectometry (PNR) and synchrotron Mössbauer reflectometry (SMR) are capable of investigating the plane-perpendicular and lateral magnetic structure of multilayers (MLs). Previously, a variety of domain formation and transformation phenomena was found and systematically studied in a Fe/Cr ML of strong antiferromagnetic coupling by PNR and SMR. Growth of the primary domains on passing the bulk-spin-flop transition was established. The domains were found to revert to their native state only in a field considerably higher than the apparent saturation field, a phenomenon referred to as the supersaturation domain memory effect (SDME). We present a comparative PNR study of two antiferromagnetically coupled Fe/Cr MLs with different magnetisation curves. We show that the distribution of the layer–layer coupling rather than the magnetic structure of the Cr spacer layer is responsible for the SDME.

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Keywords: Polarised neutron reflectometry; Multilayers; Antiferromagnetic coupling; Domains

1. Introduction

Antiferromagnetically (AF) coupled metallic multilayers (MLs) [1] have received much attention due to their relevance in fundamental science and technology alike. The archetype Fe/Cr system shows oscillatory interlayer coupling [2,3] and giant magnetoresistance (GMR) [4]. GMR is applied in broad range of everyday devices, and the *domain*- size-dependent resistance noise may limit those applications [5]. To improve the performance of devices based on nanomagnetic systems the first step could be the tailoring of the domain structure and investigation of the domain transformation dynamics in AF-coupled MLs. Recently, domain transformation processes were shown in an AF-coupled Fe/Cr ML [6]. It was shown that primary domains were formed when the magnetic field was decreased just below saturation. The primary domains became coarser on passing the bulk-spin-flop (BSF) transition [6], a phenomenon related to the fourfold in-plane anisotropy of the epitaxial ML [7–9]. The BSF transition is the rotation of the layer magnetisations from the field parallel/antiparallel alignment to the perpendicular-to-field alignment when the magnetic field is increased from zero.

The coarsened domains return to the primary state on saturating the sample. For one of the Fe/Cr MLs, the saturation field obtained from the domain size recovery was much higher than the saturation field observed by other magnetisation measurements (SQUID, VSM). The possible microscopic origin of this phenomenon, which we shall call the 'supersaturation domain memory effect' (SDME) henceforth, is investigated in this paper.

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2. Experimental details

The epitaxial Fe/Cr MLs A and B were prepared by MBE and sputtering, respectively. Sample A had 20 repetitions of the ^{57}Fe(2.6 nm)/Cr(1.3 nm) bilayer (starting with iron) grown on MgO(0 0 1) single crystal at 450 K [8]. The last Cr layer served as capping layer. Sample B was grown on MgO(0 0 1) substrate and 11.1 nm of Cr buffer deposited at 673 K. The $[\mathrm{Fe}(3.6\,\mathrm{nm})/\mathrm{Cr}(1.1\,\mathrm{nm})]_{22}/$ Cr(3.9 nm) structure was grown at 383 K [10].

The *S*-like shape of the magnetisation curve of sample A (Fig. 1a) was characteristic for a broad distribution of the coupling strength and/or for a strong biquadratic coupling. Conversely, sample B showed a well-defined saturation field in both easy and hard directions [10] of the fourfold in-plane anisotropy (Fig. 1b). All measurements described in this article were performed at RT.

SDME on sample A was investigated in detail by polarised neutron reflectometry (PNR) and synchrotron Mössbauer reflectometry (SMR) [11]. We investigated the details of domain coarsening and possible SDME on sample B by time-of-flight PNR at the REMUR reflectometer at the IBR-2 pulsed reactor of the JINR in Dubna using a position-sensitive detector [12]. The domain transformations were traced by momentum-space measurements around the structurally forbidden 1/2 Bragg peak (the first AF peak). All the measurements discussed here were made along the easy axis of magnetic anisotropy. The saturation field of sample A was (0.85 ± 0.1) T, while the supersaturation field (the field needed for erasing the domain memory) was (1.3 ± 0.05) T [11]. In case of sample B the saturation field was 0.42 T [10].

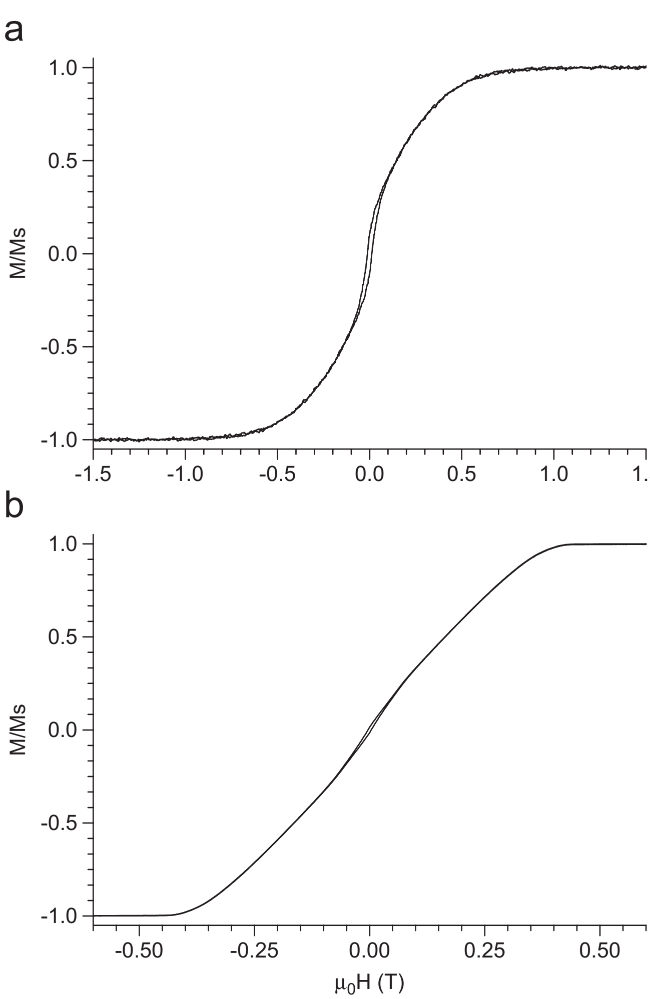

Fig. 1. Hysteresis loops of samples (a) and (b) along an easy axis of magnetic anisotropy.

3. Results and discussion

The prerequisite of SDME observation is the coarsening of the domains. Sample B also showed the domain coarsening previously observed on sample A, albeit at a different level. However, the external field at which the original small-domain state is restored was found to be different for the two samples. In contrast to sample A

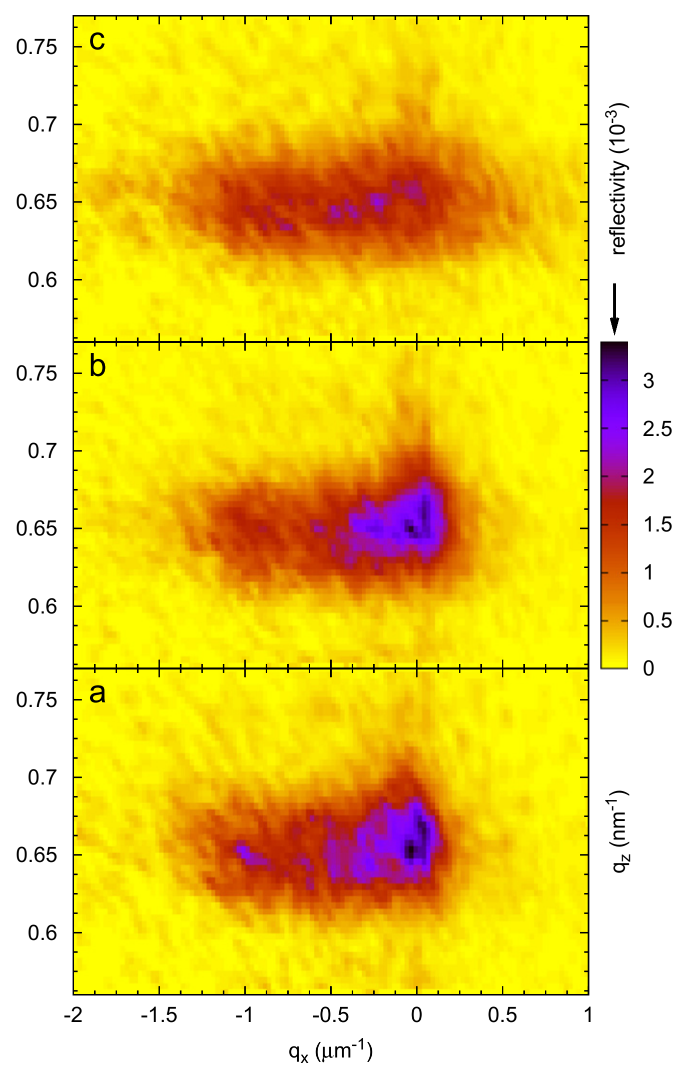

Fig. 2. Off-specular spin-flip scattering at the first AF peak of sample B measured in remanence after the application of different maximal fields (a: 0.38 T, b: 0.42 T, c: 0.46 T).

where the application of an unexpectedly high field above apparent saturation was necessary, for sample B the small-domain state was restored exactly at the saturation field derived from the magnetisation loop.

In the following, we describe measurements on sample B. To start the magnetic history from a well-defined state an above saturation field of 1.36 T was applied and then released to remanence. To transform the domains to the coarsened state the BSF transition was used. First the sample was rotated by 90° in zero field, then a field of 52 mT was applied, i.e. a field definitely inducing the BSF transition [13]. The procedure was repeated another three times to get back to the initial orientation of the sample. We monitored the potential manifestation of the SDME by measuring the off-specular scattering at the first AF peak in remanence after the application of step-by-step increasing maximal field values (Fig. 2). The orientation of the layer magnetisations compared to the polarisation of the incident neutrons was such that only spin-flip scattering was present at the AF position. The experimental data showed no difference up to the saturation field of 0.42 T (see Fig. 2), while after applying 0.46 T, i.e. a field only slightly above saturation, the well-pronounced specular peak was missing in remanence, a fact indicative of the domain state recovery.

4. Conclusions

One might speculate that the SDME observed on sample A was connected to the memory of the exchange spring of the Cr spacer. However, in view of the similarity of the Cr layer thicknesses of both samples, the presented experiments strongly indicate that the SDME of sample A was caused by the broad distribution of the saturation field [14]. Indeed, on releasing the applied magnetic field from a value slightly above the apparent saturation field, a tiny fraction of the still not saturated regions could act as seeds for the nucleation of large domains. Lacking a comparably broad distribution of the interlayer coupling, no SDME was manifested on sample B.

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