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Magnetic order and the spin-flop transition in Fe/Cr superlattices

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Abstract

We have studied the structural and magnetic properties of MBE-prepared epitaxial Fe/Cr (001) oriented superlattices. The samples consist of 20 periods with 2.5 nm Fe and 1.3 nm Cr individual layer thicknesses. The samples were characterized by X-ray diffraction, while the magnetic properties were determined by magnetoresistivity, magneto-optical Kerr effect, and polarized neutron reflectivity measurements. The transition from antiparallel to parallel alignment of the magnetizations in adjacent Fe layers was investigated using polarized neutron reflectivity measurements while applying a field parallel to the layers. A spin-flop transition due to the fourfold anisotropy in the Fe layers was observed at a field of 200 Oe. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Multilayers; Reflectometry; Magnetic anisotropy; Magnetoresistance

During the last decade, the phenomenon of antiferromagnetic coupling in magnetic superlattices has been intensively investigated, from an experimental as well as a theoretical point of view, for basic research purposes as well as for applications. This research area has substantially benefited from the unique opportunities offered by neutron reflectivity.

Fe/Cr has been the archetypal system for the study of antiferromagnetic coupling and magnetoresistance effects and has therefore also been scrutinized in detail using neutron reflectivity experiments. For example, the case of sputtered Fe/Cr (001) superlattices with thick (7.4 nm) Cr layers was presented by Adenwalla et al. [1], showing the 90° arrangement. Schreyer et al. [2] discussed the properties of molecular beam epitaxy (MBE) grown Fe/Cr (001) superlattices with relatively thick Fe layers (5.2 nm) in the framework of the theory of noncollinear exchange. In this work we have focussed on the effect of the fourfold magnetic anisotropy in the Fe layers on the reorientation of the antiferromagnetically coupled magnetizations in adjacent Fe layers.

We have investigated epitaxial Fe/Cr superlattices, which were grown on MgO (001) single crystal substrates by MBE. The samples have 20 periods, each consisting of 2.5 nm Fe and 1.3 nm Cr layer thicknesses. Reflection High Energy Electron Diffraction (RHEED) and X-ray diffraction measurements confirmed the epitaxial quality and excellent artificial layering of these samples. Magnetotransport experiments using the conventional four-probe technique clearly showed the Giant Magnetoresistance effect due to spin-dependent scattering in the antiferromagnetically coupled superlattice.

Neutron reflectivity experiments were carried out at the V6 reflectometer at the Hahn-Meitner-Institut in Berlin, using cold neutrons (wavelength $\lambda = 0.466$ nm). The experiment was carried out at room temperature and a magnetic field parallel to the layers was applied by means of a conventional electromagnet.

Fig. 1 shows a neutron reflectivity scan of the Fe/Cr superlattice using unpolarized neutrons. Two peaks can clearly be observed, originating from the chemical modulation (at $\theta = 3.5°$) and from the magnetic

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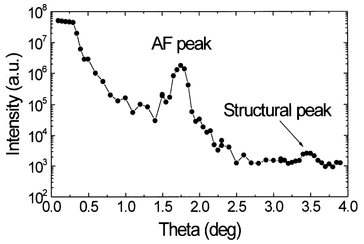

Fig. 1. Zero-field neutron reflectivity scan of the Fe/Cr superlattice, showing magnetic and structural modulation.

modulation (labeled 'AF', at $\theta = 1.75°$), which is twice as large as the multilayer periodicity. Reflectivity scans in fields parallel to the layers reveal how the magnetic modulation is suppressed in a field of about 0.6 T, in good agreement with the saturation field obtained from the magnetotransport experiments.

Fig. 2 shows the intensity of the antiferromagnetic peak (at $\theta = 1.75°$) as a function of applied field. Analysis of the neutron spin polarization allows to determine the orientation of the sample magnetization. The field is applied along one of the easy axes of the Fe layers. Initially, the Fe moments are parallel with this easy axis. At low fields (about 230 Oe), a sudden transition from non-spin-flip (NSF) to spin-flip (SF) scattering is observed. As the field is increased, the intensity decreases monotonically due to the suppression of the antiferromagnetic coupling. The low-field feature can be interpreted as a spin-flop transition; i.e. it becomes energetically favorable to have the Fe moments pointing along the easy axis perpendicular to the direction of the applied field. This spin-flop reorientation is similar to the effect in intrinsic antiferromagnets [3]. We did not observe any surface effect, like the one reported by Wang et al. [4] in Fe/Cr (211) superlattices.

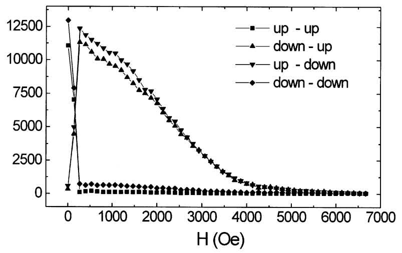

Fig. 2. Intensity of the magnetic modulation peak (at $\theta = 1.75°$), as a function of applied field using neutron polarization analysis. The sudden transition from NSF to SF scattering is due to the spin-flop reorientation of the magnetization.

In conclusion, we have studied high-quality Fe/Cr superlattices by polarized neutron reflectometry. A spin-flop reorientation of the magnetization was observed at low fields.

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References

[1] S. Adenwalla et al., Phys. Rev. B 53 (1996) 2474.
[2] A. Schreyer et al., Phys. Rev. B 52 (1995) 16066.
[3] D.L. Mills, Phys. Rev. Lett. 20 (1968) 18.
[4] R.W. Wang et al., Phys. Rev. Lett. 72 (1994) 920.