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Neutron reflectometry studies of exchange springs in $DyFe_2/YFe_2$ superlattices

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Abstract

Spin-polarised neutron reflectometry has been used to investigate a magnetic exchange spring, formed in a (75 Å $DyFe_2$/150 Å YFe_2) × 18 multilayer thin film. The existence of an exchange spring is found to enhance the level of neutron spin flipping during reflection, a strong indicator of the formation of transverse magnetic moments within the YFe_2 layers.

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Keywords: Neutron reflectometry; Magnetic multilayer; Exchange spring; Rare-earth metal; Neutron spin precession

1. Introduction

Research into Laves-phase multilayer samples of $DyFe_2/YFe_2$ has uncovered some striking results in recent times. These MBE-grown samples differ from the more commonly investigated ferromagnetic multilayers because they have anti-ferromagnetic coupling between the magnetically hard ($DyFe_2$) and magnetically soft (YFe_2) layers. This property allows them to be used in novel applications, and demonstrate interesting new physics.

It has previously been shown that it is possible to engineer magnetic compensation points in these samples by varying the thickness of the $DyFe_2$ with respect to the YFe_2 thickness [1]. It has also been shown that, by the application of magnetic fields, magnetic 'exchange springs' can be wound and unwound reversibly in the Fe moments of the YFe_2 layer [2]. These exchange springs are of great interest because they give rise to giant magneto-resistance during this winding and unwinding process [3].

In this work, we have investigated magnetic exchange springs in an MBE-grown, magnetically compensated $DyFe_2/YFe_2$ multilayer film. The measurements have been performed using the CRISP spin-polarised neutron reflectometer at ISIS, Rutherford Appleton Laboratory, UK. It will be demonstrated that, in the 'spring' region, an increased fraction of the reflected neutrons switch their spin state. This is interpreted to be spin precession, caused by the transverse magnetic moments associated with exchange springs.

2. Experimental method

The 4000 Å thick multilayer film was grown using MBE techniques with a Balzers UMS 630 UHV facility. The procedure is well documented in Ref. [4]. The sample was grown on a $(1\,1\,\bar{2}\,0)$ sapphire substrate, with

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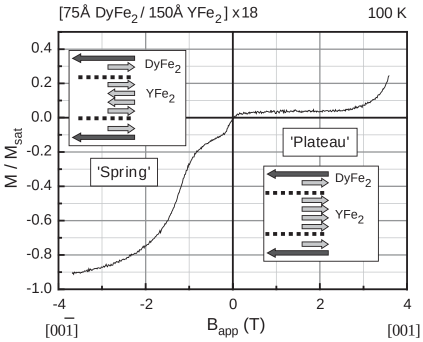

Fig. 1. A partial M–B loop for the sample, pre-polarised along $[0\,0\,\bar{1}]$. Applying a 1 T field along this direction reversibly winds and unwinds an exchange spring in the YFe_2 layer. A field applied in the [0 0 1] direction immediately saturates the Fe moments forming a field-independent 'plateau' region until the system switches at the 3.5 T Dy coercivity.

a 100 Å Nb buffer and 20 Å Fe layer. The substrate temperature was maintained at 400°C, while the Laves phase compound was synthesised by co-deposition of elemental fluxes, keeping all major axes parallel to niobium.

Using polarising mirrors, the CRISP reflectometer is capable of injecting neutrons with a single spin polarisation. It can then detect the momentum transfer of the reflected neutron and return data for a single spin polarisation. This allows measurements to be taken for spin-up injected and detected neutrons ($I_{\uparrow\uparrow}$), spin-down injected and detected neutrons ($I_{\downarrow\downarrow}$), and for spin flipping due to neutron spin precession ($I_{\uparrow\downarrow}$ and $I_{\downarrow\uparrow}$). The CRISP reflectometer can only apply a modest magnetic field of $\sim$1 T, which is insufficient to saturate the 10 μ_B Dy moments ($B_c \sim 3.5$ T at 100 K for Dy). To allow the exchange of spring formation, the Dy moments were first pre-polarised along the $[0\,0\,\bar{1}]$ easy axis using a separate superconducting magnet, and then transferred to the instrument. Once polarised, anti-ferromagnetic Dy–Fe coupling in $DyFe_2$ causes the Fe moments to align with the [0 0 1] axis. The strong Fe–Fe ($T_c \sim 600$ K) exchange field then aligns the Fe moments of the YFe_2 moments in the same direction.

Neutron measurements were subsequently performed at 100 K, with the neutron beam aligned along $[0\,0\,\bar{1}]$. Measurements were taken both with and without a magnetic field applied along this direction. The 1 T magnetic field creates competition between lowering the exchange field energy (keeping the Fe moments parallel, but anti-parallel to the magnetic field) and lowering the Zeeman energy (aligning with the field direction). As the field is increased to a critical point (the 'bending field'), the Fe moments in the YFe_2 rotate towards the $[0\,0\,\bar{1}]$ direction and wind an exchange spring (Fig. 1). The use of a magnetically compensated sample (where the net moment on the $DyFe_2$ layers exactly balances that of the

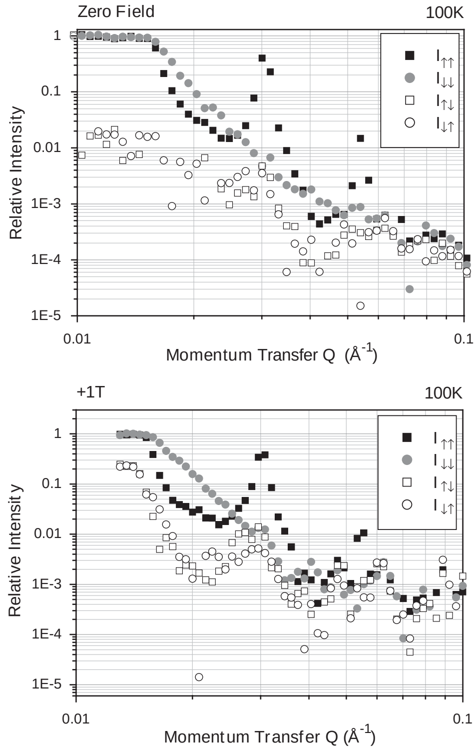

Fig. 2. Reflectometry data for zero (top) and applied field (bottom). Fe moment polarisation creates a difference in the peak intensity for $I_{\uparrow\uparrow}$ and $I_{\downarrow\downarrow}$. Exchange spring formation enhances the spin-flipping channels in the 1 T field.

YFe_2) creates a very small bending field, obtainable within the field constraint of the instrument.

3. Results and conclusions

Neutron measurements taken at zero field show a distinct splitting between the ($I_{\uparrow\uparrow}$) and ($I_{\downarrow\downarrow}$) intensities on the Bragg peaks, with limited spin-flip scattering. This is consistent with the preferential alignment of Fe moments at the YFe_2 interfaces, along [0 0 1]. When the 1 T magnetic field is applied along $[0\,0\,\bar{1}]$, this splitting remains, but a significant degree of spin-flip scattering develops on the Bragg peaks. This indicates neutron spin precession, caused by transverse components of the magnetic moments associated with the exchange spring (Fig. 2).

References

[1] M. Sawicki, et al., J. Appl. Phys. 87 (2000) 6839.
[2] M. Sawicki, et al., Phys. Rev. B 62 (2000) 5817.
[3] S.N. Gordeev, et al., Phys. Rev. Lett. 87 (2001) 186808.
[4] V. Oderno, et al., Phys. Rev. B 87 (1996) R17375.