Polarized Neutron Reflectivity Study of the Magnetic Structure of MnSi Thin Films

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Recent theoretical work proposes that helical magnets hold new possibilities for spintronics [1,2]. We are exploring using MnSi thin films for fundamental spin-dependent transport studies. MnSi is a weak itinerant-electron helical magnet with a B20 crystal structure and a lattice parameter a_{MnSi} = 0.4561 nm [3]. At ambient pressure, the material orders magnetically below a Curie temperature T_C = 29.5 K. MnSi is nearly ferromagnetic, but the Dzyaloshinskii-Moriya (DM) interaction, caused by the lack of inversion symmetry of the B20 crystal structure, destabilizes the ferromagnetism and produces a helical magnetic structure oriented along [111] with a wavelength of approximately 18 nm [4]. The helix rotates in the direction of the applied magnetic field. Above $H_{C1} \approx 0.1$ T, a conical phase forms [5], which collapses into a ferromagnetic phase above $H_{C2} = 0.6$ T [6].

In contrast to the well-studied bulk material, there has been little work done to date on MnSi thin films. Silicon substrates (lattice parameter a_{Si} = 0.5431 nm) serve as good templates for MnSi growth. There is a 3.0% lattice mismatch between a MnSi(111) surface and Si(111). From bulk measurements, one would expect the magnetic moments in these films to be in-plane and to form a helix about the [111] surface normal, which would be ideal for spin-dependent tunneling and spin-injection studies. The report presents priliminary attempts to determine the magnetic structure of MnSi(111) thin films using polarized neutron reflectometry (PNR).

Thin epitaxial Si / *t* MnSi / Si(111) films were grown by solid phase epitaxy using the molecular beam epitaxy facility at Dalhousie University. Mn was evaporated onto a clean Si(111) surface and then annealed at 400°C to produce a single crystal MnSi film. The MnSi silicide thickness inferred from the Mn-flux monitor was confirmed using x-ray reflectometry. The silicide film thickness, *t*, ranged from 7 nm to 18 nm. The amorphous Si capping layer is 18 nm thick. Thicknesses and film roughnesses were determined with x-ray reflectivity. Film roughness increased with thickness. A MnSi thickness *t* = 10 nm achieved the best balance between the requirements of large film thickness for a stronger spin-flip reflecitivity signal and low film roughness. For this thickness, models predict that a helical magnetic structure similar to that in bulk would give a large enough spin-flip signal be to detected.

Polarized and unpolarized neutron reflectivity measurements were performed on the C5 spectrometer. The neutron beam was parallel to the in-plane [11-2] direction and the magnetic field was applied along [1-10], also in the plane of the film. Measurements were performed at room temperature and at 4 K in fields as low as 0.03 T and as high as 5 T. Flipping ratios of 24 were achieved at 0.03 T. The data was modelled with Parratt32 and SimulReflec software.

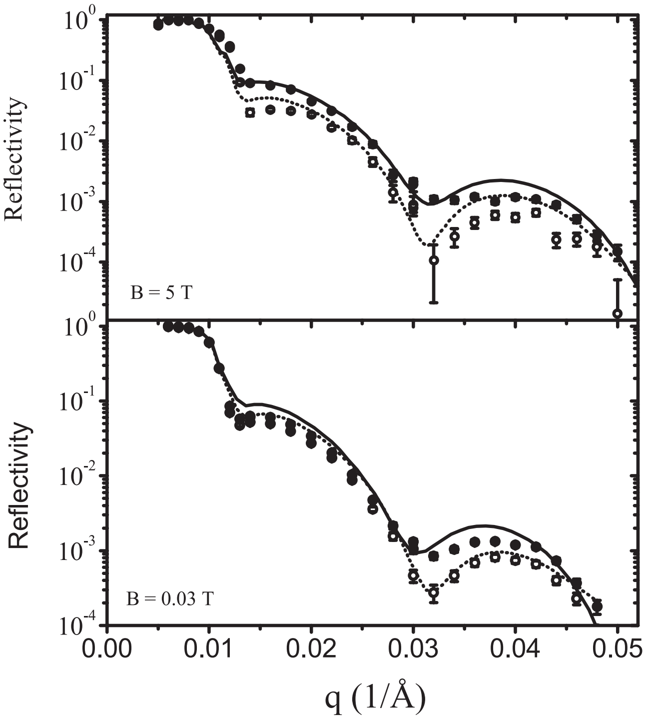

Fig 1. Polarized neutron reflectivity from a 10-nm thick MnSi(111) film. The open circles show the up-up reflectivities, and filled circles represent the down-down. The data measured in a 5 T and 0.03 T field are presented in the top and bottom graphs respectively. The solid and dotted curves show the calculated reflectivities.

The top graph of Figure 1 shows the spin-polarized neutrons reflectometry for the 10 nm MnSi sample at a temperature of 4 K in a field of 5 T, which is far above saturation. The up-up reflectivity (open circles) is below the down-down reflectivity (filled circles) due to the negative scattering length density of Mn. The model, shown by the solid and dotted curves, reproduces the features in the data. A large spin-asymmetry is present in the low-q and $q \approx 0.032$ Å^{-1} regions of the reflectivity.

The reflectivity in a field of 0.03 T is shown in the bottom graph of Figure 1. The figure shows that the spin-asymmetry is qualitatively different than in high fields. For the low field measurements the asymmetry is large for large q and small for small q. A model of the down-down and up-up scattering from a 10 nm film with a 18 nm magnetic helix pointing along [111] is shown by the solid and dotted lines respectively and reproduces the qualitative features in the data. However, no spin-flip signal was detected over the entire measured range of *q*-values, whereas the model of the helical order predicts that the spin-flip signal should be larger than the up-up signal in the vicinity of $q = 0.032$ Å^{-1}. These results show that magnetic structure in the MnSi thin films are different than in bulk. Further studies with thicker and smoother films are required to determine the magnetic structure of MnSi films. Recent progress in the grown process has enabled the growth of such films.

References

[1] O. Wessely, B. Skubic, L. Nordström, Phys. Rev. Lett. 96, 256601 (2006).

[2] J. Heurich, J. König, and A. H. MacDonald, Phys. Rev. B 68 064406 (2003).

[3] Jorgensen, J.E., Rasmussen, S. Powder Diffraction 6, 194 (1991).

[4] Y. Ishikawa, K. Tajima, D. Bloch, M. Roth, Solid State Communications 19, 525 (1976).

[5] B. Lebech, P. Harris, J. Skov Pedersen, C. I. Gregory, K. Mortensen, N. R. Bernhoeft, M. Jermy and S. A. Brown, J. Magn. Magn. Mater. 140–144, 119 (1995).

[6] Y Ishikawa, G. Shirane, J. A. Tarvin and M. Kohgi, Phys. Rev. B 16, 4956 (1977).