Size Effect in the Spin Glass Magnetization of Thin AuFe Films Studied by Polarized Neutron Reflectometry

H. Fritzsche,[1] J. M. Van der Knaap,[2] M. B. S. Hesselberth,[2] G. J. Nieuwenhuys[2]

[1] Canadian Neutron Beam Centre, National Research Council Canada, Chalk River Laboratories, Chalk River, ON, Canada K0J 1J0

[2] Kammerlingh Onnes Laboratory, Leiden University, Leiden, The Netherlands

Thin Films

During the last decades there has been a continuous theoretical and experimental interest in studying properties of spin glass systems [1]. The prerequisite for a spin glass is a competition among the different interactions between the spins with a random distribution of these interactions. The random spin arrangement in a spin glass is frozen when cooling the system below a certain temperature T_f, called the freezing temperature. This temperature has been most often determined by measuring the magnetic susceptibility as a function of temperature and identifying the cusp as T_f as it was done for the first time by Cannella and Mydosh [2]. Other measurements like the anomalous Hall effect and Mössbauer effect were successfully used to study the spin glass phase transition, whereas other methods like resistivity or magnetoresistance measurements did not show any sharp features associated with a phase transition. Recently, Polarized Neutron Reflectometry (PNR) has turned out to be an excellent tool to determine the onset of spin-glass freezing in single thin spin-glass films by measuring the temperature dependence of the AuFe spin-glass magnetization in a magnetic field of 6 T [3,4]. For temperatures far above T_f the AuFe spin-glass magnetization can be described with a Brillouin-type behavior of a paramagnet, whereas at temperatures below 50 K the measured AuFe magnetization is smaller than the one expected from a paramagnet, clearly proving the existing spin-glass frustration in these AuFe films.

A set of $Au_{97}Fe_3$ alloy films with an Fe concentration of 3 at.% and different thicknesses t = 2, 5, 10, 50 nm was prepared by co-sputtering high purity Au and Fe onto a silicon substrate. The PNR experiments were performed on the C5 spectrometer using a Cu_2MnAl Heusler monochromator at λ = 0.237 nm in combination with a PG filter to reduce the higher order contamination. The magnetic field was provided by the M5 cryomagnet with the magnetic field in the sample plane and perpendicular to the scattering plane. With this setup we achieved a flipping ratio better than 25 or a neutron beam polarization of 96%, respectively [5].

In previous PNR experiments, we revealed a size effect in the magnetization of AuFe films [4]. For the films in the thickness range from 500 nm to 20 nm, we observed a Brillouin-type behavior from 295 K down to 50 K and a constant magnetization of about 0.9 µB per Fe atom below 30 K. However, for the 10 nm thick film we observed a Brillouin-type behavior down to 20 K and a constant magnetization of about 1.3 µB per Fe atom below 20 K. In the new experiment series reported here we wanted to probe even thinner film thicknesses where the size effect should be more pronounced.

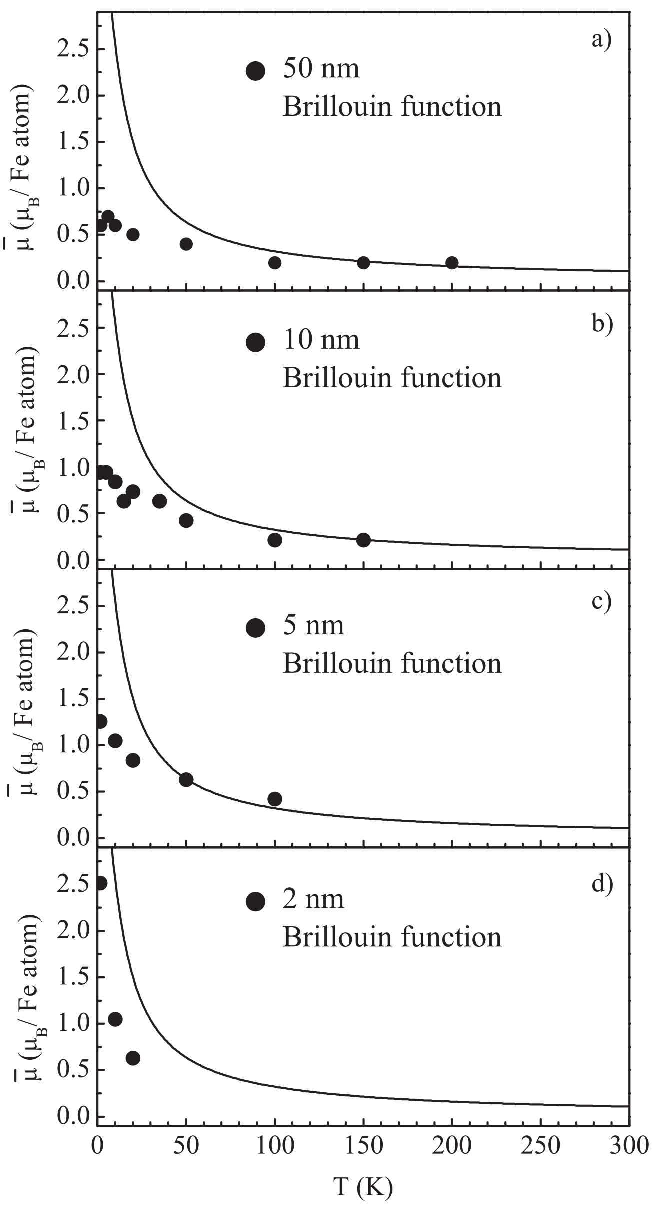

Fig 1. *Averaged magnetic moment per Fe atom versus temperature of thin $Au_{97}Fe_3$ films as derived from the fits to the PNR curve (solid circles) compared to a Brillouin function with J = 2 for isolated Fe atoms (solid line).*

Figure 1 shows the averaged magnetic moment as a function of temperature as determined from PNR measurements (solid circles) in a field of 6 T for a $Au_{97}Fe_3$ film with a thickness of

a) 50 nm, b) 10 nm, c) 5 nm, and d) 2 nm. The solid lines in Figure 1 represent the Brillouin function for isolated Fe atoms. In agreement with earlier PNR experiments [4] (i) the magnetization deviates noticeably from the paramagnetic Brillouin-type behavior below 50 K and (ii) the magnetization below 10 K is enhanced for films with thickness smaller than 10 nm compared to the bulk value or films larger than 20 nm (see Fig. 1a). As expected, the magnetization at 2 K increases with decreasing film thickness below 10 nm, proving the enhancement of the size effect with decreasing film thickness and indicating that the frustration energy becomes weaker in these ultrathin films with decreasing film thickness. So, the present series of PNR experiments exapnding the thickness range down to 2 nm nicely confirm the size effect determined previously from experiments on AuFe films in a thickness range from 500 to 10 nm.

References

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