DOMAIN STRUCTURES IN Fe/Fe$_2$N MULTILAYERS

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Many studies nowadays are concerned with the magnetic properties of thin magnetic layers or multilayers. The common goal is to find appropriate materials for so-called spintronics applications which require the control of the spin state of the carriers. Structures made of the stacking of ferromagnetic layers separated by non-magnetic layers attract a lot of attention because of possible interlayer exchange coupling in such systems. An antiferromagnetic coupling between ferromagnetic layers is of special interest as it makes it possible to control the behavior of the multilayer through an external factor like, e.g., a magnetic field or a light illumination. In spite of extensive experimental and theoretical studies the mechanism of the interlayer coupling is still not well understood.

The Fe/Fe$_2$N multilayers have been selected in order to study the interlayer coupling and to obtain a better understanding of magnetic phenomena (including the magnetization and demagnetization processes) in Fe-based system.

The Fe-N system presents a variety of phases, the crystal structure and the magnetic properties evolving with nitrogen concentrations (see [1,2] for details). In particular, orthorhombic Fe$_2$N does not show ferromagnetism at room temperature, and the Curie temperature lies between 4 and 60 K for this phase. Thus, when Fe$_2$N is used as a non-magnetic spacer between magnetic layers in a multilayered structure, one can expect an interesting temperature dependence of the magnetic properties of the system.

Fe/Fe$_2$N multilayers have been grown at the Institute of Physics of the Polish Academy of Sciences in Warsaw. Several multilayers Fe(4 nm)/Fe$_2$N(0.8-1.5 nm) were deposited on (001)-oriented GaAs substrate at room temperature by a sputtering technique. In order to avoid oxidation, a 10 nm thick Si cap layer was deposited on the top. X-ray diffraction and Kerr effect were used to characterize the samples at room temperature. The non-magnetic character of this phase was confirmed by the Kerr rotation measurements performed on a 31 nm thick amorphous layer, with a composition close to Fe$_2$N, as used for our multilayers.

Neutron diffraction measurements have been performed on a triple-axis spectrometer in order to achieve a good resolution. The 4F1 spectrometer, installed on a cold source of the Orphée reactor at the LLB, was used. The incident neutrons had a wave-vector k_i=1.55 Å^{-1} or 1.25 Å^{-1}, the beam being filtered by a cooled Beryllium to avoid harmonic contamination, 40’ Soller slits collimations were set on each side of the analyser.

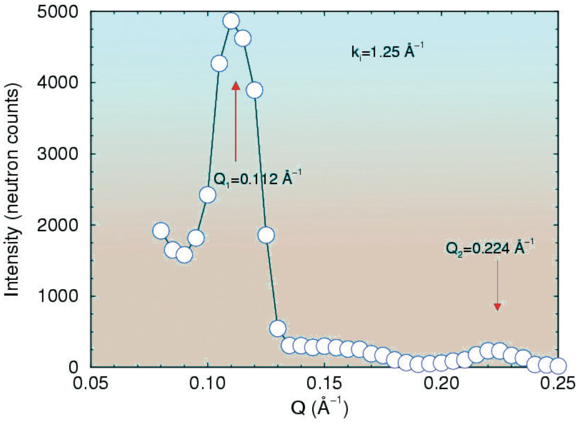

Figure 1. Magnetic peaks observed at room temperature at small angles on a multilayer Fe(4 nm)/Fe$_2$N(1.5 nm) deposited on a (001) GaAs substrate.

Because of the layered structure, diffraction peaks are expected at positions $Q_n=2n\pi/D$, where D is the period of the structure, sum of the thicknesses of a Fe layer and of a Fe$_2$N layer in the present case. The intensities of these peaks are given by $|F_{BL}(Q)|^2\sin^2(n_mDQ/2)/\sin^2(DQ/2)$, where n_m is the number of bilayers and $F_{BL}(Q)$ the form factor of the elementary bilayer, which may consist of a nuclear and a magnetic contribution, and depends on the contrast between the two layers. In the present case the contrast between Fe and Fe$_2$N is nearly zero for the nuclear contribution, and a magnetic contribution will exist only if there is a magnetic coupling between adjacent bilayers. An antiferromagnetic coupling would be revealed by a signal corresponding to a 2D distance. The measurements were performed at small angles in order to keep the magnetic form factor near its maximum value. Fig. 1 displays the result of a typical measurement on a sample whose nominal composition was Fe(4 nm)/Fe$_2$N(1.5 nm), with 22 bilayers (~120 nm thick). Two peaks are observed, corresponding to $2n\pi/D$, with n=1 and 2, and D=5.61 nm. The small bump at about n=3/2 is not a signature of antiferromagnetic coupling as we checked that no peak existed at n=1/2. It could be due to the Si coating of the sample. This means that the bilayers are ferromagneticaly coupled.

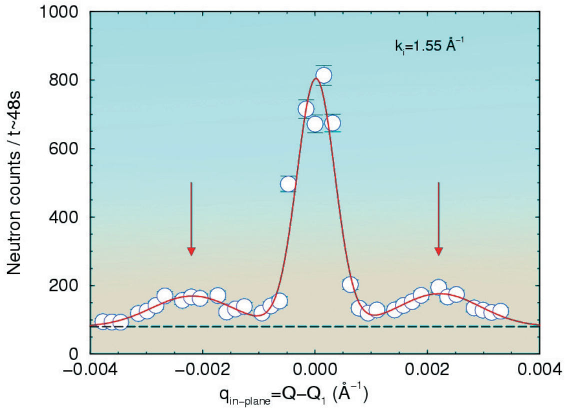

Figure 2. In-plane scan centered on the Q_1=(0,0,0.112), position of the bilayer peak, evidencing a characteristic distance of ~285 nm.

In order to check the quality of the structure, an in-plane scan was performed, perpendicular to the peak at Q_1. To our surprise, satellite peaks were found at $Q_1 \pm q_{in-plane}$, as reported on Fig. 2. These peaks are the signature of a characteristic in-plane distance $\Delta = 2\pi/q_{in-plane}$, with a long-range coherency along the stacking axis of the bilayers. This distance is then equal to 285 nm, and *a priori* points out a peculiar magnetic behavior of the multilayered structure.

MFM measurements have then been performed at the Institute of Physics of Warsaw, on several Fe/Fe_2N multilayers. They evidenced stripe-like magnetic domains on the surface of these samples, with a period varying with the Fe_2N layer thickness, typically between 180 and 240 nm. These numbers are somewhat smaller than that found by the neutron scattering, but it is likely that the two observations have a common origin, the neutron measurements revealing the coherent aspect of this domain structuration. The neutron measurement has been performed in the [110] direction of the Fe layer, the [-110] direction being perpendicular to the scattering plane. That means that the [100] and [010] axes were at ±45 degrees with respect to this direction. If, in accordance with the symmetry of the system, the stripe domains were along these axes with a period P, the Δ value would represent $P/\cos(\pi/4)$, yielding P=201.5nm. This would reconcile both results, if we suppose that effects due to the sample geometry could affect the domain structuration on the very surface, where zig-zag behavior, although visible, does not ascertain the 45 degrees assumption. Complementary neutron measurements, including reflectometry, as a function of temperature and magnetic field, should help us to get a deeper insight into this multilayer system, one of the only few for which stripe domains have been observed [3,4].

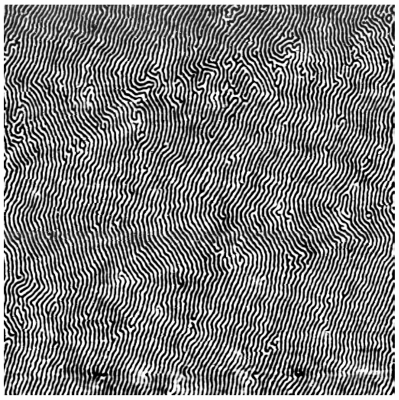

Figure 3. Stripe domains evidenced at the surface of the sample by MFM measurements (the period ~217 nm).

Note added in proof:

A last minute test confirmed that, in the [100]-[001] scattering plane, the satellite peaks are observed at $q_{in-plane}[100]=\sqrt{2}$ at $q_{in-plane}[110]$, which confirms that the domain structuration is along the [100] and [010] axis.

References

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