OFF-SPECULAR REFLECTIVITY MEASUREMENTS ON PERIODIC MAGNETIC STRIPE DOMAINS IN $Fe_{0.5}Pd_{0.5}$ THIN FILMS.

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Specular polarised neutron reflectometry with polarisation analysis allows one to probe in-depth magnetic profiles of thin films (along the normal to the film). In the case of homogeneous films, the neutron is sensitive only to the in-plane magnetisation and all the intensity is reflected in the specular direction. In the case of non homogeneous films, all the directions of the magnetisation can be explored and intensity is scattered off the specular direction. The convention is to call « off-specular » the intensity measured in the incidence plane and « surface diffraction » the intensity measured out of the incidence plane. The incidence plane is defined by the incident wave vector and the perpendicular of the surface. Off-specular reflectometry gives information about lateral structures (in the plane of the film) with typical length scales ranging from 2 µm to 100 µm. Furthermore, surface diffraction at grazing angle gives access to transverse dimensions between 10 nm and 300 nm with a resolution in that direction of a few nanometers. The combination of these three types of signals (specular, off-specular and surface diffraction) applied to magnetic systems can lead to a 3D magnetic structure measurement. Off-specular measurements are however not applicable to the study of a single magnetic dot, but it can generate unique results in several cases including patterns of domain walls in thin films with perpendicular anisotropy, arrays of magnetic dots or patterned lines in magnetic thin films.

To demonstrate the potential of non-specular neutron scattering, we have measured magnetic surface diffraction on magnetic stripe domains appearing in FePd thin films. The sample was prepared by Molecular Beam Epitaxy under ultra-high vacuum (10^{-7} Pa). A 2 nm seed layer of Cr was deposited onto a MgO (001)-oriented substrate in order to allow the epitaxial growth of the 60 nm single crystal Pd buffer layer. A 50 nm thick FePd alloy layer was then deposited at room temperature using a mono-layer by mono-layer growth method in order to induce a chemical order similar to the one found in the tetragonal structure $L1_0$. This structure consists in alternate atomic layers of Fe and Pd on a body centred tetragonal lattice [1]. After a magnetisation along the easy axis, a magnetic stripe domain structure is observed [2] (see bottom picture on Figure 1).

The diffraction measurement has been performed using a small angle neutron scattering spectrometer (the spectrometer PAPOL at the Laboratoire Léon Brillouin) in a reflectivity configuration [3]. In the experiment, the stripes were aligned along the plane of incidence. An example of diffraction is shown on figure 1. One can observe a bright specular spot and two weaker (10^{-3}) off-specular peaks. The position of these peaks along the $q_{//}$ direction reflects the periodicity of the stripe domains (100 nm). The diffraction peaks are reflected with an angle θ_o equal to the critical angle θ_c of the layer whatever the incidence angle is.

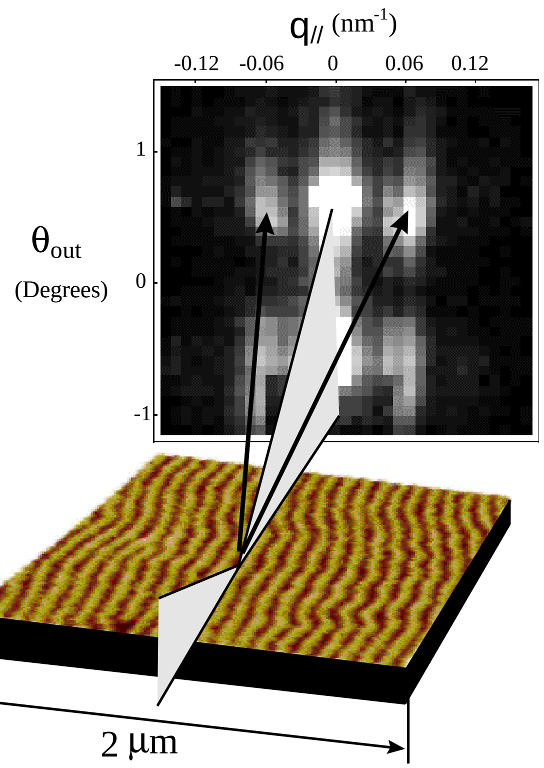

Figure 1 : diffraction geometry and off-specular scattering signal measured on a network of magnetic domains using a multidetector. The top peaks are the specular and off-specular peaks. The bottom signal is due to the refracted wave. The bottom picture is a Magnetic Force Microscopic image of magnetic domains observed in $Fe_{0.5}Pd_{0.5}$ thin films

The maximum intensity of the diffraction peaks is obtained when the incidence angle of the neutron beam on the sample is θ_c. These peaks have a behaviour similar to Yoneda peaks (or anomalous reflections) [4].

As a first approach, we have explained these observations by using a DWBA (Distorted Wave Born Approximation) approach. The considered « unperturbed » system is the flat FePd layer ; the perturbation is the magnetic structure created by the stripes. In this case, the diffuse cross-section can be written as [5] :

$$\left(\frac{d\sigma}{d\Omega}\right)_{diff} = (L_x L_y)\frac{\left|k_0^2\left(1-n^2\right)\right|^2}{16\pi^2}\left|T(\mathbf{k}_1)\right|^2\left|T(\mathbf{k}_2)\right|^2 S(\mathbf{q}_t)$$

with

$$S(q_t) = \iint_S dX\,dY\,C(X,Y)\exp\left(i\left(q_x X + q_y Y\right)\right)$$

(in the case where q_z^t is small) where $C(X,Y)$ is the magnetic roughness correlation function, $\mathbf{q}$ is the scattering vector $\mathbf{k}_2$-$\mathbf{k}_1$ and $\mathbf{q}_t$ is the wave-vector transfer in the medium. Maxima are obtained in the diffuse scattering when $\mathbf{k}_1$ or $\mathbf{k}_2$ makes an angle close to q_c since in these positions, the Fresnel coefficients **T** reach a maximum.

$S(\mathbf{q}_t)$ is the Fourier transform of the magnetic roughness correlation.

In the case of our magnetic lines, we define the correlation function of the magnetic roughness as :

$$C(X,Y) = \frac{1}{S}\iint_S M(x,y)M(x+X,y+Y)dxdy$$

The surface diffraction signal measures the Fourier transform of the magnetic correlation function. The figure 2 shows the off-specular signal calculated for an incidence angle equal to the critical angle $\theta_i=\theta_c=0.5°$. The peak positions are unchanged whatever the incidence angle is. The maximum of intensity is obtained when the incidence angle is equal to the critical angle θ_c.

The DWBA approach is however not well suited to this problem since the magnetic roughness extends over the full thickness of the magnetic layer so that the flat layer as a basis state is far from the real eigenstates of the system. We are presently working on a fully dynamical theory to be able to quantitatively analyse magnetic off-specular patterns.

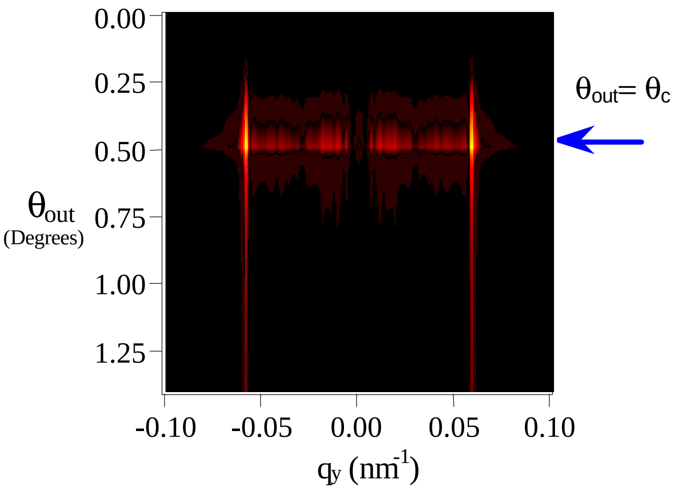

Figure 2 : calculated off-specular signal as measured on a multidetector for an incidence angle $q_{inc} = q_c = 0.5°$. The peaks maximum position does not move when the incidence angle is varied but the intensity decreases as soon as the incidence angle is moved away from the critical angle θ_c.

We hope that this work will pave the way for a new technique of 3D magnetometry making it possible to measure quantitatively magnetic structures with an in-depth and in-plane resolution. The aim is to eventually be able to obtain magnetic information on the magnetic order in the plane of thin films through polarised neutron reflectometry. Off-specular and surface diffraction will then make it possible to probe in-plane magnetic structures of sizes ranging from 10 nm to 100 µm.

References

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