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Non-specular polarized neutron scattering from rough interfaces in periodic multilayered magnetic structures

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Abstract

Periodic magnetic multilayers Fe/Ge were studied by polarized-neutron reflectometry. The effect of quasi-Bragg enhancement of non-specular diffuse scattering from imperfect interlayer boundaries was observed and explained in terms of neutron diffraction on interfaces with correlated roughnesses.

Keywords: Multilayers; Polarized neutrons; Reflectometry; Roughness

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Neutron reflectometry turns out to be a powerful instrument in the study of fine structural properties of thin films and interfaces [1]. However, polarized neutrons in application to periodic magnetic multilayered structures yield some new capabilities in obtaining information on the magnitude and spatial distribution of imperfections of the interlayer boundaries [2]. Layer-to-layer correlations of these imperfections cause coherent enhancement of non-specular diffuse scattering, depending on the incident polarization direction with respect to the multilayer magnetization.

Periodic multilayered structure Fe(118 Å)/Ge(82 Å) containing 12 bilayers was deposited by electron beam evaporation technique on a glass substrate $5 \times 80 \times 210\,\mathrm{mm}^3$. The incident beam with the neutron wavelength 4.3 Å and primary polarization $\geqslant 0.98$ was used. Angular divergencies in the plane perpendicular to the faces of layers and in the plane of the layers were 0.2 and 27 mrad, respectively. The sample was magnetized in the surface plane in the external magnetic field 115 Oe which was found to be enough for saturation. The neutrons reflected specularly and scattered by an angle $\alpha + \alpha'$, α being the grazing angle of incidence, were registered by a one-dimensional position-sensitive detector.

In Fig. 1 the contour plots in logarithmic scale of the scattering intensity distribution in the coordinates of angles (α, α') are presented for the neutron polarization directed along with (a) and opposite to (b) the sample magnetization. Five characteristic stripes can be distinguished on the map. Stripe 1 corresponds to the beam passed through the sample. Stripe 4 is the specularly reflected part of the beam. It contains Bragg maxima of the first order at $\alpha = \frac{1}{2}\alpha_B = 12.6$ mrad and of the second order $\alpha = 21.6$ mrad marked with arrows. The other three, namely, stripes 2, 3 and 5 are completely due to non-specular scattering and would be of special interest to us. The nature of these stripes has been elucidated in the theory of neutron scattering at multilayers with correlated roughnesses developed on the basis of DWBA method [2].

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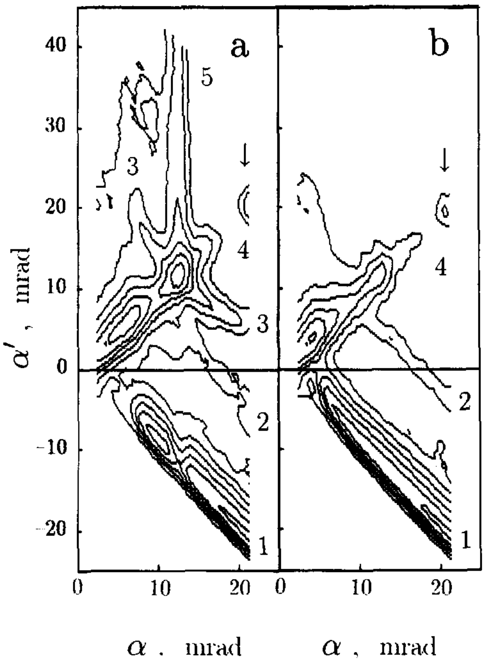

Fig. 1. Scattering intensity distribution for neutrons initially polarized along with (a) and opposite to (b) magnetization direction.

The most intensive of these non-specular stripes in Fig. 1(a) is number 3 (marked in the figure at its two ends). It is the coherently enhanced part of the diffuse scattering which appears when interface roughnesses are correlated in the direction transverse to the multilayer plane and the Bragg condition is satisfied for the momentum transfer. This stripe fits the condition $\alpha + \alpha' \approx \alpha_B$ and is slightly curved due to refraction in the vicinity of critical angles of total reflection, 7 mrad for both α and α'. This stripe is polarization-dependent and, hence, it is absent in Fig. 1(b).

For stripe 2 the condition $\alpha + \alpha' \approx \frac{1}{2}\alpha_B$ is satisfied. This enhancement is the result of interference within each bilayer of scattered waves born by the waves propagating in forward and backward directions and represents an incoherent part of the diffuse scattering. Its intensity is proportional to the number of bilayers and, hence, it is much weaker than stripe 3. Stripe 2 is similar for both Figs. 1(a) and (b), i.e. it is independent of the incident polarization. It is alluring to interpret this stripe as relating to some period in the structure which is twice as large than the chemical multilayer period 200 Å, for instance, due to antiferromagnetic coupling of Fe layers through Ge (e.g., Ref. [3]). Its manifestation in the non-specular effect should be attributed in this case to the interfaces correlated roughness as well. However, one may hardly await such a magnetic superstructure for non-epitaxial Fe layers separated by rather thick ($\simeq$100 Å) semiconductor spacers. Nevertheless, an unambiguous answer can be obtained as a result of more complex study involving a polarization analysis not available in this experiment.

Stripe 5 is the incoherent diffuse scattering as well. For this stripe the diffuse scattering is magnified as the Bragg condition for the incoming momentum is satisfied [2]. The similar enhancement of diffuse scattering takes place in imperfect crystals in the vicinity of Bragg maxima. In Fig. 1(b) it is suppressed together with the Bragg maximum, but apart from stripe 3 it is strongly asymmetric with respect to the position of the Bragg maximum. The reason is not clear so far.

It should be noted that in the case of ideal interfaces of the multilayer stripes only 1 and 4 would be present and stripes 2, 3 and 5 exist only owing to roughness of interlayer boundaries.

References

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