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Interfacial roughness and the giant magnetoresistance effect of Fe/Cr multilayers

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Abstract

We have performed magnetoresistance and neutron-scattering measurements on Fe/Cr multilayers in order to clarify the relationship between the giant magnetoresistance (GMR) effect and interfacial roughness between the Fe and Cr layers.

The giant magnetoresistance (GMR) effect in magnetic multilayers has been investigated intensively since Baibich et al. discovered the effect in an Fe/Cr multilayer in 1988 [1]. In the multilayers the resistivity change $(\rho(H) - \rho(H \gg 1))/\rho(H \gg 1)$ is very large compared with the conventional bulk magnets. Up to now it has been revealed that the antiferromagnetic coupling of ferromagnetic layers through non-magnetic spacer is essential to the GMR effect. However, it is still an open question whether the moderate interfacial roughness between the magnetic and non-magnetic layers enhances the GMR effect or not [2, 3]. Neutron scattering is the most powerful technique to study such roughness because it is directly reflected in the profile of off-specular diffuse scattering [4]. X-rays are also available to investigate the roughness, but the sensitivity to magnetism gives the neutron an advantage over X-rays.

We have already made a brief report on the study of interfacial roughness in Fe/Cr multilayers by neutron scattering, and showed that an Fe/Cr multilayer grown on a MgO substrate and a similar one on Al_2O_3 have different interfacial roughnesses [5]. However, these samples have a different stacking number of Fe/Cr bilayers, so we could not directly compare the magnitude of the GMR effects with each other. In this paper, we report the results of magnetoresistance and neutron-scattering measurements of Fe/Cr multilayers on MgO and Al_2O_3 with the same stacking number of Fe/Cr bilayers.

Multilayers of Cr(10.0 nm)/[Fe(3.0 nm)/Cr(1.0 nm)] × 30/Cr(10.0 nm)/Nb(35.0 nm) were grown on MgO, sample A, and on Al_2O_3, sample B, by molecular beam epitaxy with the sample plane being the (0 0 1) direction of BCC Fe and Cr [6]. The neutron-scattering measurements were performed on the TOPAN spectrometer at JRR-3M in JAERI in Tokai. The wavelength of the incident neutron beam was fixed at 0.25 nm using a PG monochromator in focusing geometry. A PG analyzer and filter were used to reduce the background and remove the higher-order contamination, respectively. Magnetoresistance was measured by a conventional 4-wire method.

Fig. 1 shows the magnetic-field dependence of resistivity for samples A (a solid line) and B (a broken line) at room temperature. Currents were parallel to the (1 1 0) BCC direction of Fe and Cr in the sample plane and the magnetic fields were applied normal to the in-plane currents. The magnitude of the resistivity change for sample

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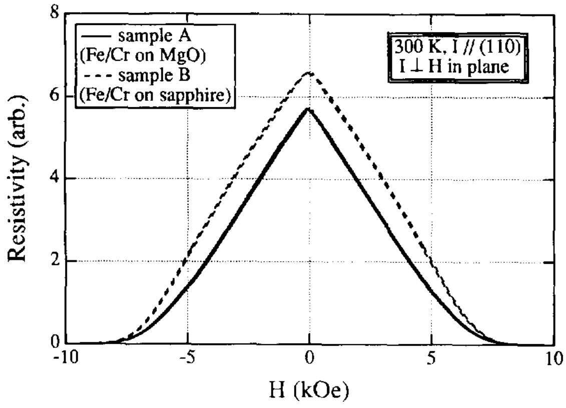

Fig. 1. The magnetic-field dependence of resistivity of Fe/Cr multilayers on MgO, sample A (solid line) and that on Al_2O_3, sample B (broken line).

B is 6.6%, larger than that of sample A which is 5.7%. On the other hand, the saturation fields, above which the resistivity shows no field dependence, of both samples are almost the same (~ 9.5 kOe).

The θ–2θ scans and Q_z scans, of samples A and B at room temperature are displayed in Figs. 2(a) and 3(a), respectively. Hereafter we define the direction normal to the sample plane as the z-axis, and the sample plane as the xy-plane. The scans in antiferromagnetic state of ferromagnetic Fe layers (FMFEL) are plotted by solid circles and those in the forced ferromagnetic state induced by external magnetic field by open circles in these figures. The peaks appearing around 0.08 Å^{-1} correspond to the antiferromagnetic structure of the FMFEL with twice the lattice spacing of Fe/Cr bilayer of 4 nm. Bragg peaks due to the Fe/Cr bilayers are observed around 0.16 Å^{-1}. We name the former the $\frac{1}{2}$ peak and the latter the first peak. The intensities of the $\frac{1}{2}$ peak decrease with increasing field, and the peak disappears in the ferromagnetic state. This is due to the fact that the antiferromagnetic alignment of the FMFEL goes to the ferromagnetic one through the canting state. We cannot observe any clear difference between the two samples in the Q_z scans.

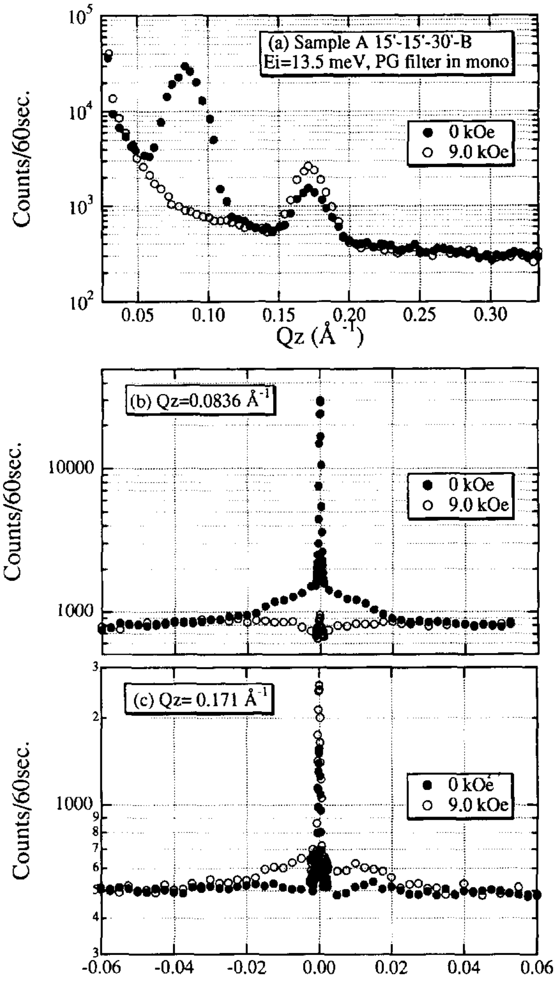

Fig. 2. The Q_z scan (the θ–2θ scan) (a), the Q_r scan around the 1/2 peak (b) and the first peak (c) of Fe/Cr multilayer on MgO substrate (for the 1/2 and first peak, see text). These scans were done at room temperature.

The profile of off-specular diffuse scattering around the $\frac{1}{2}$ and the first peaks of sample A are shown in Fig. 2(b) and (c) as a function of Q_r, and that of sample B in Fig. 3(b) and (c), respectively. Here, we assume that there is no anisotropy in the sample plane and define $Q_r^2 = Q_x^2 + Q_y^2$ where Q_x and Q_y are the x and y components of the scattering vector. The Q_r scan is similar to the rocking scan with the scattering angle fixed as schematically represented in Fig. 4. The off-specular diffuse scattering around the $\frac{1}{2}$ peak of sample B is more clearly observed than that of sample A in the absence of magnetic fields. The diffuse scattering around the 1st peak is induced by magnetic fields in both samples, and the diffuse scattering of sample B is also larger than that of sample A. It is noted that this diffuse scattering has a magnetic origin and that X-rays are insensitive to the magnetic disorder at the interfaces. This observation clearly indicates that the magnetic disorder at the interface in Fe/Cr multilayers enhances the GMR effect. However, if the interfacial roughness is extremely large, it is expected to reduce the GMR effect. It is important to estimate the interfacial roughness quantitatively using an appropriate model, for example by a model in which the roughness is described as a Fractal surface [7]. This work is now in progress.

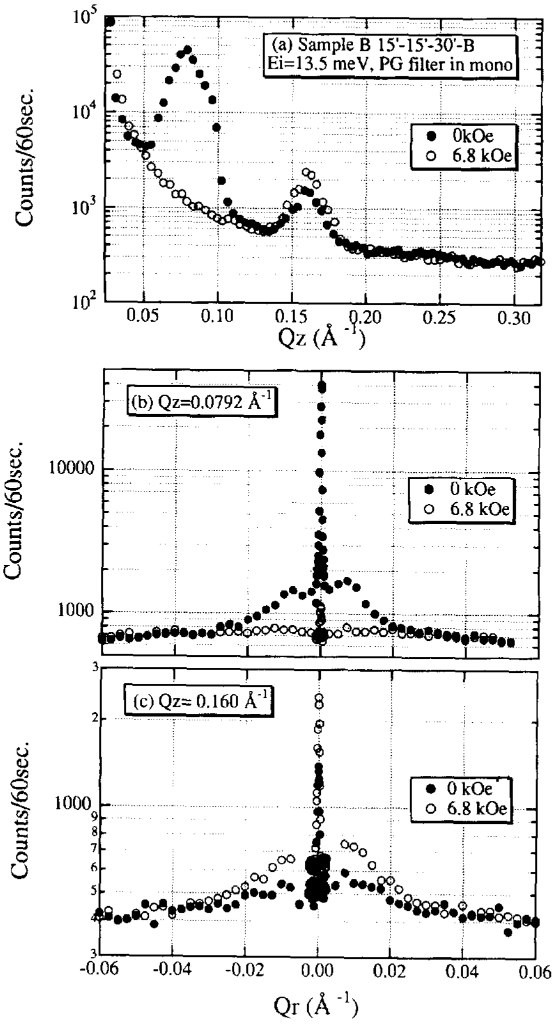

Fig. 3. The Q_z scan (a), and the Q_r scan around the 1/2 peak (b) and the first peak (c) of Fe/Cr multilayer on Al_2O_3 substrate at room temperature.

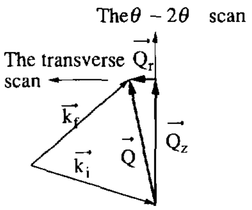

Fig. 4. Schematic representation of the Q_r scan.

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