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Growth of and giant magnetoresistance effect in epitaxial Fe/Cr superlattices

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The discovery of a giant magnetoresistance (GMR) effect in Fe/Cr superlattices has stimulated studies of the spin-dependent scattering and oscillatory behavior of interlayer exchange coupling in magnetic multilayer structures. Interface roughness has been theoretically shown to play an important role in both phenomena; however, the relation between the roughness and the GMR effect is still controversial from the experimental viewpoint. The contradictions in the experimental results that have been reported may be due to uncontrollable factors in the polycrystalline samples that were used. Studies using well-characterized samples are therefore needed. *In situ* observation using reflection high-energy electron diffraction (RHEED) in molecular beam epitaxy (MBE) has made it possible to grow superlattices having well-defined interface roughness. Because Fe and Cr have the same crystal structure (body-centered cubic) and very close lattice constants, epitaxial Fe/Cr superlattices should grow in layer-by-layer growth mode. For this reason, the epitaxial Fe/Cr superlattice is a good model system for investigating the effect of the interface roughness on the GMR effect and on the exchange coupling. We have investigated the MBE-growth of (001)- and (110)- oriented Fe/Cr superlattices and their GMR effect. We found that the growth conditions change the interface roughness and morphology of the Fe/Cr superlattices and affect the GMR and the interlayer exchange coupling behaviors. The following is a summary of the experiments we conducted and their results.

To discuss how the GMR properties are affected by the interface roughness, we grew (001)-oriented Fe/Cr superlattices by changing the growth temperature on MgO(001) substrates. The resulting superlattices showed different degrees of atomic mixing but almost the same geometrical roughness at the Fe/Cr interface. While the magnetoresistance ratio and the magnetic field dependence of the magnetoresistance $\Delta R/R(H)$ and magnetization $M(H)$ changed systematically depending on the growth temperature, we did discover a universal relation,

$\Delta R/R(H) \propto - M(H)^2$, that is consistent with the theoretical model. The nonlinear behavior of $M(H)$ that occurred with an increasing growth temperature was found to be related to the biquadratic exchange coupling.

We performed neutron scattering measurement on the Fe/Cr(001) superlattices grown on MgO(001) or $Al_2O_3(10\bar{1}2)$ substrates. The off-specular diffuse scattering that appeared around the Bragg point corresponding to the antiferromagnetic arrangement of the Fe-layer moments indicated the existence of the magnetic roughness (magnetic disorder) at the interface. The intensity of this scattering in the Al_2O_3 sample was larger than that in the MgO sample. A systematic substrate dependence on the GMR properties was found in a series of Fe/Cr(001) superlattices grown on MgO(001) and $Al_2O_3(10\bar{1}2)$ substrates under the same growth conditions. This indicates that the magnetic interface roughness is correlated to the GMR properties. The differences observed in the GMR properties and in the degree of magnetic interface roughness between the MgO and Al_2O_3 samples are apparently due to the differences in their crystal growth features; however, the details of this still need to be clarified.

The (110)-oriented Fe/Cr superlattices showed a self-organized quasi-periodic faceted morphology, as shown in Fig. 1. The faceted grain width, defined in Fig. 1, was controlled by adjusting the growth parameters. The self-organized faceted morphology in the Fe/Cr(110) superlattices results from the kinetic roughening, the lower surface free energy of the {100} plane than that of the {110} one, and a very large sticking probability of the adatoms to the steps that parallel to the [001] axis. A large uniaxial magnetic anisotropy and GMR properties were induced in the (110) plane. When a magnetic field was applied to the easy direction (that parallel to the [001] axis), the saturation field of the GMR was 1/3-1/4 of that for the hard direction (that parallel to the [$\bar{1}$10] axis). A large increase in the magnetic field sensitivity is attractive for application to magnetoresistive sensors.

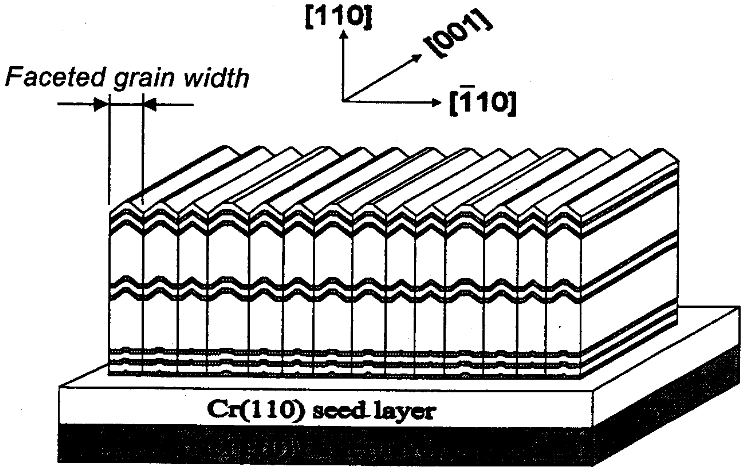

Figure 1. Schematic drawing of faceted Fe/Cr(110) superlattices.