INTERFACE MAGNETISM OF Fe/Nd MULTILAYERS STUDIED BY MÖSSBAUER SPECTROSCOPY

K. MIBU, N. HOSOITO and T. SHINJO

Institute for Chemical Research, Kyoto University, Uji, Kyoto-fu 611, Japan

Fe/Nd multilayers with ^{57}Fe enriched interfaces are prepared to investigate crystal structure and magnetism at the interface by Mössbauer spectroscopy. The intermixture at the interface is less than two atomic layers. The magnetic moments of interface Fe atoms align collinear and turn at a certain temperature or at a certain magnetic field with keeping the collinear structure. By annealing, the interface component with smaller hyperfine field decreases and the perpendicular magnetic anisotropy increases.

Metallic multilayers with artificial superstructures have been attracting much attention from scientific and technical viewpoints this decade. In case of Fe/rare-earth metal (RE) multilayers, the subjects which have been reported recently are magnetic anisotropy, magnetic interaction between Fe layers, and so on. In some kinds of Fe/RE multilayers, perpendicular magnetic anisotropy and spin reorientation have been observed when the layer thicknesses are properly controlled /1,2/. However the origin of the magnetic anisotropy is still open for discussion because of lack of information about the interface crystallographic and chemical structures. To investigate microscopic crystal structure and magnetism at the interface, we prepared two [Fe(39Å)/Nd(28Å)] multilayers with ^{57}Fe (50%) enriched interface layers of 6Å at one side of the Fe layers, and performed a ^{57}Fe Mössbauer study. The samples were prepared by deposition in ultrahigh vacuum with the sequences of ^{56}Fe(33Å)/^{57}Fe(6Å)/Nd(28Å) (sample A) and Nd(28Å)/^{57}Fe(6Å)/^{56}Fe(33Å) (sample B), as shown in fig. 1 (a). The substrates were cooled to be about -50 °C during the deposition. ^{57}Fe Mössbauer spectra were measured by a conventional absorption method. The incident γ-ray direction was normal to the film plane. From Mössbauer study of non-enriched Fe/Nd multilayers, it is known that the Fe layer of [Fe(39Å)/Nd(28Å)] consists of α-Fe at the inner part of the layer and Fe atoms with smaller hyperfine fields at the interface region of about 5Å thick /2/. The interface Mössbauer spectrum was derived by subtracting the spectrum of α-Fe from the measured spectrum, however the S/N ratio was not sufficient to investigate the interface properties in detail. It is also known that the direction of the Fe magnetic moments in this multilayer changes from in-plane to perpendicular to the film plane when the temperature is lowered.

Mössbauer spectra at 300K for samples A and B are shown in fig. 1 (b). The distribution of the hyperfine field derived from fitting the spectra is shown in fig. 1 (c). For both samples, the hyperfine field is distributed continuously with a maximum at 32T and the spectrum cannot be fitted with a few sites. The component with the peak hyperfine field is attributed to the ^{57}Fe atoms adjacent to the ^{56}Fe layer, and the continuously distributed component with smaller hyperfine fields is from those near to the Nd layer. In an ideal case,

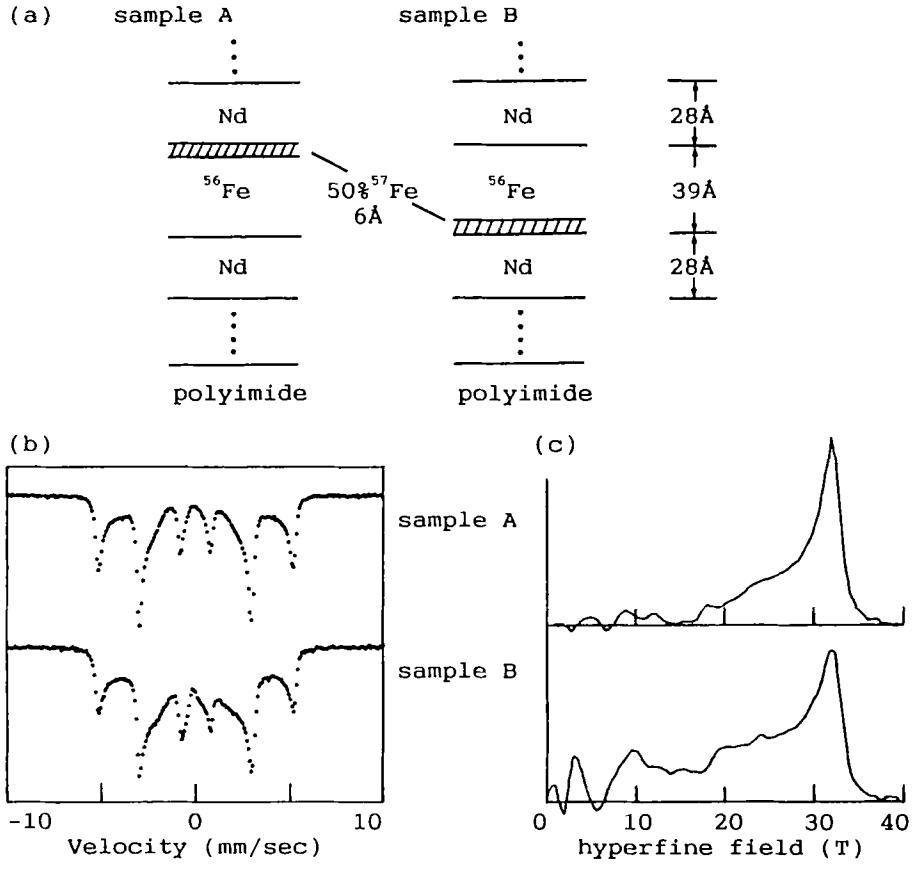

Fig. 1 (a) Structures of the prepared samples with ^{57}Fe enriched interfaces. (b) Mössbauer spectra for the two samples at 300K. (c) Distribution of the hyperfine field derived from the spectra. The direction of the hyperfine field is assumed to be parallel to the film plane.

the enriched layer of 6Å consists of three Fe atomic layers. In the present case, the situation is not ideal. If the distribution of the hyperfine field is divided into three parts with equal areas tentatively, the average hyperfine field for each portion is estimated to be 21T, 30T, and 32T for sample A, and 12T, 25T, and 31T for sample B. Possible origins of the reduction of the hyperfine field are formation of an Fe-Nd amorphous alloy by intermixing and/or formation of chemically pure amorphous-like Fe at the interface as well as intrinsic interface effects. The intermixture at the interface is at most one or two atomic layers in these samples. The spectra for samples A and B are relatively similar if compared with the cases of Fe/Sb /3/ and Fe/Mn interfaces /4/. (Notice that the enriched layer is a little thicker in this work.) However sample B has a larger ratio of the component with the smaller hyperfine field than sample A has, which means Fe layer deposited on Nd layer has crystallographically disarranged interface rather than the other interface.

Temperature dependence of the spectra for sample B is shown in fig. 2 (a). The intensity ratio of the magnetically split six lines

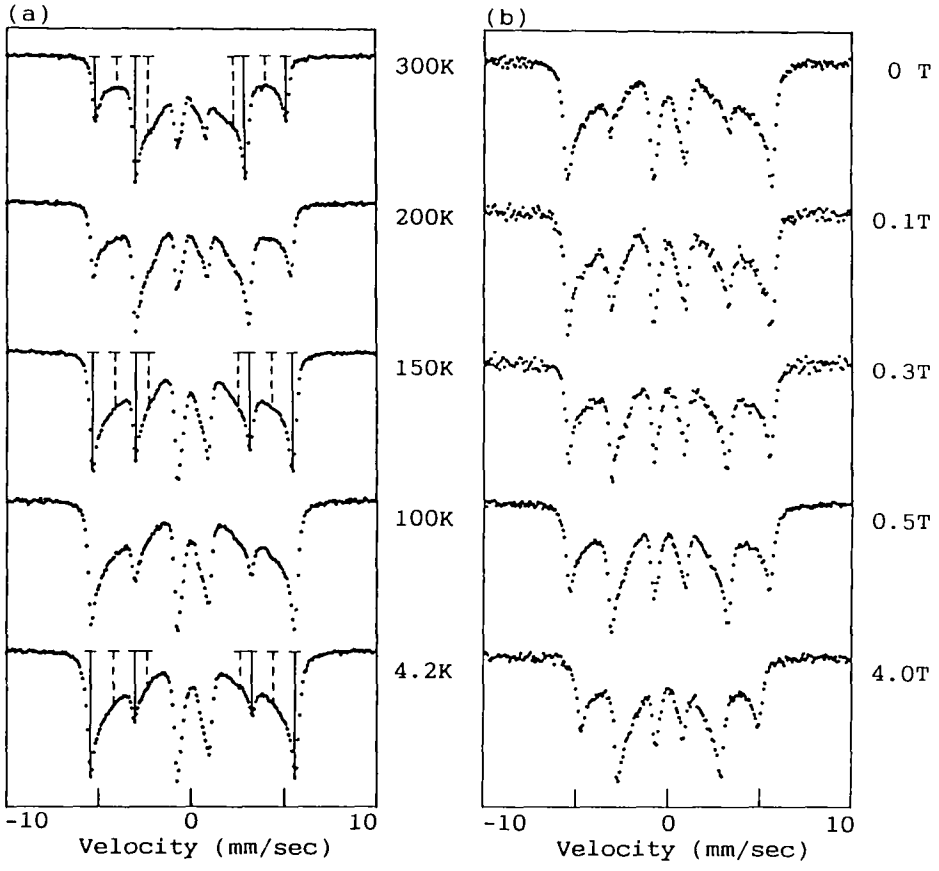

Fig. 2 (a) Temperature dependence of Mössbauer spectra for sample B. The intensities of outer four lines of magnetically split six lines are indicated. The solid lines correspond to the hyperfine field at the peak in the distribution curve, and the broken lines at 78% of the peak value, respectively. (b) Mössbauer spectra at 5.0K for sample B when magnetic fields are applied parallel to the film plane.

changes at 150K, which indicates that the Fe magnetic moments turn from in-plane to perpendicular to the film plane. To investigate the direction of the Fe magnetic moments at different positions of the enriched layer separately, outer four lines of magnetically split six lines for the peak hyperfine field and for the hyperfine field of 78% of the peak value are indicated in the figure. From the estimation of the average hyperfine fields mentioned above, the former component is considered to be from the ^{57}Fe atoms adjacent to the ^{56}Fe layer and the latter is from the middle part of the enriched layer. The Fe magnetic moments of both components turn to the perpendicular direction at the same temperature. As shown in the preceding paper, the Nd and the Fe layer magnetization are coupled through an exchange interaction at the interface and they are making a certain angle with each other. From the result of this paper, the Fe-Fe ferromagnetic interaction at the interface region is found to be strong enough to keep the Fe magnetic

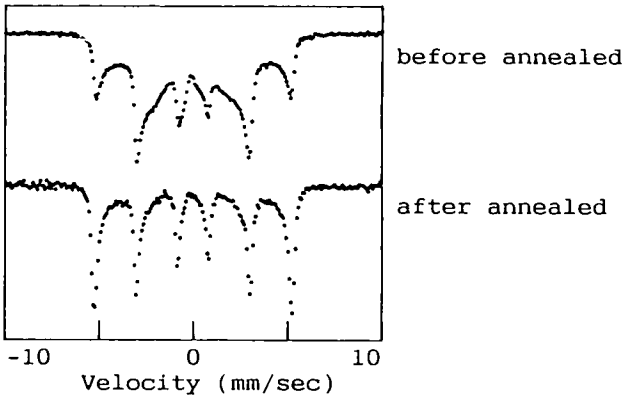

Fig. 3 Mössbauer spectra for sample B at 300K before and after annealed.

moments collinear. The direction of the Fe magnetic moments just adjacent to the Nd layer is difficult to determine because the average hyperfine field is expected to be 38% of the peak value and the six-line pattern is overlapping with larger hyperfine field components.

When a magnetic field is applied parallel to the film plane, the Mössbauer spectra at 5.0K for sample B change as shown in fig. 2 (b). When large fields are applied, all Fe magnetic moments align parallel to the film plane ferromagnetically. No antiferromagnetic component is observed. When the field is reduced, the Fe magnetic moments turn gradually to the perpendicular direction. In this case, the Fe magnetic moments are also kept collinear.

The interface structure of a multilayer is expected to change by annealing because it is in a non-equilibrium state. Sample B was annealed at 200°C in a vacuum of 10^{-8} Torr for 24 hours. High vacuum of 10^{-8} Torr is necessary to avoid oxidization of the Nd layer during annealing. From X-ray diffraction measurements, it turned out that the artificial periodicity was maintained and oxidization of Nd layer was negligible after annealed in this condition. The Mössbauer spectra at 300K before and after annealed are shown in fig. 3. The component with smaller hyperfine field decreases and the perpendicular magnetic anisotropy increases. The decrease of the interface component with smaller hyperfine field is considered to be caused by crystallization of chemically pure amorphous Fe formed at the interface or negative diffusion of Fe atoms from the Fe-Nd amorphous alloy at the interface. There is a proposition that the perpendicular magnetic anisotropy of Fe/RE multilayers is originated from the anisotropy of an Fe-RE amorphous alloy formed at the interface region. However, the present result does not support this proposition.

References

/1/ K. Yoden, N. Hosoito, K. Kawaguchi, K. Mibu and T. Shinjo, Jpn. J. Apple. Phys. 27(1988)1680
/2/ K. Mibu, N. Hosoito and T. Shinjo, J. Phys. Soc. Jpn. 58(1989) 2916
/3/ T. Shinjo, N. Hosoito, K. Kawaguchi, T. Takada, Y. Endoh, Y. Ajiro and J. M. Friedt, J. Phys. Soc. Jpn. 52(1983)3154
/4/ N. Nakayama, T. Katamoto and T. Shinjo, J. Phys. F: Met. Phys. 18(1988)935