Magnetic and Structural Changes of Au/Fe Multilayers Induced by Ar Ion Irradiation and Thermal Annealing

I. SAKAMOTO¹, H. TANOUE¹, N. HAYASHI¹,
M. NAWATE², S. HONDA² and Y. IKEDA³

1) Electrotechnical Laboratory, 1-1-4 Umezono, Tsukuba, Ibaraki 305, Japan

2) Hiroshima University, 1-4-1 Kagamiyama, Higashi-Hiroshima, Hiroshima 739, Japan

3) Japan Atomic Energy Research Institute, Tokaimura, Ibaraki 319-11, Japan

Abstract - The magnetic and structural changes of $[1.2\text{nm Au}/0.3\text{nm Fe}]_{180}$ multilayers (MLs) induced by Ar ion irradiation and thermal annealing have been investigated by Conversion Electron Mössbauer Spectroscopy (CEMS). The distributions of hyperfine fields (H_{hfs}) estimated from CEM spectra indicate the decrease of the H_{hfs} due to the breaks of the Fe layer structure in Au/Fe MLs by the ion irradiation and the thermal treatment. The thermal annealing causes the paramagnetic doublet peaks due to Fe clusters and the split six-line peaks arising from metallic α -Fe phase. However, the ion irradiation does not induce metallic α -Fe phase because of the mixing effects by ion irradiation.

I. INTRODUCTION

Metallic multilayers (MLs) have been investigated extensively because of their potentiality as new materials. Studies of Au/Fe MLs have been performed for academic study and practical use of the giant magnetoresistance (GMR) and the perpendicular magnetic anisotropy. Since artificially layer structures are not in the thermal equilibrium state, the structures are inevitable to change by heat treatments. Still more, ion irradiations cause a structural change of MLs as shown in Tb/Fe MLs by Richomme et al[1].

In this paper, we have been investigated the stability of Au/Fe MLs for thermal treatments and ion irradiations in order to clarify the difference of both treatments in Au/Fe MLs.

II. EXPERIMENT

Au/Fe MLs were prepared on glass substrates at $(4 - 8) \times 10^{-7}$ Torr by electron beam evaporation techniques. The layer thicknesses of Au and Fe were kept at 1.2 nm and 0.3 nm, respectively. Repetitions of Au and Fe layers were done until the total thickness of Fe layers reached about 50 nm, which was sufficient for CEMS measurements. Small angle X-ray diffraction patterns (XRD) indicated that these films had a good layer structure. Thermal treatments were done at each annealing temperature, T_a for 30 min in a vacuum better than 1×10^{-6} Torr. Ion irradiations were performed by 400 keV Ar ions at room temperature. The irradiation was done at 1.5

$\times 10^{-6}$ Torr and the beam current was kept at levels of $0.6 \mu\text{A}/\text{cm}^2$. CEMS measurements were carried out at room temperature by the detection of the conversion electrons using a He + 10% CH⁴ gas-flow type proportional counter and using a Mössbauer spectrometer equipped with a 370 MBq or a 740 MBq Rh matrix ⁵⁷Co source. We analyzed the CEM spectra by least-squares fitting with overlapped Lorentzian curves, and then obtained the hyperfine parameters[2].

III. RESULTS AND DISCUSSION

The CEM spectra of the $[1.2\text{nm Au}/0.3\text{nm Fe}]_{180}$ ML irradiated with 400 keV Ar ions in the fluence range up to 9×10^{13} ions/cm² are shown in Fig. 1. The spectrum for the as-deposited state (Fig. 1a) shows broader peaks than those of metallic α -Fe phase. The broader peaks probably arise from the interface layer, and the discontinuous Fe layer, because they usually come from a distribution of hyperfine fields (H_{hfs}) or magnetic relaxation process, and so the larger values of peak widths are reasonable for the $[1.2\text{nm Au}/0.3\text{nm Fe}]_{180}$ ML. In addition, the intensities of 2nd and 5th peaks of Fig. 1(a) are smaller than those of the other peaks; that is, the direction of H_{hfs} is out of the film plane. As shown in Fig. 2, the distributions of the H_{hfs} based on the Hesse-Rübartsch method were estimated from the CEM spectra of Fig. 1 assuming that the

Fig. 1. CEM spectra of $[1.2\text{nm Au}/0.3\text{nm Fe}]_{180}$ ML; (a) as-deposited, (b) 3×10^{13} ions/cm², (c) 9×10^{13} ions/cm².

intensity ratios of 1st, 2nd and 3rd peaks were 3 : 1 : 1 with the fixed values of the peak widths and the isomer shift[2, 3]. As shown in Fig.2, the distributions of the H_{hfs} positioned toward the lower field but not the higher field than the as-deposited case with increasing ion fluence up to 9×10^{13} ions/cm². These redistributions toward the lower field indicate the breaks of the Fe layer structure in Au/Fe MLs due to the mixing effects of Ar ion irradiation. Richomme et al. observed a demixing at the interfaces of Tb/Fe MLs only at low fluence; that is, the increase of the mean H_{hfs} [1]. But we did not observe any demixing of the Fe and Au atoms in Au/Fe MLs.

Figure 3 shows the CEM spectra of the $[1.2\text{nm Au}/0.3\text{nm Fe}]_{180}$ ML after thermal treatments at each temperature. Although the CEM spectrum after annealing

Fig. 2. Distributions of H_{hfs} estimated from CEM spectra in Fig. 1; (a) as-deposited, (b) 3×10^{13} ions/cm², (c) 9×10^{13} ions/cm².

at 230 °C shows the decrease in the intensities of 1st and 6th peaks, the annealing at 300 °C has induced the paramagnetic doublet peaks and the split six-line peaks of metallic α -Fe phase[4]. The distributions of the H_{hfs} estimated from the CEM spectra in Fig. 3 are shown in Fig. 4. In these cases, we assumed that the intensity ratios of 1st, 2nd and 3rd peaks were (a) 3 : 1 : 1, (b) 3 : 1 : 1, (c) 3 : 2 : 1 with the fixed values of the peak widths and the isomer shift. We can see in Fig. 4 that the distributions of the H_{hfs} positioned toward the lower field and the higher field than the as-deposited case regardless of the intensity ratios. Supposing from the appearances of the paramagnetic phase and α -Fe phase at 300 °C, the redistributions toward the lower field and the higher field are reasonable as an intermediate state.

Fig. 3. CEM spectra of $[1.2\text{nm Au}/0.3\text{nm Fe}]_{180}$ ML; (a) as-deposited, (b) $T_a = 230^\circ\text{C}$, (c) $T_a = 300^\circ\text{C}$

IV. CONCLUSION

The distributions of H_{hfs} estimated from the CEM spectra indicate the decrease of the H_{hfs} due to the breaks of the Fe layer structure in Au/Fe MLs by the ion irradiation and the thermal treatment. The thermal annealing causes the paramagnetic doublet peaks due to Fe clusters and the split six-line peaks arising from metallic α -Fe phase. However, the ion irradiation does not induce metallic α -Fe phase because of the mixing effects by ion irradiation.

Fig. 4. Distributions of H_{hfs} estimated from CEM spectra in Fig. 3; (a) as-deposited, (b) $T_a = 230^\circ\text{C}$, (c) $T_a = 230^\circ\text{C}$

REFERENCES

- [1] F. Richomme, J. Teillet, A. Fnidiki and M. Toulemonde, Nucl. Instr. and Meth. in Phys. Res. B, vol. 122, pp. 507-509, 1997.
- [2] Z. Klencsar, E. Kuzmann and A. Vertes, J. Radioanalytical and Nuclear Chemistry, Articles, vol. 210, pp. 105-118, 1996.
- [3] J. Hesse and A. Rübartsch, J. Phys. E: Sci. Instr., vol. 7, pp. 526-532, 1974.
- [4] I. Sakamoto, K. Koguma, M. Nawate and S. Honda, J. Magn. Magn. Mater., vol. 165, pp. 208-211, 1997.