Journal of Magnetics 6(4), 129-131 (2001)

Effect of Highly Oriented Layer on GMR and Magnetic Properties of NiFe/Cu Thin Film Prepared by Magnetron Sputtering

Yong-Goo Yoo[1], Seong-Cho Yu[1,*], Seong-Gi Min[1], Kyeong-Sup Kim[2] and Pyung-Woo Jang[3]

[1]*Department of Physics, Chungbuk National University, Cheongju 361-763, Korea*
[2]*Institute for Basic Sciences, Chungbuk National University, Cheongju 361-763, Korea*
[3]*Department of Physics, Chongju University, Cheongju 360-764, Korea*

(Received 1 December 2001)

In order to investigate the effect of the interface on GMR, [NiFe(25 Å)/Cu(24 Å)]$_2$/Si thin film was epitaxially grown on HF-treated Si (001) substrate using a DC magnetron sputtering method. Typical GMR effects could be observed in epitaxial film with a weak antiferromagnetic exchange coupling while non epitaxial film showed unsaturated and broad MR curves probably due to inter-diffusion between NiFe and Cu layers. Ferromagnetic resonance (FMR) experiment showed two distinct absorption peaks in all films. Each peak was revealed to come from each NiFe layer with different magnetic property. In FMR measurement, very clear interface in epitaxial films could be confirmed by a lower value of line width (ΔH) and higher M_s of epitaxial film than those of non epitaxial films, respectively.

Key words : GMR, epitaxial film, FMR, antiferromagnetic

1. Introduction

Antiferromagnetically coupled thin films have been studied because of their high potential for the application such as giant magnetoresistance (GMR) sensor from the past decade [1, 2]. In sandwich structure of magnetic and non-magnetic layers, the GMR effect was known to be originated from the scattering of polarized electrons at the interface as well as defects in bulk area [3, 4]. But it was also reported that the GMR effect was strongly dependent upon the scattering of polarized electrons only at the interface between different layers [5, 6]. It is well known that interfacial roughness diffuses spin information of transporting electrons that causes lower GMR effect. However, the effect of roughness at the interface was not completely understood.

NiFe/Cu multilayer films have been studied because of excellent soft magnetic properties. However, with the increase of NiFe layer thickness, inter-diffusion between NiFe and Cu layer at the interface was promoted [7, 8] because Ni atoms diffuse into Cu layer due to the high solubility of Ni in Cu. GMR properties becomes worse and worse with increasing NiFe layer thickness as a result [8].

In this work, thin films made of NiFe and Cu layers, which are known to have clear magnetic interface, were epitaxially grown on HF-treated Si (001) substrates. The inter-diffusion effect was studied with the variation of magnetoresistance (MR) and ferromagnetic resonance (FMR) measurement for epitaxial and non-epitaxial films.

*Tel: +82-431-261-2269; e-mail: scyu@chungbuk.ac.kr

[NiFe(25 Å)/Cu(24 Å)]$_2$/Si thin films were epitaxially grown on HF-treated Si (001) substrates by a DC magnetron sputtering method. For the purpose of good comparison, non-HF-treated Si (001) substrates were placed very close to the HF-treated Si (001) substrates, at the center of substrate holder in every sputtering. Base pressure of the chamber was better than 4.5×10^{-7} torr at room temperature. The sputtering pressure was 1 mtorr and deposition rate was 1 Å/sec..

Epitaxial growth of thin film could be confirmed by X-ray diffraction (XRD) profile with Cu K_α radiation. The MR ratio was measured by the conventional four-point method at room temperature under a maximum in-plane field of 120 Oe. Magnetic properties were analyzed with a vibrating sample magnetometer (VSM) and X-band ferromagnetic resonance (FMR) at room temperature.

Figure 1 shows θ-2θ scan results of [NiFe(25 Å)/Cu(24 Å)]$_2$ films deposited on the HF-treated substrates as well as on the non-HF-treat substrate. Diffraction peak only from (002) planes of Cu and NiFe in film on the HF-treated substrates can be seen. From this (002) peak epitaxial growth could be confirmed in [NiFe/Cu]$_2$ films on the HF-treated substrates [9]. Normally (111) peak is strongest as shown in the film deposited on the non-HF-treated substrate and in Cu and NiFe powder diffraction data. From the nature of

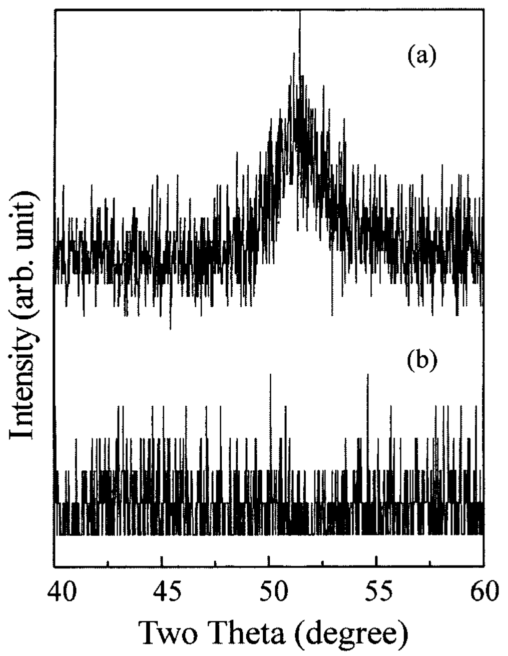

Fig. 1. XRD patterns of (a) epitaxial film and (b) non-epitaxial film with [NiFe(25 Å)/Cu(24 Å)]$_2$ stacking.

epitaxial growth, sharper and less rough interface as well as less inter-diffusion at the interface could be assumed in the films on the HF-treated substrates.

Figure 2 shows variations of MR value of films with [NiFe(25 Å)/Cu(24 Å)]$_2$ epitaxial and non-epitaxial films at room temperature under a maximum field of 120 Oe. The MR ratio of the epitaxial film is much larger than that of the non-epitaxial film even though its absolute MR value is much smaller than reported MR value of films with larger stacking layers. A low MR value may be due to a less stacking number of layers because a less stacking number gives rise to a non-uniformity of the layer properties and incomplete antiferromagnetic coupling, leading to a low MR value [10]. The non-epitaxial film showed unsaturated and broad MR curve under a maximum field of 120 Oe, which is similar to the behavior of superparamagnetic materials. It could be formed due to inter-diffusion between NiFe and Cu layers as explained below. From Fig. 2 it can be seen that the epitaxial growth can promote spectroscopic reflection of electron due to clear interface compared with the non-epitaxial film sputtered simultaneously. Spectroscopic reflection induced by a good interface extends electron mean free path of electrons, so that the GMR effect can be seen dominant, which means that a lower resistivity of the epitaxial film than that of the non-epitaxial film.

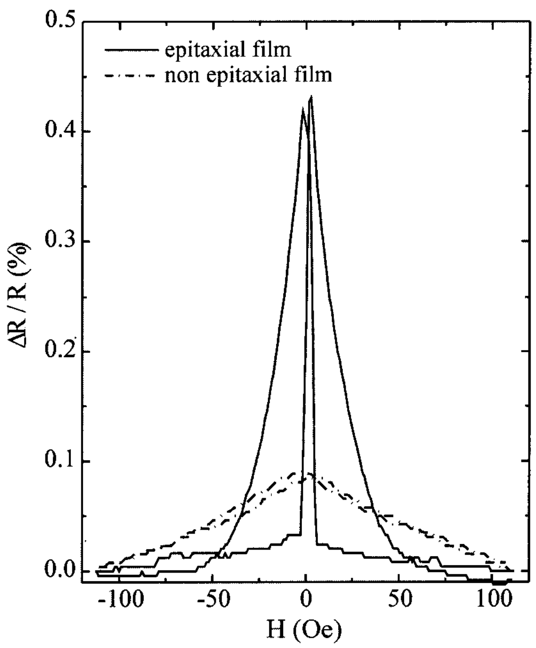

Fig. 2. MR curves of epitaxial and non-epitaxial film with [NiFe(25 Å)/Cu(24 Å)]$_2$ stacking at room temperature.

The electric resistivity was 0.20 and 0.29 μΩcm, respectively for HF-treated, and non treated samples. Lower resistivity of the former reflects that the possibility of spectroscopic reflection of electrons at the interface is higher, so that the mean free path spin polarization is longer, and spin flipping by interface less possible. Thus, larger GMR effect was observed for the HF-treated one.

Highly defined interface could give rise to better antiferromagnetic coupling between layers. Better antiferromagnetic coupling of the epitaxial film could be confirmed in VSM hysteresis loops as shown in Fig. 3. Figure 3 shows hysteresis loops of [NiFe(25 Å)/Cu(24 Å)]$_2$ thin films measured at room temperature. The squareness of epitaxial film and non-epitaxial film were 0.71 and 0.9, respectively. Low squareness of epitaxial film means stronger antiferromagnetic coupling, or better alignment of electron spins, which gives the larger MR value than that of non-epitaxial film.

In order to understand a low MR value as well as inter-diffusion between Cu and NiFe layers of epitaxial film,

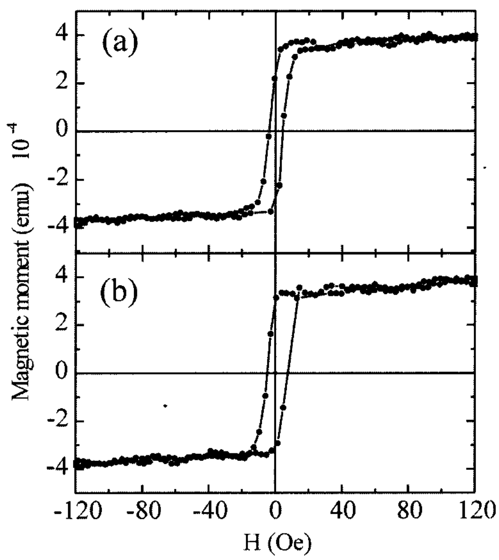

Fig. 3. The hysteresis loops of (a) epitaxial film and (b) non-epitaxial film with [NiFe(25 Å)/Cu(24 Å)]$_2$ stacking.

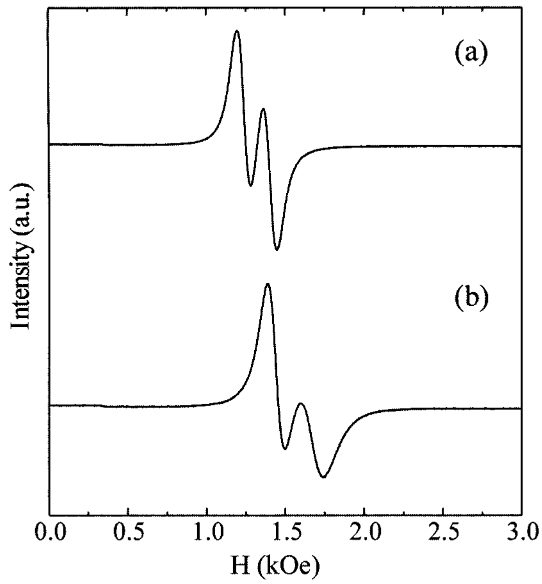

Fig. 4. FMR absorption derivatives of (a) epitaxial film and (b) non-epitaxial film with [NiFe(25 Å)/Cu(24 Å)]$_2$ stacking.

FMR experiment was done. Figure 4 shows FMR absorption derivatives of epitaxial and non-epitaxial [NiFe(25 Å)/Cu(24 Å)]$_2$ thin films measured at room temperature. Two absorption peaks appear in both films. Microwave energy could be absorbed in the interior (bulk) and/or interface of thin films. In our case each peak was seemed to come from each NiFe layer because only one absorption peak could be clearly seen in the films with NiFe/Cu and Cu/NiFe/Cu type structure. However, which absorption derivative comes from the first NiFe layer of [NiFe(25 Å)/Cu(24 Å)]$_2$ is not clear yet.

In Fig. 4 absorption derivatives of epitaxial film are sharper than those of non-epitaxial film. The line width (ΔH) of the first and second absorption of the epitaxial and non-epitaxial films are 8.3 and 8.2, and 11.1 and 14.1 Oe, respectively. Because high ΔH in FMR reflects non-uniformity of the magnetic phase, larger ΔH of non-epitaxial film means a larger the inter-diffusion and roughness at the interface compared with the epitaxial film. This inter-diffusion and roughness could also be inferred from the low resonance field (H_r) of epitaxial film. In FMR of soft magnetic film a smaller in-plane resonance field means a larger saturation magnetization (M_s). If inter-diffusion occurred at the interface, M_s should decrease. Therefore lower H_r of epitaxial film reflects a sharper interface between NiFe and Cu layer. Clear interface could also be confirmed by the resonance field difference ($\Delta H_r = H_{r1} - H_{r2}$) of each layer. ΔH_r of the epitaxial film and non-epitaxial film are 148 and 195 Oe, respectively. Lower ΔH_r value of the epitaxial film means the magnetic properties of each layer is more similar than those of the non-epitaxial film.

[NiFe(25 Å)/Cu(24 Å)]$_2$ thin film was deposited by a DC sputtering method. Thin film was epitaxially grown on the HF treated Si(001) substrates in order to get magnetically clear interface between NiFe and Cu layer.

XRD profile of epitaxial film showed a good (002) epitaxial growth of Cu and NiFe layer. In MR measurement, epitaxial film showed typical GMR curve due to antiferromagnetic exchange coupling even though it was small, while non-epitaxial film shows unsaturated and broad curve with a very low MR value. It could be analyzed that the highly defined interface of the epitaxial film ensured antiferromagnetic coupling compared with the non-epitaxial film. Lower resistivity of HF-treated sample revealed that better interface enables less spin flipping at the interface and larger GMR effect.

FMR absorption peaks were consisted of two peaks in all films, which were considered to come from each NiFe layer. Very clear interface in the epitaxial films could be confirmed by a lower value of ΔH, H_r and ΔH_r of epitaxial film than those of non-epitaxial films, respectively.

Acknowledgement

This work was supported by the Korean Research Foundation Grant (KRF-2000-DP-0159).

References

[1] S. Gider, B. U. Runge, A. C. Marley, and S. S. P. Parkin, Science **281**, 797 (1998).
[2] Zhi Gang Wang, Yoshihisa nakamura, IEEE Trans. Magn. **32**(2), 520 (1996).
[3] P. Zahn, J. binder, I. Mertig, R. Zeller, and P. H. Dederichs, Phys. Rev. Lett. **80**(19), 4309 (1998).
[4] C. Prados, D. V. Dimitrov, and G. C. Hadjipanayis, J. Mag. & Mag. Mat. **192**, 19 (1999).
[5] Tadashi Kai, and Kazuo Shiiki, J. Mag. & Mag. Mat., **195**, 537 (1999).
[6] J. Ben Youssef, K. Bouziane, O. Koshkina, H. Le Gall, M. El Harfaoui, M. El Yamani, J. M. Desvignes, and A. Fert, J. Mag. & Mag. Mat. **165**, 288 (1997).
[7] Jenica Neamtu, M. Volmer, and A. Coraci, Thin Solid Films **343-344**, 218 (1999).
[8] T. Lucinski, F. Stobiecki, D. Elefant, D. Eckert, G. Reiss, B. Szymanski, J. Dubowik, M. Schmidt, H. Rohrmann, and K. Roell, J. Mag. & Mag. Mat. **177**, 192 (1997).
[9] Chin-an Chang, J. Vac. Sci. Technol. A **9**(1), 98 (1991).
[10] M. Urbaniak, T. Lucinski, and F. Stobiecki, J. Mag. & Mag. Mat. **190**, 187 (1998).