Journal of Magnetics 7(1), 14-17 (2002)

Mumetal Growing Temperature Effect on the Exchange Coupling of Cu/mumetal/Al Oxide/Co/Cu Multilayers

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(Received 8 November 2001)

Magnetic multilayers of a ferromagnetic (FM)/insulator (I)/ferromagnetic (FM) structure have been studied to investigate magnetic exchange coupling between two FM layers. As the Mumetal ($Ni_{77}Fe_{14}Mo_5Cu_4$ wt%) growth temperature increases, the grain size and the surface roughness increase simultaneously. The smallest coupling field is obtained at 40°C where the grain size is larger than that of the 20°C sample. The exchange coupling field increases again at temperatures higher than 40°C due to increase in the surface roughness of the Mumetal.

Key words : exchange coupling field, surface roughness, grain size, boundary

1. Introduction

Magnetic multilayers having a ferromagnetic (FM)/insulator (I)/ferromagnetic (FM) structure have been extensively studied in recent years because magnetic tunnel junctions (MTJ) have shown large magnetoresistances which enables the realization of magnetic sensors and magnetic memory devices [1-5]. In these systems, two FM layers are situated close to each other, resulting in a generation of exchange coupling between them. This exchange coupling usually shifts both the magnetic hysteresis loop and magnetoresistance curve from zero magnetic field and causes problems in switching field uniformity when the multilayer is used for device applications [2, 4]. Therefore, this exchange coupling should be avoided.

The origins of exchange coupling are magnetostatic exchange coupling and interlayer exchange coupling between the two FM layers. Interlayer exchange coupling is intrinsically affected by interface structures such as interlayer roughness and grooves in each layer [6], and magnetostatic exchange coupling becomes significant when the sample dimensions are small.

We have used cross-sectional transmission electron microscopy (TEM) to investigate the interlayer microstructure of Ta/Mumetal/Al oxide/Co/Ta samples, as displayed in Fig. 1. Mumetal has a polycrystalline structure, and the Al oxide layer shows a sinusoidal curvature. Large curvature is seen at the grain boundaries of the Mumetal layer, as indicated by the arrows in Fig. 1(a). Figure 1(b) represents a schematic diagram of this curvature generation at the grain boundaries. Here, we suppose that the areal density of the grain boundary is decreased by increasing the grain size of the Mumetal layer. A decrease in the grain boundary density will also cause a decrease in the curvature density. This decrease in the curvature density will, in turn, cause a decrease in the exchange coupling between the two magnetic layers.

For this purpose, we fabricated Cu/Mumetal layer samples and investigated their surface microstructures and magnetic properties as functions of the growth temperature of the bottom Mumetal layer. The temperature of this bottom layer was varied in order to change the grain size. We also fabricated whole multilayer samples of Cu/Mumetal/Al oxide/Co/Cu to investigate the interlayer exchange coupling, as well as the switching field of the Mumetal layer where magnetization reversal in the soft Mumetal layer finishes. The measured exchange coupling field and switching field are discussed in terms of the surface roughness and the grain size of the bottom layer.

2. Experiments

Cu 45/Mumetal 50/Al oxide 1/Co 22/Cu 20 (nm) multi-

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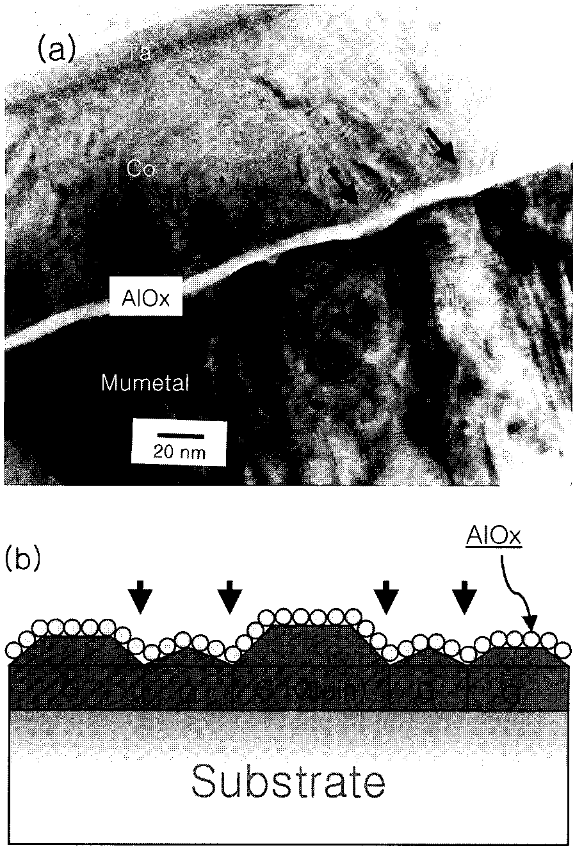

Fig. 1. (a) Cross-sectional TEM image of Ta/Mumetal/Al oxide/Co/Ta multilayers. (b) Schematic diagram for curvature generation.

layers were fabricated by rf magnetron sputtering on the Si wafers with thermally grown SiO_2. The base pressure was less than 3×10^{-7} Torr, and the sputteirng gas pressure was 3×10^{-3} Torr. The thickness of the Cu, Mumetal, AlO_x, and Co layers were measured by TEM and scanning electron microscopy (SEM), and the growth rate was calculated by dividing the thickness by the deposition time. The detailed conditions for fabrication are summarized in Table 1. The Cu layer was deposited at 20°C; then, the Mumetal layer was grown at various substrate temperatures between 20°C and 90°C. An Al layer with a thickness of 1 nm was then deposited and naturally oxidized at room temperature in an atmosphere of O_2 at 20 Torr for 20 minutes.

Table 1. Detail fabrication conditions.

Parameter	Value
Base pressure (Torr)	$< 3\times10^{-7}$
Sputtering Ar pressure (Torr)	3×10^{-3} (Co, Mumetal, Al) 1×10^{-3} (Cu)
Target-substrate distance (mm)	45
Target diameter size (inch)	4
RF power (W)	Mumetal (60), Co (60), Al (45), Cu (60)
Growth rate (Å/s)	Mumetal (0.74), Co (1.1), Al (0.77), Cu (1.5)
Mumetal growing temperature (°C)	20, 40, 50, 60, 75, 90
Substrate	Si wafer with 135-nm thermal oxide

The crystalline phase of the multilayer was investigated by using x-ray diffraction (CuKα) experiment at 50 kV and 150 mA. The relative grain size variation of the crystalline Mumetal phase was calculated using the Scherrer formula. The surface morphology of the Cu/Mumetal bottom layer was measured by using atomic force microscopy. The switching field of the Mumetal and the Co layers were measured using vibrating sample magnetometer (VSM). The exchange coupling field was measured from the minor loop of the multilayer as a magnetic field larger than the switching field of the Mumetal layer was applied in field steps of 0.15 Oe by using helmholtz coil.

3. Results and Discussion

Because the microstructure and surface morphology of the bottom layer affect each other, we first fabricated the bottom layer, which was composed of Cu/Mumetal at various growth temperatures. Fig. 2 shows the 2-dimensional surface morphology of the Cu/Mumetal deposited at various temperatures. The dimensions of the AFM images are 1 μm×1 μm. As the temperature increased, crystallization proceeded but the grain size did not change significantly as can be seen in Fig. 2.

Figure 3(a) and 3(b) show the growth temperature dependence of the measured roughness and the coercive force H_c, of the Mumetal layer, respectively. The root-mean-square roughness, R_{rms}, increases gradually with the Mumetal growth temperature. The H_c increases slowly until 75°C and then increases rapidly. It seems that the magnetic properties do not undergo a large change until 75°C.

Figure 4(a) shows XRD patterns for the Cu/Mumetal/Al oxide/Co/Cu structure. The Mumetal and the Co layers are crystallized with a preferred (111) orientation and the Mumetal (200) peak appears at temperatures above 20°C. However, no significant change occurs in the multilayer crystalline structure. The grain size calculated from the Mumetal (111) peak is shown in Fig. 4(b). A small jump in the grain size is seen between 40°C and 50°C. As a whole, the relative grain size of the Mumetal (111) phase increases as the temperature increases.

Figure 5 shows the normalized magnetic hysteresis loops of samples for various growth temperatures. Generally,

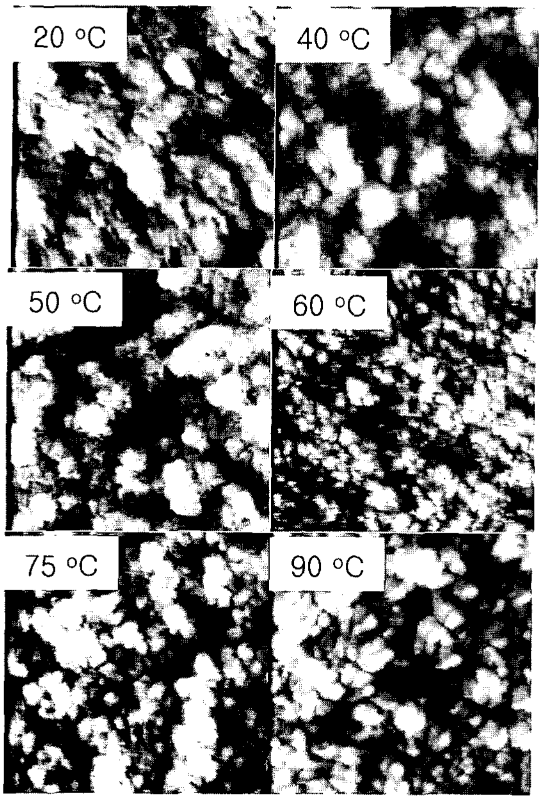

Fig. 2. two-dimensional surface morphology of the Cu/Mumetal bottom layer grown at various temperatures.

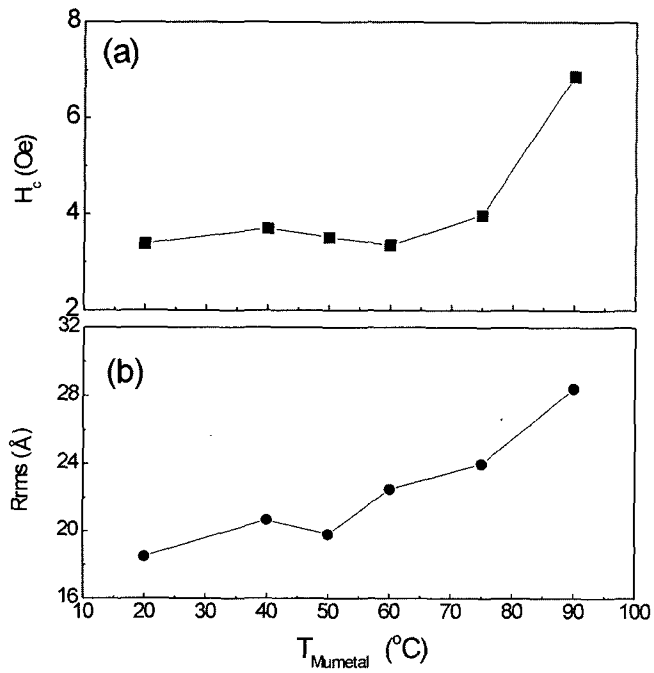

Fig. 3. Growing temperature dependence of the (a) coercive force. (b) surface roughness of the Cu/Mumetal bottom layer.

because of the exchange coupling between two layers, the switching field in each layer changes when the magnetic

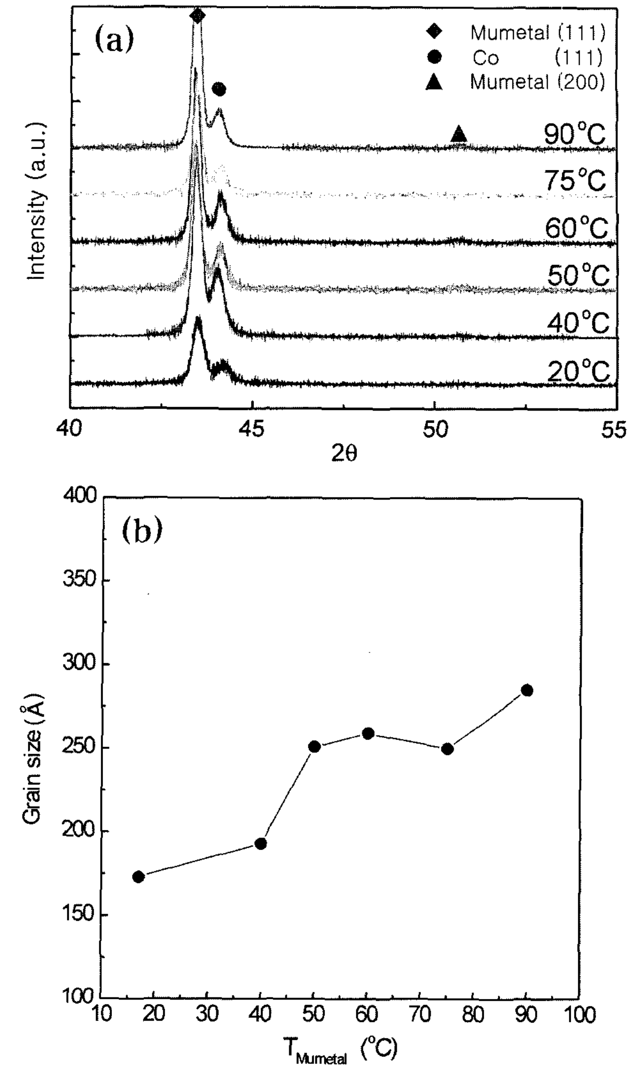

Fig. 4. (a) XRD patterns of Cu/Mumetal/Al oxide/Co/Cu. (b) Grain size of Mumetal (111) as a function of the growing temperatures.

hard and soft layers are placed too close. As a result, the switching field of hard layer decreases, and the coercive force of the soft layer increases. Therefore, a large switching field difference between two layers and a swift magnetization reversal indicate small exchange coupling and vice versa.

The coercive force of the Co single layer is more than 40 Oe but the switching field of Co in the multilayer decreases down to around 25 Oe as shown in Fig. 5. The coercive force of the Mumetal single layer is less than 4 Oe, but the switching field of Mumetal in the multilayer increases up to around 10 Oe. This result suggests that interlayer exchange coupling exists. Among all the temperatures used in this research, the swiftest magnetization reversal of the Mumetal layer occurred at 40°C.

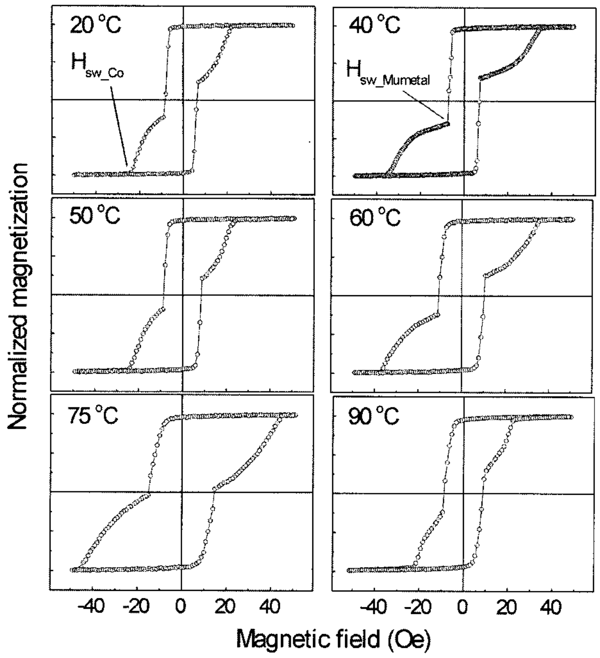

Fig. 5. Normalized magnetic hysteresis loops of Cu/Mumetal/Al oxide/Co/Cu multilayers at various growing temperature.

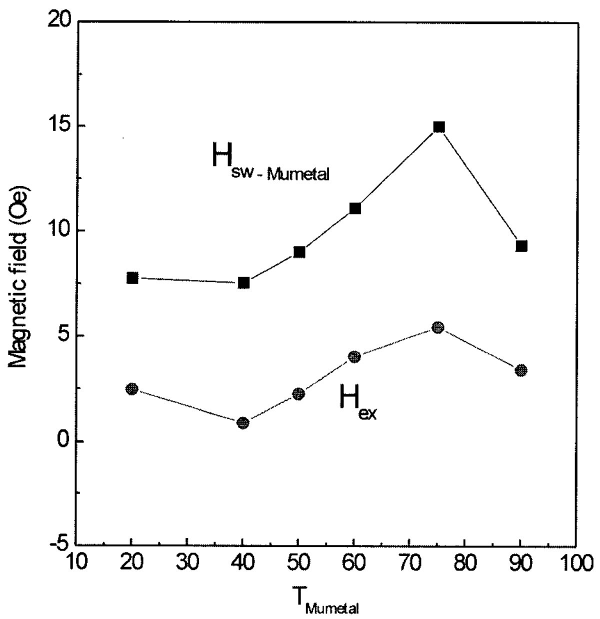

Fig. 6. Switching field and exchange coupling field of Cu/Mumetal/Al oxide/Co/Cu multilayers.

Figure 6 shows the switching field (H_{sw}) of Mumetal and the exchange coupling field (H_{ex}) obtained from the displacement of the minor hysteresis loop of Cu/Mumetal/Al oxide/Co/Cu. The variation of the switching field with Mumetal growth temperature has almost the same behavior as the exchange coupling field. The smallest exchange coupling field is less than 1 Oe at 40°C, and the Mumetal grain size at 40°C is larger than that at 20°C, as shown in Fig. 2. This suggest that the H_{ex} is dominated by the grain size when the surface roughness is not large. However, the exchange coupling field increases again for growth temperatures higher than 40. The increase in the Mumetal surface roughness is thought to play the dominant role in the increase of the exchange coupling for temperatures above 40°C.

4. Conclusions

The exchange coupling between Co and Mumetal thin films with an Al oxide layer has been investigated as a function of the growth temperature of the bottom Mumetal layer. The grain size and the surface roughness of the bottom Mumetal layer increase simultaneously when the growth temperature increases. The interlayer exchange coupling field measured from the minor hysteresis loop of the multilayer has its minimum value at a growth temperature of 40°C. When the temperature is higher than 40°C, the exchange coupling increases with growing temperature, which could be due to an increase in the Mumetal surface roughness. It is thought that the grain size and the surface roughness of the Mumetal are competing factors in the exchange coupling of the multilayer.

Acknowledgment

This work was supported by the Korea Science and Engineering Foundation through the Research Center for Advanced Magnetic Materials (ReCAMM).

References

[1] B. D. Schrag, A. Anguelouch, Gang Xiao, P. Trouilloud, Yu Lu, W. J. Gallagher, and S. S. S. P. Parkin, J. Appl. Phys. **87**(9), 4682 (2000).

[2] S. S. P. Parkin, K. P. Roche, M. G. Samant, P. M. Rice, R. B. Beyers, R. E. Scheuerlein, E, J. O'Sullivan, S. L. Brown, J. Bucchigano, D. W. Abraham, Yu Lu, M. Rooks, P. L. Trouilloud, R. A. Wanner, and W. J. Gallager, J. Appl. Phys. **85**(8), 5828 (1999).

[3] S. Tehrani, E. Chen, M. Durlam, M. DeHerrera, J. M. Slaughter, J. Shi, and G. Kerszykowski, J. Appl. Phys. **85**(8), 5822 (1999).

[4] P. P. Freitas, J. L. Costa, N. Almeida, L. V. Melo, F. Silva, J. Bernardo, and C. Santos, J. Apppl. Phys. **85**(8), 5459-5461 (1999)

[5] S. M. Hong, H. C. Lee, T. K. Kim, N. Tezuka, and T. Miyazaki, J. Kor. Mag. Soc. **9**(6), 291 (1999).

[6] W. F. Egelhoff, Jr., P. J. Chen, C. J. Powell, R. D. McMichael, and M. D. Stiles, Progress in Surface Science **67**, 355 (2001).