Research Article

Study of Magnetization Reversal Process in FeCo/Ru/FeCo Exchange Coupled Synthetic Antiferromagnetic Multilayers

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FeCo/Ru/FeCo exchange coupled synthetic antiferromagnetic multilayers were prepared with two sputtering modes. One is continuous sputtering mode, and the other mode is layer-by-layer sputtering mode. The former mode implies that substrate faced the target and film growth process was continuous when FeCo layers were sputtering, whereas the latter implies that substrate was rotating with the mask at a speed of 5 rpm when FeCo layers were sputtering. It was found that the exchange coupling field H_{ex} of sample sputtered by layer-by-layer mode was higher than the one sputtered by continuous mode. Domain structures were measured with applying varied in-plane magnetic fields along the easy axis in order to study the magnetization reversal process. We found it is a domain wall move process. When the applied field is smaller than H_{ex} , both the two magnetic layers have domain structure and the domain structure of the two layers is reversed correspondingly. When the applied field is varying in the range of $-H_{ex}$ to H_{ex} , the domain wall of the two layers moves correspondingly at the same time.

1. Introduction

Synthetic antiferromagnetic (SAF) multilayer [1] is comprised of two ferromagnetic layers separated by a nonmagnetic metallic spacer layer in which the ferromagnetic layers are coupled through antiferromagnetic interlayer exchange. Such interlayer coupling is subject to the thickness of the nonmagnetic layer [2] and is highly sensitive to structural defects [3]. In an ideal situation with proper thickness of nonmagnetic layer and low structural defects, no remanence can be observed in easy axis and the total magnetization becomes zero when the applied magnetic field is smaller than exchange coupling field H_{ex} . In recent years, there have been many studies on SAF multilayers, as it shows great promise as soft underlayers for perpendicular recording media [4, 5], high moment write head material [6], and high frequency application [7]. But the reversal process in FeCo/Ru/FeCo SAF multilayers has not been studied yet. It is not known if the reversal process is a domain wall move process or moment coherent rotation process.

In this present study, FeCo/Ru/FeCo SAF layers were prepared under two different FeCo sputtering modes which significantly changed the surface intermixing, so different exchange coupling fields H_{ex} were measured. MFM measurements with different applying in-plane magnetic fields in the easy axis were done to study the reversal process in FeCo/Ru/FeCo multilayers.

2. Experiment

SAF multilayers Ru/FeCo(10 nm)/Ru(d_{Ru} nm)/FeCo(10 nm)/Ru were prepared on SiO₂ substrate by using DC magnetron sputtering with a Fe₇₀Co₃₀ target and a Ru target. The base pressure was lower than 3×10^{-5} Pa. A magnetic field around 100 Oe was applied along the substrate surface during deposition for inducing in-plane magnetic anisotropy in the films. Ru layers are deposited with power of 15 W, Ar-gas pressure of 0.5 Pa, and substrate rotating speed of 5 rpm. The thickness of Ru interlayer d_{Ru} varied from 0.60 nm to 1.20 nm. All samples used a Ru seed layer (2 nm) and a Ru

FIGURE 1: Schematic diagram of sputter system.

TABLE 1: Deposition conditions of two series samples.

	Power	Ar pressure	Rotating speed	Sputtering rate
Series A	10.0 W	0.2 Pa	No rotation	0.10 nm/sec
Series B	17.8 W	0.2 Pa	5 rpm	0.25 nm/rot

capping layer (3 nm). The multilayers were prepared in a multilayer sputtering system and the schematic diagram is shown in Figure 1. We prepared two series samples, and the conditions are given in Table 1. FeCo layer of series A was prepared with a continuous sputtering mode: substrates were not rotating and facing FeCo target through the hole in the mask during deposition. FeCo layer of series B was prepared with a layer-by-layer sputtering mode: substrates and the mask were rotating at the same speed.

Magnetic properties were measured by a vibrating sample magnetometer (VSM). The domain structure was measured by a magnetic force microscopy (MFM) applying different in-plane magnetic fields along easy-axis. A FePt tip was adopted and measurement conditions were vibrating the amplitude of the tip of 15 nm for morphology measurement and 3 nm for phase measurement with scan height of about 10 nm and constant Q factor of about 6000. Before being measured, FePt tip was magnetized by VSM along the pinpoint direction.

3. Results and Discussions

Upon investigation of the relationship between the exchange coupling field H_{ex} and the thickness of Ru interlayer d_{Ru} in SAF films, it was found that the H_{ex} of SAF coupled structures is related to d_{Ru} . As shown in Figure 2, with the increase of d_{Ru} , the H_{ex} of series B samples increases and reaches a maximum value when $d_{Ru} = 0.90$ nm, and when d_{Ru} increases further ($d_{Ru} > 0.90$ nm), H_{ex} decreases drastically. We also found that the H_{ex} of series A samples had the same results: the H_{ex} value got maximum when $d_{Ru} = 0.90$ nm but the value of series B samples was much larger than series A samples. Figures 3(a) and 3(b) show the $M-H$ of two series samples with $d_{Ru} = 0.90$ nm. It was shown that the exchange coupling field H_{ex} of series B sample is higher than series A sample: about 185 Oe for series B sample and about 80 Oe for series A sample. Figures 3(c) and 3(d) show two series samples without Ru spacer layer. It was shown that

the induced anisotropy field H_k of series B sample is higher than series A sample. This result agrees with the SAF layers' result, because the effective anisotropy field H_k relates to the exchange coupling field H_{ex} in SAF sandwich films [7]. It is well known that the interlayer coupling of samples grown by MBE is larger than that grown by sputtering, because of the larger surface intermixing in the sputtered samples due to the substrate bombardment by neutral atoms. This gives rise to random component in the atom distribution near the interface and to a destructive interference of the scattered electronic waves, so the coupling is frustrated [8, 9]. We think the growth process of series B samples is similar to MBE process, and it can effectively decrease the bombardment by neutral atoms compared with the growth process of series A samples. So we can conclude that the layer-by-layer growth mode can decrease the surface intermixing and get laser induced anisotropy field H_k and exchange coupling field H_{ex} .

In order to study the reversal process of SAF multilayers, we measured MFM images applying varied in-plane magnetic field along easy-axis. From the MFM measurement we found the surface of the two series samples is very flat and the average roughness is less than 0.1 nm. Figure 4 shows the MFM images of series B sample with $d_{Ru} = 0.90$ nm measured with different in-plane magnetic field. The magnetic field applied along the easy-axis direction and ranged from 1500 Oe to -1500 Oe. Because of the multilayer structure, we can just measure domain structure of upper FeCo layer. But we can deduce the bottom layer's domain structure according to magnetic properties of exchange coupled SAF multilayers. Figure 4(a) shows MFM images measured when the as-deposited sample had not been applied magnetic field, we can see clear domain structure. Figure 4(b) shows MFM images measured with 1500 Oe in-plane magnetic field, and we cannot see very clear domain wall structure, which means magnetization is saturated and almost all magnetic moments array along the applied field. From Figure 4(c) it can be seen when applied magnetic field decreases to 1000 Oe, many small reverse domains appear. Figure 4(f) is measured when the applied in-plane magnetic field decreases from 1500 Oe to 200 Oe. From Figures 4(c)–4(f), it can be seen those small reversed magnetic domains grow bigger and the domain wall moves with change of the applied in-plane magnetic field. Figures 4(g)–4(l) were measured with the applied in-plane magnetic field range from 150 Oe to -200 Oe. From $M-H$ loop we can get the total magnetization of film are zero when the applied magnetic field are smaller than the exchange coupling field H_{ex} . But we can see clearly domain wall structure, so we can deduce that the bottom FeCo layer has the same domain structure as the upper layer, but the magnetization direction is reverse correspondingly. From marked parts in Figures 4(g)–4(l) we can see the domain wall moves process, so we can deduce that the domain wall of the two layers moves correspondingly at the same time. Figures 4(m)–4(p) show the MFM images measured when the applied magnetic field ranges from -300 Oe to -1500 Oe, we can see the positive domain becomes smaller and disappears. So, we can conclude that the reversal process in SAF multilayers is a domain wall move process, and the domain wall in both upper layer and bottom layer moves

FIGURE 2: Dependence of H_{ex} of series A and B samples on d_{Ru} .

FIGURE 3: $M-H$ loop of (a) series A sample with $d_{\text{Ru}} = 0.90$ nm, (b) series B sample with $d_{\text{Ru}} = 0.90$ nm, (c) series A sample without Ru spacer layer, (d) series B sample without Ru spacer layer.

FIGURE 4: MFM images of FeCo(10 nm)/Ru(0.90 nm)/FeCo(10 nm) prepared with layer-by-layer mode measured with in-plane magnetic field range from 1500 Oe to -1500 Oe.

with the varying in-plane magnetic fields; when the in-plane magnetic field is smaller than exchange coupling field H_{ex} , the domain structure in the two layers is the same but the magnetization direction is reverse correspondingly, and the domain wall in the two layers moves correspondingly at the same time.

4. Conclusion

Synthetic antiferromagnetic multilayers Ru/FeCo(10 nm)/Ru(d_{Ru} nm)/FeCo(10 nm)/Ru were prepared with two FeCo sputtering mode: continuous mode and layer-by-layer mode. The exchange coupling field H_{ex} of SAF film deposited by

layer-by-layer mode is higher than samples deposited by continuous mode because of decrease of surface intermixing due to the substrate bombardment by neutral atoms. The magnetization reversal process is a domain wall move process. When the applied field was smaller than H_{ex} , both the two magnetic layers have same domain structure and the domain structure of the two layers was reverse correspondingly. It is also found that the domain wall of the two magnetic layers move correspondingly at the same time when the applied field is smaller than H_{ex} and changing.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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