Investigation of the Exchange Coupling Field between $\text{Ni}_{81}\text{Fe}_{19}/\text{Fe}_{50}\text{Mn}_{50}$ Bilayers in Spin Valve Devices by Ion Bombardment to Interfaces

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Abstract--- $\text{Ni}_{81}\text{Fe}_{19}/\text{Fe}_{50}\text{Mn}_{50}$ bilayers were deposited by using dual ion beam sputtering apparatus which can control the crystallographic structures at interfacial monoatomic layers of the multilayers by ion bombardment to the growing film surfaces. In this study, Ar ions were bombarded to the interfaces of Ni-Fe/FeMn bilayers. The relationship between the structure at the interfaces and the exchange coupling field H_{ex} were investigated. Ion bombardment to the interfaces at proper energy promoted (111) orientation of FeMn crystallites to increase H_{ex} between Ni-Fe and FeMn layers. Ion bombardment to 2~20 monolayers at the interfaces promoted crystallization of FeMn layers while the ion bombardment to the whole FeMn layers suppressed any crystallization.

Key words: exchange coupling field, dual ion beam sputtering, ion bombardment, interfacial structure

I. INTRODUCTION

High exchange coupling field H_{ex} induced by layer of antiferromagnetic alloy, such as FeMn, in tunneling magnetoresistance and Spin Valve devices was essentially required for applying them to 'read-out' heads and memory devices [1][2]. Many kind of Spin Valves, in which FeMn layers were used as the antiferromagnetic layers, have been studied [3], however, the relationship between film structures and H_{ex} has not been cleared perfectly. It has been reported that f.c.c. γ -phase FeMn crystallites was required to possess sufficient H_{ex} instead of b.c.c. α -phase FeMn crystallites with more stable structure, because α -phase FeMn could not reveal antiferromagnetic properties at room temperature [4]. In this study, ion bombardment to the interfaces between Ni-Fe and FeMn layers was performed. We have already reported that the structure at interfaces of $[\text{Ni-Fe/Cu}]_{30}$ multilayers are modified by ion bombardment to a couple

of monolayers at the interfaces [5]. The structure at the interfaces between Ni-Fe and FeMn layers was controlled by the ion bombardment to the interfaces and then, the relationship between crystallinity and H_{ex} at the layer was investigated.

II. EXPERIMENT

Ni-Fe/FeMn bilayers were deposited using the dual ion beam sputtering apparatus, as shown in Fig. 1. It is possible to bombard ions to the growing film surfaces using bombarding ion source. Si, Ni-Fe and FeMn targets were attached to the rotatable targets holder.

Fig. 2 shows the schematic construction of Ni-Fe/FeMn bilayers. Si (100) wafers were used as substrates. 50 Å-thick Si_3N_4 layers were deposited as buffer layers, where Si target was reactive-sputtered using mixture of N_2 and Ar as a working gas. The partial gas pressures of N_2 and Ar were set at 0.08 and 0.02 mTorr, respectively. Ni-Fe(100

Fig. 1: Schematic illustration of the Dual Ion Beam Sputtering system.

Fig. 2: Schematic construction of specimen multilayers.

Table 1: Deposition conditions

Sputtering Gas	Ar and/or Kr
Sputtering Gas Pressure	0.2 mTorr
Substrate	Si(100) wafer
Substrate Temperature	Room Temperature
Acceleration Voltage of Sputtering Ion Source V_{ms}	500 V
Acceleration Voltage of Bombarding Ion Source V_{sg}	0~350 V

Å)/FeMn(200 Å) bilayers were successively deposited on the Si_3N_4 buffer layers. Ar ions were bombarded to the interfaces between Ni-Fe and FeMn layers. The acceleration voltage of bombarding ion source V_{sg} was changed in the range from 0 to 350 V. The density of bombarding ion current was fixed. The number of ion bombarded monolayers at interfaces was changed in the range between 0 and 120, where the later number corresponded to the whole FeMn layer. The specimen bilayers were deposited using the substrate holders with and without intentional magnetic field H_{sub} of 250 Oe during layer deposition. Other deposition conditions are as listed in Table 1.

Crystallographic structures were analyzed by X-ray diffractometry (XRD). Magnetic characteristics were evaluated by vibrating sample magnetometer (VSM).

III. RESULTS AND DISCUSSION

Fig. 3 shows the XRD diagrams of Ni-Fe/FeMn bilayers with ion bombardment to 2 monolayers at the interfaces for various V_{sg} . Exactly, the specimen films were Ar ion-bombarded to initial two monolayers of FeMn layers, when they were deposited successively on Ni-Fe layers.

Fig. 3: XRD diagrams of Ni-Fe/FeMn bilayers with ion bombardment to 2 monolayers at interfaces.

Fig. 4: V_{sg} dependences of H_{ex} and J_k of Ni-Fe/FeMn bilayers with ion bombardment to 2 monolayers at interfaces.

Intentional magnetic field was not applied to the films during the deposition. The crystallographic structures of Ni-Fe layers were not influenced by the ion bombardment, while those of FeMn layers were strongly influenced. For the bilayer without ion bombardment, (111) planes of FeMn crystallites were not oriented. The Ni and Fe atoms could not construct the stable Ni-Fe crystallites with (111) orientation, because of the relatively low energy of sputtered particles. Therefore, hetero-epitaxial growth between Ni-Fe and FeMn crystallites was not expected and the crystallographic structure of FeMn layers was amorphous like. However, growth of FeMn crystallites with (111) orientation were enhanced at V_{sg} above 100 V. It seems that ion bombardment at proper energy promotes formation of clear interfaces and make it easy to grow γ -FeMn crystallites with the most closely packed (111) plane

parallel to the Ni-Fe layer plane. On the contrary, (111) peak of FeMn crystallites decreased with increase of V_{sg} above 300 V. Ion bombardment at higher energy seems to promote intermixing at the interfaces between Ni-Fe and FeMn layers. This intermixing seems to degrade the growth of (111) planes of FeMn crystallites.

Fig. 4 shows the V_{sg} dependence of the exchange coupling field H_{ex} . H_{ex} is defined as the shift of hysteresis loop measured in the direction of easy axis by VSM. H_{ex} was not detectable for the Ni-Fe/FeMn bilayers without ion bombardment to the interfaces, while H_{ex} was significantly high at V_{sg} above 100 V. H_{ex} took the maximum value of 33.2 Oe at V_{sg} of 100 V in which relatively strong (111) peak of FeMn crystallites was observed, as shown in Fig. 3. And H_{ex} gradually decreased with increase of V_{sg} . This decrease of H_{ex} corresponds to the decrease in height of (111) peak of FeMn crystallites, as shown in Fig. 3. Therefore, it is concluded that (111) planes of γ -FeMn crystallites were essentially required to induce H_{ex} to adjacent Ni-Fe layers.

H_{ex} was induced in the direction of not only easy axis but also hard axis in the bilayers deposited using the substrate holder without intentional magnetic field H_{sub} . Therefore, Ni-Fe/FeMn bilayers were deposited at H_{sub} of 250 Oe to induce magnetic anisotropy into the bilayers. Fig. 5 shows the XRD diagrams of Ni-Fe/FeMn bilayers deposited with H_{sub} with ion bombardment to Ni-Fe/FeMn interfaces for various V_{sg} . In this case, (111) planes of FeMn crystallites were oriented at V_{sg} above 200 V. The energy to promote growth of (111) planes of FeMn crystallites was different from that for the bilayers deposited at H_{sub} of 0 Oe. This change of energy seems to be originated from the difference in deposition rate. The influence of ion bombardment depends on the average energy per deposited atoms E_{ave} . [6]. E_{ave} is defined as;

$$E_{ave} = E_{ion} R_i$$

where E_{ion} is energy of bombarding ion and R_i is defined as;

$$R_i = \frac{J_i}{J_A}$$

where J_i is flux of ion and J_A is flux of deposited atoms. The deposition rates of FeMn layers on the substrate holder without H_{sub} and with H_{sub} were 14.9 and 20.0 Å/min., respectively. Therefore, the holder with H_{sub} exhibited smaller E_{ave} than one without H_{sub} . Consequently, the

Fig. 5: XRD diagrams of Ni-Fe/FeMn bilayers with ion bombardment to 2 monolayers at interfaces.

Fig. 6: V_{sg} dependences of H_{ex} and J_k of Ni-Fe/FeMn bilayers with ion bombardment to 2 monolayers at interfaces.

energy to promote preferential growth of (111) planes of FeMn crystallites seems to increase for the film on the holder with H_{sub} . Since the motion of bombarding ions is affected by the magnetic field, especially for low V_{sg} , the E_{ave} to promote the growth of (111) planes of FeMn crystallites on the holder with H_{sub} is different from one without H_{sub} .

Fig. 6 shows the V_{sg} dependences of H_{ex} of the bilayers deposited with H_{sub} . H_{ex} was observed only in the direction of easy axis. H_{ex} was induced at V_{sg} above 200 V corresponding to the voltage to orient (111) planes of FeMn crystallites and gradually decreased with increase of V_{sg} . This tendency was similar to that for the bilayer deposited without H_{sub} . However, the bilayers exhibited

lower H_{ex} than ones deposited without H_{sub} .

Fig. 7 shows the XRD diagrams of Ni-Fe/FeMn bilayers with ion bombardment to the interfaces for various bombarded monolayers at V_{sg} of 200 V. Ion bombardment was started when the first monolayers of FeMn layers were deposited. A 200 Å-thick FeMn layer was consisted of about 120 monolayers. Ion bombardment to 2~20 monolayers at the interfaces promoted (111) orientation of FeMn crystallites. However, when ion bombardment to more than 40 monolayers at the interfaces were performed, (111) peak of FeMn crystallites disappeared. Bombarding ions give energy to the adatoms on the substrates to increase mobility of random walk. However, Ar ions are easily incorporated into the Ni-Fe and FeMn layers. Therefore, excessive ion bombardment destroyed the γ -FeMn crystallites. H_{ex} was observed only for the bilayers that reveal good (111) orientation of FeMn crystallites.

Fig. 7: XRD diagrams of Ni-Fe/FeMn bilayers with ion bombardment to the interfaces for various bombarded monolayers.

IV. CONCLUSIONS

$Ni_{81}Fe_{19}/Fe_{50}Mn_{50}$ bilayers were deposited by using dual ion beam sputtering apparatus. The relationship between exchange coupling field H_{ex} and the structure at the interfaces was investigated with ion bombardment to the interfaces. The obtained results were as follow;

(1) Ion bombardment to the interfaces at proper energy promotes the formation of clear interfaces between Ni-Fe and FeMn layers and growth of (111) planes of γ -FeMn crystallites.

(2) (111) orientation of γ -FeMn crystallites is required for applying preferable H_{ex} between Ni-Fe and FeMn layers.

(3) Ion bombardment to 2~20 monolayers at the interfaces promotes (111) orientation of γ -FeMn crystallites, while that to the whole FeMn layers caused degradation of the crystallinity in the films.

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