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Effect of Ta underlayer on magnetic properties of FeMn/NiFe films

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ABSTRACT

Effect of Ta underlayer on the magnetic properties of sputter-prepared NiFe(5 nm)/FeMn(20 nm) bilayer films have been studied. The magnetic properties of studied films are optimized by modification of working Ar pressure deposition of Ta (P_{Ta}) in the range of 2–12 mTorr and thickness of Ta (t_{Ta}) in the range of 0–25 nm. X-ray diffraction results show that the crystallinity of the FeMn(111) strongly depends on the P_{Ta} and t_{Ta}. All studied films exhibit smooth and flat surface with root-mean-square roughness below 1 nm due to deposition at RT. Large EB field (H_{eb}) of 65–123 Oe with small coercivity (H_c) of 5–16 Oe is obtained. Besides, the change of H_{eb} with various P_{Ta} and t_{Ta} are related to the crystallinity of FeMn(111) layer, interfacial roughness, and also strain/stress. Correlation between magnetic properties and microstructure is also discussed. This study suggests that proper Ta underlayer is crucial in the exchange bias for NiFe/FeMn bilayer system.

1. Introduction

Exchange bias (EB), characterized by a shift of hysteresis loop originated from the interaction between the ferromagnetic (FM) and antiferromagnetic (AFM) layers, has been extensively investigated due to wide applications in advanced spintronic devices and giant magnetoresistance heads [1–2]. Since most of the devices based on EB are in polycrystalline thin film form, the investigations of thin FM and AFM bilayers are important [1–2]. However, the EB field (H_{eb}), the magnetic field strength which M-H loop is shifted, strongly depends on crystallinity, thickness, morphology, and grain size of AFM and FM layers and also the interface between AFM/FM [3–5]. Therefore, controlling the microstructure for both the AFM and FM layers, and the interface become the important issues to overcome.

Due to high both exchange anisotropy and blocking temperature, FeMn/NiFe bilayer becomes a commonly used EB system [1]. However, field cooling from Neel temperature of 490 K to room temperature is (RT) required for the formation of AFM state may lead to the interdiffusion between NiFe and FeMn layers and thus degrades the EB field. Therefore, RT deposition is proposed to avoid from the intermixing in this system. In order for the formation of AFM state in FeMn layer, $Fe_{50}Mn_{50}/Ni_{81}Fe_{19}$ films are prepared on SiO_2/Si(100) substrates at room temperature by sputtering at the external magnetic field of 1 kOe induced by NdFeB sintered magnets in this work.

Since exchange bias is considered as an interface phenomenon, and therefore, the morphology and roughness may affect EB. The proper underlayer was reported helpful in promotion of interface quality and crystalline of AFM and FM layers [6–7]. Accordingly, Ta is adopted as an underlayer in this study in order to obtain better crystallinity FeMn and NiFe layers, and also interface. In this study, effect of Ta underlayer on the magnetic properties of FeMn(20 nm)/NiFe(5 nm) films prepared on SiO_2/Si(100) substrates at room temperature (RT) by sputtering at the external magnetic field of 1 kOe induced NdFeB sintered magnets are reported.

2. Experiment

FeMn(20 nm)/NiFe(5 nm)/Ta(t_{ta} nm) films with various thickness of Ta underlayer (t_{Ta}) in the range of 0–25 nm and working pressures (P_{Ar}) in the range of 2–12 mTorr were deposited on SiO_2/Si(100) substrate by DC magnetron sputtering system. The adopted SiO_2/Si(100) substrates have very flat surface with very low root-mean-square surface roughness (R) of below 0.2 nm, measured by an atomic force microscopy (AFM) (MS-838, Force Precision Instrument, Taiwan). The base pressure was better than 5×10^{-7} Torr. In order to induce unidirectional

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anisotropy, an external magnetic field of about 1 kOe, induced by high performance NdFeB sintered magnet, was applied during deposition. The structural characterization was carried out by X-ray diffractometer (XRD) (PHILIPS X'PERT Pro MPD, Netherlands) using Cu Kα radiation. Magnetic properties were measured by an alternating gradient magnetometer (AGM) (MicroMag™2900, USA). The thickness and surface morphology of the sample were measured by both AFM and scanning electron microscopy (SEM) (JEOL JSM-6500F, Japan). The microstructure was directly observed by a transmission electron microscopy (TEM) (JEOL JEM-2100, Japan).

3. Results and discussion

Fig. 1(a)–(d) shows the in-plane hysteresis loops of FeMn(20 nm)/NiFe(5 nm)/Ta (20 nm) films at various P_{Ar} of 4, 6, 8, 10 mTorr, respectively. Clearly, the hysteresis loop shifts along the negative direction of the applied magnetic field and this indicates an EB for this series of samples. The exchange bias field (H_{eb}) and coercivity (H_c) as function of P_{Ar} for Ta deposition is summarized in Fig. 2(a). Obviously, large H_{eb} of 65–109 Oe is obtained for $P_{Ar} = 2$–12 mTorr. With the increase of P_{Ar}, H_{eb} increases from 65.3 Oe for $P_{Ar} = 2$ mTorr to 109 Oe for $P_{Ar} = 8$ mTorr at first, and then decreases to 79 Oe for $P_{Ar} = 12$ mTorr. On the other hand, low H_c of 5–15 Oe is found for low P_{Ar} in the region of 2–8 mTorr, but H_c is largely increased to 31–39 Oe for high $P_{Ar} = 9$–12 mTorr.

The effect of Ta underlayer is further studied in FeMn(20 nm)/NiFe (5 nm) films with various t_{ta}. The results are shown in Fig. 1 (e)–(h). The sample without Ta underlayer shows no exchange bias. When Ta layer is induced and increased in thickness, biasing field as well as coercivity of the NiFe layer increases. The magnetic properties are summarized in

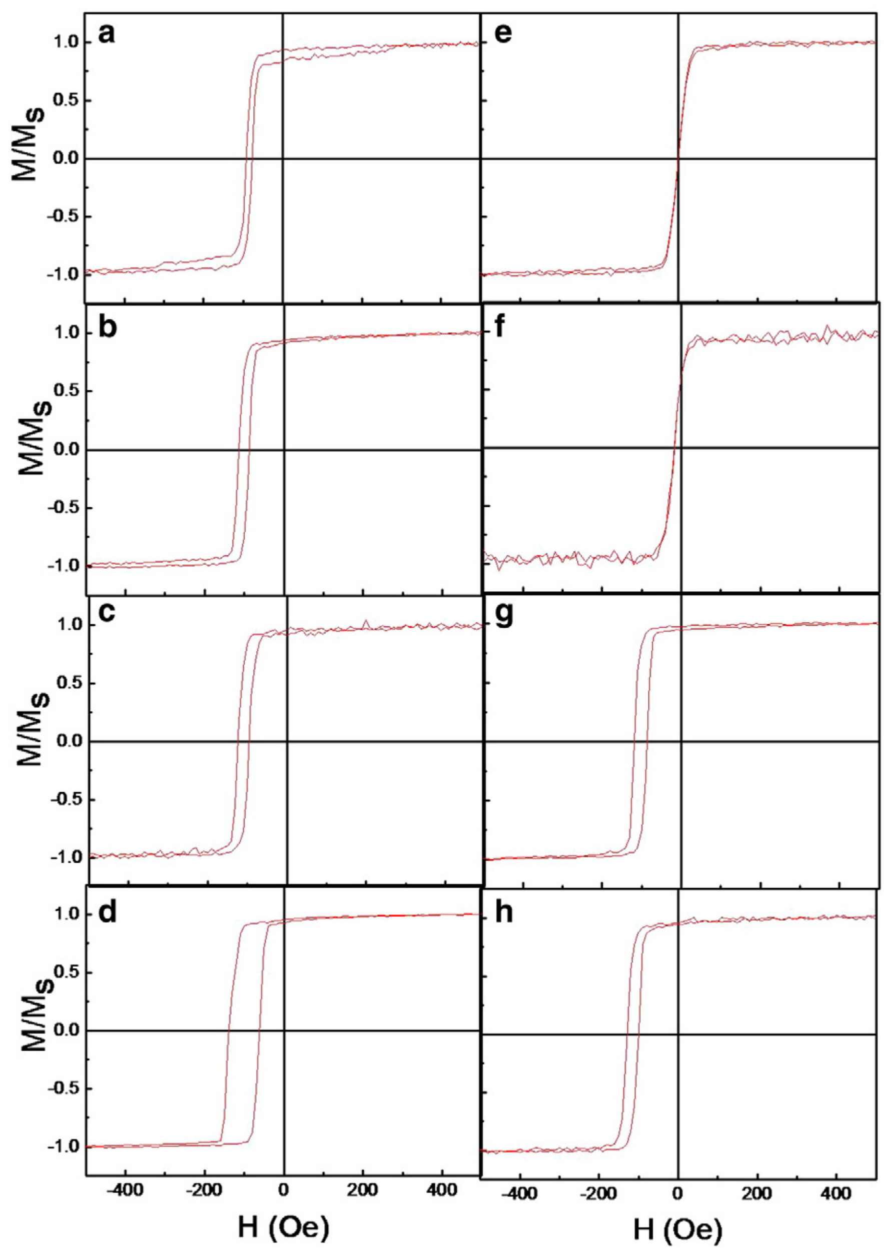

Fig. 1. Magnetic hysteresis loops of FeMn/NiFe films with working pressure of (a) 4 mTorr, (b) 6 mTorr, (c) 8 mTorr, and (d) 10 mTorr, and with Ta thickness of (e) 0 nm, (f) 5 nm, (g) 10 nm, (h) 20 nm.