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Exchange bias effects in Ni_2MnAl/Ferromagnet film bilayers

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Abstract

Exchange bias effects in Heusler alloy Ni_2MnAl /Ferromagnet film bilayer samples were investigated. 3 nm-thick ferromagnetic thin films (FM = Fe, Co, Co_2MnSi) were deposited onto epitaxially grown Ni_2MnAl layer. A Shift of the magnetization curve were observed for all samples. Maximum value of the exchange filed (H_{ex}) and the unidirectional anisotropy constant were 160 Oe and 0.029 erg/cm^2 for the Ni_2MnAl/Co_2MnSi sample. Observed value of H_{ex} is nearly 5 times larger than an earlier work using Ni_2MnAl Heusler alloy.

1. Introduction

Spin-valve structures [1] which include multilayers consisted from ferromagnetic materials and an antiferromagnetic material are commonly used in spintronic devices, such as, reader of hard disc drives (HDDs) and magnetoresistive random access memories (MRAMs). For the antiferromagnetic material, one of the widely used compounds is Iridium-Manganese (Ir-Mn) alloy [2] which exhibits large exchange anisotropy and high corrosion resistance. One drawback of the Ir-Mn alloy is the scarcity of Iridium, that is, Iridium is one of the rarest elements on the earth, which will be a risk of stable supply. Another drawback is a point that the fcc-(111) orientation is necessary to get large exchange anisotropy for the Ir-Mn alloys, which sometimes causes lattice mismatch problem to the bcc (001) oriented multilayers for magnetic tunnel junctions (MTJs), and current perpendicular to plane giant magnetoresistance (CPP-GMR) junctions.

In this research, we focused on Heusler alloy which is a class of materials including ferromagnets, ferrimagnets, and antiferromagnets [3]. A merit of the Heusler alloys is a good lattice matching to the highly spin polarized materials; e.g., Fe-Co alloys, half-metallic Heusler alloys themselves, and to the MgO tunneling barrier which is widely used for MTJs with (001) crystal orientations. Several compounds are known as antiferromagnetic Heusler alloys, such as, Fe_2VSi [4], Ru_2MnSi [5], Ni_2MnAl [6]. Among the compounds, Ni_2MnAl was studied for its relatively high Neel temperature, rare metal free components and the stable *B*2 phase which is required for the antiferromagnetic property [7, 8].

2. Experimental Procedures

Film samples were deposited by an ultra-high vacuum compatible magnetron sputtering system. The stacking structure of the samples was MgO (100) substrate/Ni_2MnAl (100 nm)/Ferromagnet (FM) layer (3 nm)/Al (3 nm); here, FM layers were Fe, Co, and Co_2MnSi. The deposition temperature was an ambient temperature for all samples, and post annealing was done at 300ºC only for the sample using Co_2MnSi. The Ni_2MnAl layer was deposited by co-sputtering technique using Ni, Mn, and Al metal targets, and the film composition was found to be $Ni_{52}Mn_{25}Al_{23}$ (at.%) which was examined by inductively coupled plasma optical emission spectroscopy technique. Other layers were deposited using a metal (or alloy) target. The Al layer was deposited as a protection layer. The crystal structure was measured by x-ray diffractometer (XRD). Magnetization curves were measured using superconducting quantum interference device (SQUID) at 10 K and 300 K, after a filed cooling process under 10 kOe.

3. Results and Discussion

The epitaxial relationship of MgO(001)[100] / Ni_2MnAl(001)[110] was confirmed for all the samples. The (002) superlattice diffraction was also confirmed, which indicates that the samples have *B*2 ordering. The (111) diffraction was not observed for the present samples, which implies the absence of $L2_1$ ordering of the Ni_2MnAl layer. Long-range order parameter of the *B*2 structure was estimated using a following equation;

$$S_{B2} = [I(002)_{exp}/I(004)_{exp}] / [I(002)_{sim.}/I(004)_{sim.}] \quad (1).$$

Where $I(hkl)_{exp.(sim.)}$ represents experimental (simulated) integrated intensity of the (*hkl*) diffraction. Estimated values of S_{B2} were about 0.5 for the Ni_2MnAl/Fe and Ni_2MnAl/Co_2MnSi samples, and about 0.4 for the Ni_2MnAl/Co sample. Diffractions from the 3 nm-thick ferromagnetic layers were not observed because of the thin film thickness. According to our previous works, there was no hysteresis for the magnetization curve of the Ni_2MnAl film without ferromagnetic layer at 10 K, which suggests that the Ni_2MnAl film was not ferromagnetic even at low temperature [9]. Figure 1 shows magnetization curves of Ni_2MnAl/FM, (FM: Fe, Co, Co_2MnSi) samples measured at 10 K. Shifts of the hysteresis loop was observed for all samples. The magnitudes of the exchange field (H_{ex}) were

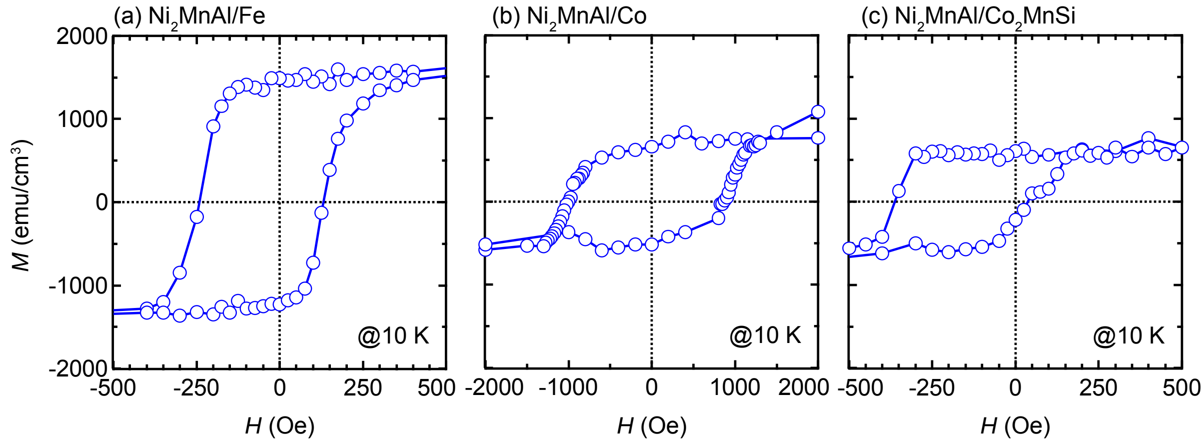

Figure 1. Magnetization curves of Ni_2MnAl/FM bilayer samples mearued at 10 K. FM layers were (a) Fe, (b) Co, and (c) Co_2MnSi

55 Oe, 65 Oe, and 160 Oe for the Ni_2MnAl films stacked with Fe, Co, and Co_2MnSi layers, respectively. H_{ex} of the Ni_2MnAl/Co_2MnSi sample was nearly 5 times larger than that of previously reported value for the Ni_2MnAl/Ni_2MnGe sample in ref. [10]. The unidirectional anisotropy constant (J_k) was estimated using a following equation.

$$J_k = M_s d_F H_{ex} \qquad (2).$$

Where M_s, d_F are the saturation magnetization and the thickness of the ferromagnetic layer, respectively. Estimated values of J_k were 0.027 erg/cm^2, 0.015 erg/cm^2, and 0.029 erg/cm^2 for the samples using Fe, Co, and Co_2MnSi layers, respectively. The origin of the ferromagnetic material dependence of the exchange bias effect is still under discussion, however, the lattice matching and distortion is possibly an important factor affecting the magnitude of J_k, as were discussed for the exchange bias effects using Ir-Mn antiferromagnet [11]. Magnetization curves were also measured at 300 K, however, shifts of hysteresis loops were not observed for all the samples, which probably because of the Neel temperature close to the room temperature [6].

4. Summary

Exchange bias effects of bilayer samples using Heusler alloy Ni_2MnAl and ferromagnetic material (Fe, Co, Co_2MnSi) were investigated. Shifts of magnetization curves were observed for all the samples at 10 K. The exchange bias field (H_{ex}) and unidirectional exchange constant (J_k) exhibited maximum value in the Ni_2MnAl/Co_2MnSi sample. The estimated values of H_{ex} and J_k were 160 Oe and 0.029 erg/cm^2, respectively. Larger value of H_{ex} was achieved compared with the earlier work for the Ni_2MnAl/Ni_2MnGe sample [10].

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