Exchange Bias and Spin-Valve Giant Magnetoresistance in Multilayers with Mn-17 mol%Ir-2 mol%Pt Antiferromagnetic Layer

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We fabricated bottom spin valves (SV) films using Mn-17 mol%Ir-2 mol%Pt antiferromagnetic material. A bottom SV composing of Ta/Ni-20 mol%Fe seed layer shows an improved exchange field (H_{ex}). The high H_{ex} of about 17.4 kA/m was obtained in Si(100)/Ta 3 nm/NiFe 3 nm/Mn-17 mol%Ir-2 mol%Pt 7 nm/Co-10 mol%Fe 1 nm/NiFe 5 nm/Ta exchange biasing layer. The giant magnetoresistance (GMR) and the thermal stability of bottom SVs were evaluated by comparing with a top SV. Bottom SV showed the higher GMR ratio of about 5.2% than a top SV with same thick ferromagnetic layer. It seems that a large short circuit effect of conductance in a free layer of a bottom spin valve. In order to improve thermal stability of a bottom SV, we inserted the synthetic antiferromagnetically coupled pinned layers (Co-Fe/Ru/Co-Fe) between the Mn-17 mol%Ir-2 mol%Pt and Cu layers. Thus, the enhanced thermal stability of H_{ex} can be obtained in bottom synthetic SVs.

(Received September 21, 2001; Accepted March 20, 2002)

Keywords: manganese-iridium-platinum, exchange bias, giant magnetoresistance, spin valve, synthetic antiferromagnetic coupling

1. Introduction

Antiferromagnetic (AFM) materials have been extensively studied because of their key importance in MR heads and spin valve read heads.^{1,2)} We have developed a ternary AFM material of Mn-17 mol%Ir-2 mol%Pt³⁾ which showed the larger exchange bias field (H_{ex}), the higher thermal stability and the better chemical resistance than Mn-Ir AFM material. Mn-17 mol%Ir-2 mol%Pt is a disordered phase (face centered crystal structure),³⁾ which doesn't need any annealing process at a high temperature. This is a prominent candidate material for a high sensitive sensor or a magnetic head. We prepared the bottom spin valve (SV) with Mn-17 mol%Ir-2 mol%Pt AFM material. The bottom SV of Mn-17 mol%Ir-2 mol%Pt, Mn-Ir and Mn-Fe, compared with a top SV, generally shows a low H_{ex} and poor thermal stability. If a bottom SV have a high H_{ex} and a good thermal stability, it can be applicable a symmetry or dual type SVs, which show an excellent GMR. A synthetic antiferromagnet consisting of Co-10 mol%Fe/Ru/Co-10 mol%Fe multilayer with a strong antiferrocoupling, improve a thermal stability over a large temperature and control a magnetostatic interaction between a pinned layer and a free layer in a sub-micron device.⁴⁾

In this sturdy, we fabricated bottom SVs with various seed layer thickness and evaluated their magnetic properties and GMR response by comparing with a top SVs. In order to improve the thermal properties, we applied synthetic antiferromagnet to a bottom SV and evaluated the thermal stability of a H_{ex} and GMR.

2. Experimental Procedure

Mn-17 mol%Ir-2 mol%Pt exchange biased SVs were deposited on the (100) Si wafer in a magnetron sputtering system with a base pressure of 4×10^{-5} Pa. The deposition pro-

cesses were done in Ar pressure of 0.4 Pa. And the deposition rates were in the range of 0.05–0.13 nm/s. The top and bottom SVs were classified with the stacking sequence of an AFM and a ferromagnetic (FM) layer. For the bottom SV, with the Mn-17 mol%Ir-2 mol%Pt (10 nm) under the Co-10 mol%Fe layer, the seed layers of Ta/Ni-20 mol%Fe were used for an enhanced exchange field.⁵⁾

The exchange coupling energy ($J_{ex} = \mu_0 H_{ex} M_F t_F$, M_F and t_F are a magnetization and a thickness of ferromagnetic) of the SVs with 3 nm thick Co-10 mol%Fe pinned layer was 0.22 mJ/m² for a top type and 0.1 mJ/m² for a bottom at a Co-10 mol%Fe layer a 3 nm. The synthetic SVs were prepared by deposition synthetic antiferromagnet (Co-10 mol%Fe 3 nm/Ru 0.8 nm/Co-10 mol%Fe 3 nm) between Mn-17 mol%Ir-2 mol%Pt and Cu layers in top and bottom SVs. Magnetic properties of SVs were measured by using vibrating sample magnetometer. X-ray diffraction measurement were performed to structurally characterize the SVs. The GMR was measured by using a four-point probing tester in an external field. And, the thermal stability of GMR and H_{ex} was evaluated at various temperatures in air.

3. Results and Discussion

Figure 1 shows the variation of a H_{ex} and a coercivity (H_c) in bottom SVs as a function of a Ni-20 mol%Fe seed layer thickness. As the thickness of Ni-20 mol%Fe seed layer increase the H_{ex} and H_c increase gradually. The H_{ex} of 3.2 kA/m was obtained at Ni-20 mol%Fe seed layer of 3 nm. The increase of H_{ex} and H_c seems to be attributed by a change of the crystalline of Mn-17 mol%Ir-2 mol%Pt by variation of Ni-20 mol%Fe seed layer.

For a SVs with γ -phase AFM, The (111) texture of AFM have been known to improve H_{ex} at the interface between AFM and FM layers. As shown in Fig. 2, the (111) peaks of Mn-17 mol%Ir-2 mol%Pt and Ni-20 mol%Fe become stronger with increasing a Ni-20 mol%Fe seed thick-

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Fig. 1 Variations of H_{ex} and H_c of Si/Ta 3 nm/Ni-20 mol%Fe *t* nm/Mn-17 mol%Ir-2 mol%Pt 10 nm/Ni-20 mol%Fe 10 nm.

Fig. 2 X-ray diffraction patterns of Ta 3 nm/Ni-20 mol%Fe *t* nm/Mn-17 mol%Ir-2 mol%Pt 10 nm/Ta 5 nm as a function of a seed layer (Ni-20 mol%Fe) thickness.

ness.

The thicker Ni-20 mol%Fe could be expected to better promote (111) texture of the Mn-17 mol%Ir-2 mol%Pt layer. The Ni-20 mol%Fe seed thickness of over 3 nm was considered to render a large H_{ex} to a bottom SV film. We also confirmed the developed the (111) texture of Mn-17 mol%Ir-2 mol%Pt AFM layer by using a High resolution TEM.

Figure 3 shows the dependence of H_{ex} on Mn-17 mol%Ir-2 mol%Pt thickness for bottom SVs composed of Ta/Ni-20 mol%Fe 3 nm/Mn-17 mol%Ir-2 mol%Pt *t* nm/Co-10 mol%Fe 2 nm/Ta 5 nm. The high H_{ex} of 17.4 kA/m was obtained at Mn-17 mol%Ir-2 mol%Pt thickness of 6 nm. And the SVs with thicker Mn-17 mol%Ir-2 mol%Pt show a steep decrease of the H_{ex} . In case of a top SV, the decrease of H_{ex} is not steep like a bottom SV. It may be thought that the number of AFM grains strongly blocking the spin reversal of FM in a bottom SV is smaller than that of top SV.⁶⁾ However, we

Fig. 3 Variation of Magnetic properties as a function of Mn-17 mol%Ir-2 mol%Pt thickness. The film structure used is Ta 3 nm/NiFe 3 nm/Mn-17 mol%Ir-2 mol%Pt *t* nm/Co-10 mol%Fe 1 nm/Ta 3 nm.

Fig. 4 Variation of H_c and H_{ex} as a function of Co-10 mol%Fe thickness in Si/Ni-20 mol%Fe 3 nm/Mn-17 mol%Ir-2 mol%Pt 6 nm/Co-10 mol%Fe *t* nm/Ni-20 mol%Fe 10 nm/Ta multilayers.

failed to characterize the effect of grain size on the H_{ex} in a bottom SVs by using various analyzing tools.

We tried to improve the H_{ex} of bottom SVs by inserting the Co-10 mol%Fe layer into the Mn-17 mol%Ir-2 mol%Pt and Ni-20 mol%Fe layer. Figure 4 shows the variation of the H_{ex} and H_c in typical structure of Si/Ta 3 nm/Ni-20 mol%Fe 3 nm/Mn-17 mol%Ir-2 mol%Pt 6 nm/Co-10 mol%Fe (*t*) nm/Ni-20 mol%Fe (10-*t*) nm/Ta 3 nm multilayers. After annealing at 453 K for 1 h, the H_{ex} of 13.5 kA/m could be obtained in Bottom SV including 1 nm thick Co-10 mol%Fe layer. The high magnetization value of Co-10 mol%Fe can be thought to give a high anisotropy to a bottom SV. The high H_{ex} of a bottom SV shows that Mn-17 mol%Ir-2 mol%Pt can be a candidate for a dual or a symmetric valve.

We prepared a top SV composing of Ta 3 nm/Ni-20 mol%Fe 6 nm/Co-10 mol%Fe 1.5 nm/Cu 2.5 nm/Co-10 mol%Fe 1.5 nm/Ni-20 mol%Fe 3.5 nm/Co-10 mol%Fe

Fig. 5 MR curves of (a) a synthetic top SV, (b) synthetic bottom SV, (c) top SV and (d) bottom SV.

1 nm/Mn-Ir-Pt 10 nm/Ta 1.5 nm and a bottom SV composing of Ta 3 nm/Ni-20 mol%Fe 3 nm/Mn-17 mol%Ir-2 mol%Pt 7 nm/CoFe 1 nm/Ni-20 mol%Fe 5 nm/Cu 2.5 nm/Co-10 mol%Fe 1.5 nm/Ni-20 mol%Fe 6 nm/Ta 1.5 nm. A top SV film shows a high H_{ex} of about 22.7 kA/m and GMR ratio of about 4.8%. A bottom SV shows a high H_{ex} of about 18.8 kA/m and GMR ratio of about 5.2% comparable with a top SV. Because the free layer of a bottom SV is located at near of surface, the spin dependent scattering mainly occurs in free layer. For a bottom SV, the dependence of GMR on free layer thickness is much larger than the a top SV.⁷⁾

The GMR devices with sub-micron size require the stable spin rotation and the better thermal stability. Thus, in order to obtain an enhanced thermal stability of H_{ex} and GMR we applied a synthetic antiferromagnetically coupled pinned layer to a bottom SV. We deposited a synthetic antiferromagnet (Co-10 mol%Fe, P1 30 nm/Ru 8 nm/Co-10 mol%Fe, P2 30 nm) between Mn-17 mol%Ir-2 mol%Pt and Cu layers of bottom SVs.⁸⁾ The spin rotation of a pinned layer is controlled by the magnetization reversal of P1 (adjacent with Mn-17 mol%Ir-2 mol%Pt) and P2 (adjacent with Cu). The strong AFM coupling of P1 and P2 contributes to the large H_{ex} , which is called the effective exchange field ($H_{eff,ex}$) in a synthetic SV. The $H_{eff,ex}$ is defined as a external field at a half of maximum GMR. Figure 5 shows the MR curves of various SVs. A synthetic top SV is composed of Ta 3 nm/Ni-20 mol%Fe 6 nm/Co-10 mol%Fe 1.5 nm/Cu 2.5 nm/Co-10 mol%Fe 3 nm/Ru 0.8 nm/Co-10 mol%Fe 3 nm/Mn-17 mol%Ir-2 mol%Pt 10 nm/Ta 1.5 nm. A synthetic bottom SV is composed of Ta 3 nm/Ni-20 mol%Fe 3 nm/Mn-17 mol%Ir-2 mol%Pt 7 nm/Co-10 mol%Fe 3 nm/Ru 0.8 nm/Co-10 mol%Fe 3 nm/Cu 2.5 nm/Co-10 mol%Fe 1.5 nm/Ni-20 mol%Fe 6 nm/Ta 1.5 nm. The $H_{eff,ex}$ of both synthetic SVs exhibits higher than a conventional SVs. A synthetic top SV shows the $H_{eff,ex}$ of 98.26 kA/m. A synthetic bottom SV exhibits the $H_{eff,ex}$ of 71.43 kA/m. The synthetic top SVs show a decrease of GMR by a shunt effect due to a thicker pinned layer.^{9,10)} But, for a synthetic bottom SV a GMR is roughly constant. It represents that a spin dependent scattering largely comes from a free layer. We found that a synthetic bottom SV did not depends strongly on the thickness of pinned layer

Fig. 6 Temperature dependence of (a) H_{ex} , (b) GMR of various SVs. The Co-10 mol%Fe layer of 1nm was inserted between Ni-20 mol%Fe and Mn-17 mol%Ir-2 mol%Pt layers.

but when the one of P1 and P2 layers is much thinner than the mean free path of spin a bottom SV shows a low GMR ratio.¹¹⁾

We evaluated the thermal stability of a H_{ex} , a $H_{eff,ex}$ and a GMR in various SVs. As shown in Fig. 6, synthetic SVs exhibit an excellent thermal stability of H_{ex} due to a strong antiferromagnetic coupling of pinned layers. However, It is interesting that the thermal properties of GMR in a synthetic bottom SV is similar to that of a conventional SV. The intermixing of Co-10 mol%Fe/Ru/Co-10 mol%Fe layers may cause the rapid decrease of GMR in a synthetic top SVs. It needs a further study on the intermixed layer of Co-10 mol%Fe/Ru/Co-10 mol%Fe.

4. Conclusions

In summary, we fabricated a various SVs composing of Mn-17 mol%Ir-2 mol%Pt AFM layer. The high H_{ex} of a bottom SV film can be improved by the promotion of a (111) texture in Mn-17 mol%Ir-2 mol%Pt layer. A high $H_{eff,ex}$ could be obtained in synthetic top and bottom SVs. For a synthetic bottom SV, the thermal stability of GMR was superior to a synthetic top SV. It is thought that the intermixed interface of Co-10 mol%Fe/Ru/Co-10 mol%Fe layer should cause a poor thermal stability of GMR at a high temperature.

Acknowledgments

We gratefully acknowledge the financial support from the Korea Research Foundation (KRF-99-042-E00106 E5105).

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