ENHANCEMENT OF THE FIELD-SENSITIVITY OF A PLANAR HALL EFFECT SENSOR BY USING A WEAK EXCHANGE BIAS COUPLING STRUCTURE

Tran Quang Hung[1], Sunjong Oh[1], Jong-Ryul Jeong[1], and CheolGi Kim[1*]
[1] Department of Materials Science and Engineering, Chungnam National University, 220 Gungdong, Yuseong-gu, Daejeon 305-764, Korea
[*] Corresponding author: C. G. Kim, email: cgkim@cnu.ac.kr, tel.: (82) 42-821-6632

Introduction

The planar Hall effect (PHE) in magnetic materials, which is known as the anisotropic magnetoresistance (AMR), has been studied a little so far [1]. In 1968, Vu Dinh Ky has studied the PHE in the Ni, Co, Fe, and Ni-Fe films and has found the quadratic dependence of the PHE on the magnetization. Later K. L. Yau *et al* have studied systematically the PHE in the Ni_xFe_{1-x} foils and have found out that the existence of the parabolic behavior in a PHE voltage profile at the saturation fields of the Ni-Fe foils [2-4]. The PHE sensor has been well developed in single layer, bilayer and spin-valve thin films for different applications. However, the field-sensitivity of the sensor is normally small. Hence, a novel structure, which can alter high field-sensitivity is highly desirable from both fundamental and application point of views.

Present work deals with the enhancement of the field-sensitivity of a PHE sensor by using a weak exchange bias coupling bilayer structure introduced a very thin Cu spacer layer between the FM and AFM layers. The field-sensitivity of the PHE sensors based on a bilayer, a spin-valve and a weak exchange bias coupling structures were thoroughly investigated while maintaining the same thickness of the active layer in all three investigated thin films for better understand the role of the field-sensitivity in multilayer thin films.

Experiments

The cross-junction sensors with junction size of 50 μm×50 μm were fabricated by a magnetron sputtering and a photo lithography system. The sensor materials are Ta(3)/NiFe(10)/Cu(1.2)/NiFe(2)/IrMn(10)/Ta(3) (nm), Ta(3)/NiFe(10)/IrMn(10)/Ta(3) (nm) and Ta(3)/NiFe(10)/Cu(0.2)/IrMn(10)/Ta(3) respectively. The electrodes of the sensor were made of Au. The sensor was passivated by SiO_2 layer to protect the sensors from the environment. The single sensor junction was captured by microscope that is shown in Fig. 1(a). The sensing current of 1 mA was applied to the sensor during experiments. The output voltages were measured by means of a Keithley 2182A Nanovoltmeter with a sensitivity of 10 nV.

Results and Discussion

The planar Hall effect voltage (V_{PHE}) profile of fabricated sensor as a function of applied magnetic fields ranging from -300 Oe to +300 Oe using bilayer structure is shown in Fig. 1(b). This V_{PHE} profile shows a linear response to a certain point, reaches the maximum voltage about 125 Oe and decreases the voltage signal when the external magnetic fields continue to be increased. The field-sensitivity of the sensor, which is calculated in the linear region by the change of PHE voltage in the applied magnetic field range ($\Delta V/\Delta H$), is about 1.6 μV.Oe^{-1}. It is observed that V_{PHE} reaches the maximum value at the exchange bias field of bilayer structure.

Fig. 1(c) shows the V_{PHE} profile of a spin-valve structure, it reveals the same characteristics as the V_{PHE} profile of the bilayer structure. Because of the very high exchange bias field (~550 Oe), the magnetization direction of the FM pinned layer remains in the direction of exchange bias field. Whereas, the magnetization of FM-free layer can easily be rotated in low magnetic fields due to the small FM coupling between the FM-free and FM pinned layers in the spin-valve structure. Then, at the small applied magnetic fields, the PHE voltage is almost contributed from the FM-free layer, and the maximum PHE voltage is obtained at about the interlayer coupling field (~11 Oe). The field sensitivity of PHE sensor based on spin-valve structure is calculated similar to the bilayer structure, and it is observed to be about 5μV.Oe^{-1}.

In addition, the maximum PHE voltage in the spin-valve structure (about 37 μV) is smaller compared with bilayer structure (ie., approximately 116 μV). This is because the amount of shunt current passing through other layers in spin-valve structure is larger than that of the bilayer structure, since the resistivity of IrMn is normally one order larger than that of Permalloy and two orders larger than the Cu. Therefore, in bilayer structure (AFM/FM) the applied current almost passes through the FM layer only while in spin-valve structure (FM/Cu/FM/AFM), the transport current dominates in Cu layer cause of very low Cu resistivity. Subsequently, the active current passed through the FM layer in bilayer structure is larger than that of the spin-valve structure.

Furthermore, N. J. Gökemeijer et al [5] have observed long-range coupling between FM and AFM layers while introducing a very thin non-magnetic layer, the coupling strength was found to be decay exponentially when increasing the thickness of non-magnetic layer. This structure has the small exchange bias coupling (the VPHE reaches maximum voltage at small magnetic field) and very thin Cu layer (active current is enhanced) so that the PHE sensor based on this structure has ability to alter high field sensitivity.

The voltage profile of PHE sensor based on a weak exchange bias coupling structure is illustrated in Fig. 1(d). This profile reveals similar behaviors as in the bilayer structure, it reaches the maximum voltage at the exchange bias field (at about 15 Oe). On the other hand, the thickness of Cu layer in this structure is ultrathin (the nominal thickness of about 0.2 nm), so that the shunt current through this layer is negligible. The maximum PHE voltage value in this structure is conserved as in bilayer structure. The experimental results show the maximum PHE voltage value of about 108 μV, this value is comparable with the maximum PHE voltage of a typical bilayer structure. The field sensitivity calculated by the slope of the PHE voltage profile is about 12 $\mu V.Oe^{-1}$. This is about one order larger than the field sensitivity of PHE sensor using typical bilayer structure and more than twice compared with the field sensitivity of spin-valve structure.

Conclusion

In summary, we investigated field sensitivity of PHE sensor in three samples: (*i*) a bilayer thin film, (*ii*) a spin-valve thin film and (*iii*) a weak exchange bias coupling bilayer thin film. Base on the obtained results we a have employed the bilayer structure with weak exchange bias coupling for the development of high-sensitivity PHE sensor. Using the proposed structure, the PHE sensor can obtain high sensitivity around 12 $\mu V.Oe^{-1}$ at low external magnetic field. Whereas, by using typical bilayer structure, maximum PHE voltage is obtained only at high magnetic field due to strong exchange coupling in AFM/FM interface, resulting in low field sensitivity of the sensor. In spin-valve structure, the maximum voltage can be achieved at smaller magnetic fields compared with the bilayer structure but the large amount of shunt current through the spacer and FM pinned layers lessens the amplitude of the PHE voltage profile, hence, the sensitivity is limited to some extents.

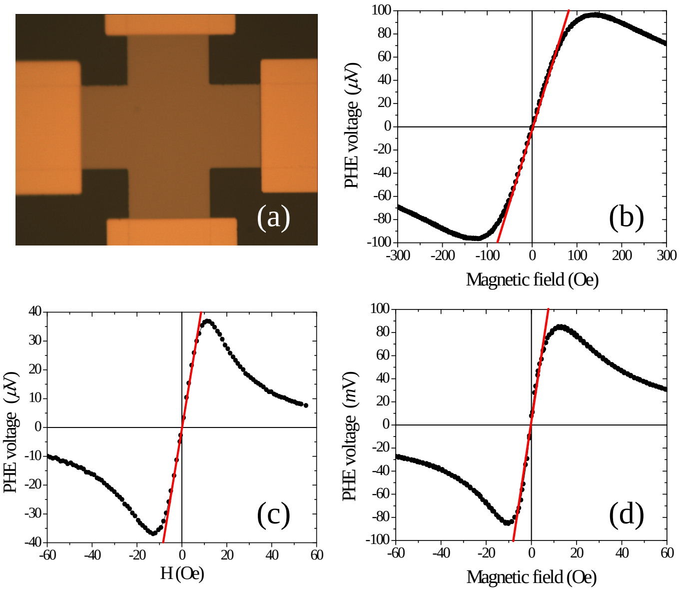

Fig. 1 (a) Micrograph of the single 50 μm×50 μm PHE sensor junction, (b)-(c) the PHE profiles of the bilayer structure, spin-valve structures and bilayer structure with a thin spacer layer between AF and FM layers.

References

[1] Colman Goldberg and R. E. Davis, Phys. Rev. Lett., **94**, 1121 (1954)

[2] Vu Dinh Ky, Physica Status Solidi b, vol. **26**, 565 (1968).

[3] K. L. Yau and J. T. H. Chang, J. Phys. F: Metal Phys., 1, 38 (1971).

[4] T. Q. Hung, S. J. Oh, S. A. Kumar, J. R. Jeong, D. Y. Kim, and C. G. Kim, IEEE Trans. Magn., to be published

[5] N. J. Gökemeijer, T. Ambrose, and C. L. Chien, *Phys. Rev. Lett*., **79** (1997) 4270.