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Exchange Coupling of Ferromagnetic/Antiferrmagnetic through Nonmagnetic Layer in Antiferromagnetic

Jong-Min Kim*, Young-Sung Kim
Advanced Material Process of Information Technology, Sungkyunkwan University

1. INTRODUCTION

Exchange biasing usually denoted the unidirectional anisotropy arising in exchange coupled ferromagnetic (FM)/antiferromagnetic (AFM) system. It is characterized by a shift of the hysteresis loop, the so-called exchange bias field(H_{EB}), and/or an increase in the coercive field(H_C). Recently, exchange biasing has been extensively studied in terms of numerous system parameters. Some of these parameters include interracial roughness[1], FM thickness[2], AFM thickness[3], and dilution in the AFM[4], Other studies investigated the effects of spin-flop coupling in the AFM[5], changes in the domain state distribution in the AFM upon field cooling[6], and distance between the AFM and FM layer via the insertion of a nonmagnetic spacer layer between them[7].

While some experiments suggest that exchange anisotropy is in fact strictly interfacial, other experiments have shown that the bulk of the AFM plays an equally important role. The importance of these two factors in H_{EB} motivates our study. In our study, we examine the role of non-interfacial AFM layers by propagating a probing layer through the AFM and measuring the resultant changes in H_{EB} using magneto-optical Kerr effect (MOKE) magnetometry.

2. EXPERIMENT

We used Fe/NiO bilayers in which nonmagnetic materials (MgO, Ag, Cu) was buried in the NiO at various distances from the Fe/NiO interface. The films were grown in the dc magnetron-sputtering chamber. Two different types of samples were grown. In the first type, which we shall identify as type-I samples, we change the thickness of NiO layer from 0 Å to 450 Å. The thickness of Fe is 20 Å. The structure of first samples are 20 Å Ru / 20 Å Fe / x Å NiO / 150 Å Ag. These samples were used reference to compare with second type samples. The second type of sample (type-II samples) involves inserting a thin MgO, Ag, Cu films inside the NiO. We change the depth of nonmagnetic materials, which has thickness of 2.5, 5.0, 7.5 Å, in NiO. The structure of second samples are 20 Å Ru / 20 Å Fe / x Å NiO / 2.5 Å , 5.0 Å, 7.5 Å MgO, Ag, Cu / 500-x Å NiO / 150 Å Ag, where x is from 0 Å to 210 Å. During growth, the samples were backed with a permanent magnet to induce an in-plan easy axis in the Fe film. Finally, the samples were heated to 180°C and then cooled in a 1kOe field to room temperature. The direction of the applied field during field cooling was chosen along the same direction as the growth field. The magnetic properties were characterized by magneto-optical Kerr effect (MOKE) at room temperature with the field applied parallel to the common uniaxial and unidirectional anisotropy axis.

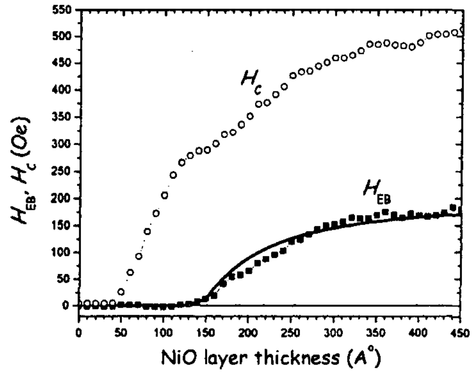

Figure 1. Dependence of exchange bias field coercive field on NiO thickness. The solid line in H_{EB} shows the best fit of generalized Meiklejohn−Bean approach equation.

3. RESULTS AND DISCUSSION

As seen in Figure 1, the H_{EB} and the H_C of type-I samples, which has structure of 20 Å Fe / x Å NiO (x is from 0 Å to 450 Å) show a strong dependence on thickness of AFM NiO. The H_{EB} appears at 130 Å and then increasing until 400 Å, after 400 Å the H_{EB} has constantly 180 Oe. The H_C begins to increase at 30 Å, and has about 520 Oe in 450 Å. As the thickness of NiO thicker, the H_{EB} and H_C have enhanced. In this case, H_{EB} is affected by bulk NiO. This means that the exchange bias is long-range coupling when looking from the point of view of the AFM. The solid line are fits to the using generalized Meiklejohn-Bean approach equation[8].

In type-II samples, the H_{EB} and H_C show a strong dependence on depth of nonmagnetic layer(Figure 2). Initially, the H_{EB} is reduced, where at depth is 20~30Å, it is minimized, and then slowly begins increasing. In initial, the reduction of H_{EB} is because the H_{EB} is enhanced by rough Fe/NiO interface when nonmagnetic layer is in Fe/NiO interface. Crystallographic orientation and grain size are the main parameters influencing FM/AFM H_{EB} that could be modified by nonmagnetic clusters. As the thickness of MgO layer thicker, the MgO layer sufficiently decouples the thin interfacial NiO from bottom NiO. The H_{EB} of thickness of 5.0 Å MgO is smaller than that of 2.5 Å MgO. The H_{EB} of Ag sample is bigger than that of MgO sample in initial. This means that the Ag layer less decouples the thin interfacial NiO from bottom NiO than MgO layer. This property was reported in other group's work[7]. The H_{EB} of Cu sample decreases until 30Å and continually increases. Comparing samples of 5.0 Å non-magnetic materials (MgO, Cu, Ag), the H_{EB} of MgO sample is lowest and that of Cu and Ag are similar. MgO is more decoupling than others materials. The variety of Cu sample is largest. The H_{EB} of 7.5 Å Ag sample is not different with that of 5.0 Å Ag sample, whereas the H_{EB} of Cu sample is lower than that 5.0 Å Cu sample. This means that the Ag layer has strong coupling the thin interfacial NiO with bottom NiO. These results indicate that the exchange coupling across a nonmagnetic layer is specific to the nonmagnetic materials, which it is electronic and geometric in nature. NiO and MgO have rocksalt crystal structure comprised of alternating Ni^{2+}, Mg^{2+} cations and O^{2-} anions with lattice constants of 4.195 Å for NiO, 4.21 Å for MgO. Cu and Ag have fcc crystal structure with lattice constant of 3.61 Å, 4.09 Å, respectively. The decoupling of MgO is largest, whereas the that of Ag is smallest. It is because the crystal structure of NiO and MgO are similar as mentioned in above. The result that the decoupling of Ag smallest consistent with the result of FM/nonmagnetic spacer/AFM [9].

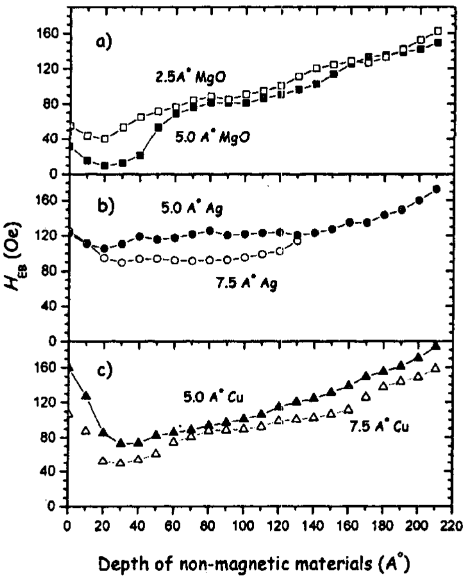

Figure 2. Dependence, H_{EB} vs. Depth of nonmagnetic layer, (a) MgO ,(b) Ag ,(c) Cu.

4. SUMMARY

The H_{EB} was investigated for exchange coupling 20 Å Fe / x Å NiO (type-I samples), 20 Å Fe / x Å nonmagnetic layer(MgO, Ag, Cu)/(500-x Å) NiO (type-II samples). In type-I samples, the H_{EB} is long-range coupling when looking from the point of view of the AFM. The H_{EB} consistent with a generalized Meiklejohn-Bean approach. The critical thickness, which H_{EB} is observed, is 130 Å. In type-II samples, MgO layer more decouples the thin interfacial NiO from bottom NiO than other nonmagnetic layer. And the decoupling of Ag smallest. This means that the Ag layer has strong coupling the thin interfacial NiO with bottom NiO.

5. REFERENCES

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