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Universal time relaxation behavior of the exchange bias in ferromagnetic/antiferromagnetic bilayers

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Abstract

The resilience of the exchange bias (H_{Ex}) in ferromagnet / antiferromagnet bilayers is generally studied in terms of repeated hysteresis loop cycling or by protracted annealing under reversed field (training and long-term relaxation respectively). The stability of H_{Ex} is fundamental for practical application of exchange bias systems. In this paper we report measurements of training and relaxation in FeNi films coupled with the antiferromagnet FeMn. We show that H_{Ex} suppressed both by training and relaxation was partially recovered as soon as a field cycling for consecutive hysteresis loop measurement was stopped or the magnetization of the ferromagnet was switched back to the biased direction.

I. Introduction

The stability of exchange bias (H_{Ex}) in exchange coupled ferromagnet (FM) / antiferromagnet (AF) systems is important because of its influence on the properties of spin valves and magnetic tunnel junctions. The blocking temperature (T_B), the temperature at which the H_{Ex} vanishes, has attracted much attention because of its close relevance to the thermal stability.[1] On the other hand, it has been observed that in many exchange biased systems the H_{Ex} depends on the number of measurements. This so-called 'training effect' has been used to describe such decreases of the H_{Ex} with sequential measurements of hysteresis loops.[2,3] In this report, we show that because of a finite measurement time the training effect with the number of measurements is inevitably mixed with a time relaxation behavior of AF domains caused by a change of neighboring FM spin direction, so it is hard to separate each contributions in a typical experimental condition.[4] Moreover, we show that such a time relaxation behavior of the H_{Ex} exists in both exchange biased systems with epitaxial or polycrystalline AF layers.

II. Experimental

We prepared two types of exchange coupled FM/AF bilayer systems based on polycrystalline AFs. Polycrystalline NiFe/FeMn bilayers on Si substrates were prepared by ultrahigh vacuum dc sputtering with Ar pressure of 0.5 Pa. FeMn/NiFe bilayers were also prepared on a long rectangular Si substrate within a magnetic shield, resulting in a uniaxial domain structure in the NiFe was locked into the biased layer. The magnetic hysteresis loop M(H) of NiFe layer was measured by a vibrating sample magnetometer (VSM). It took about 4 minutes to collect each M(H) loop data.

III. Results and Discussions

The training effect with different FeMn thickness was summarized in Figure 1. The thicker is the FeMn layer, the weaker the training effect. In addition, the training effect becomes relatively weak at low temperature. On the other hand, the H_{Ex} of the seventh hysteresis loop was partially recovered by a relaxation for 30 minutes at +H for the field sweep +H→ - H→+H. Figure 2(a) shows a long time relaxation behavior of the H_{Ex} for the several FeMn thicknesses. The magnetic field was cycled in the form of - H→ +H→ - H and the time-dependent hysteresis loop data were collected after the cycling magnetic field was stopped at - H for 30 minutes. H_{Ex} gradually decreases with increasing the time and iseems to scale with log(t), where t is the time. The scaling constant decreases with increasing the FeMn thickness. On the other hand, a long time recovery behavior was also observed when the cycling magnetic field stays in +H for a finite time. Figure 2(b) displayed a long time decay and recovery behaviors of the H_{Ex} for 4 nm FeMn sample. These results indicate that the observed training effect is not simply due to the number of measurement. The increase or decrease of the H_{Ex} with the time is explained by a relaxation behavior of AF domain configuration to minimize the total magnetic energy.

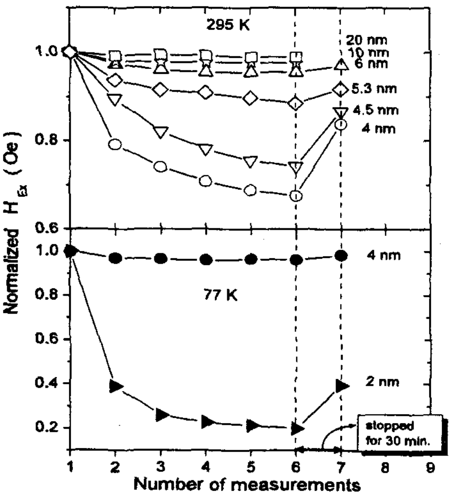

Figure 1

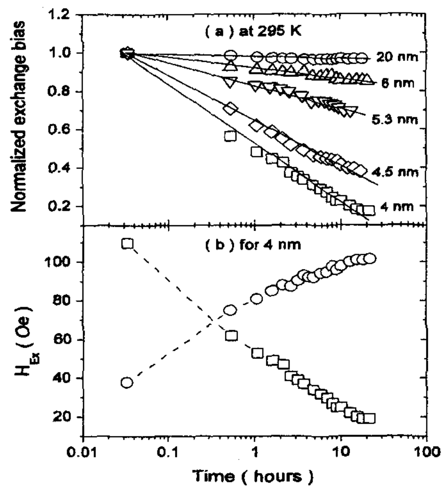

Figure 2

IV. Conclusions

We have investigated the training effect and the time relaxation behavior in exchange coupled FeMn/NiFe bilayers. Our systematic study revealed that in exchange bias systems the H_{Ex} is dependent on measurement timeas well as measurement number, and thus a change in the H_{Ex} is caused by a time relaxation behavior of AF domain configuration to minimize the total magnetic energy.

Figure Caption

Figure 1. Normalized H_{Ex} as a function of the number of loop measurement for different FeMn thicknesses (a) at 295 K and (b) at 77 K.

Figure 2. (a) Normalized H_{Ex} as a function of the time for different FeMn thicknesses at 295 K. (b) Decay and recovery behavior as a function of the time for 4 nm FeMn at 295 K.

References

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