Exchange bias in NiFe/FeMn/NiFe multilayers

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Abstract

FeMn based spin valves often consist of a NiFe/FeMn/NiFe trilayer structure. We have investigated the evolution of exchange bias at the bottom and top interfaces in the NiFe(5nm)/FeMn(x)/NiFe(5nm) trilayer structure as a function of FeMn thickness in the range 3 nm to 30 nm. The XRD results indicate (111) textured growth for NiFe and FeMn layers. The magnetization studies using VSM show two hysteresis loops corresponding to the bottom NiFe seed layer and top NiFe layers with greater bias for the bottom NiFe layer, for FeMn thickness equal to and above 5 nm. The larger exchange bias for the bottom seed layer is confirmed by the surface sensitive MOKE hysteresis loop measurements which show gradual weakening of the MOKE hysteresis loop for the bottom NiFe layer with increasing FeMn thickness. The observed large exchange bias in a spin valve structure is usually attributed to the pinning NiFe layer on top of the FeMn layer, even when a NiFe seed layer of a few nm thickness is present, whereas, in reality it may be arising from the bottom seed layer, as shown by the present study.

Keywords : Exchange bias, Multilayers, Spin valves, MOKE

1.Introduction

Modern read heads and the GMR and TMR based MRAMs have a spin valve multilayer architecture [1]. At the heart of a spin valve GMR structure is an AFM/FM bilayer that provides the necessary exchange bias through exchange anisotropy. Despite enormous research efforts during the past decade, and other investigations ever since its discovery forty years back, the exchange bias phenomenon has eluded adequate scientific understanding [2-3]. In the case of a spin valve with FeMn antiferromagnetic layer, when NiFe is used as a seed layer to facilitate the growth of (111) -FeMn antiferromagnetic phase, a NiFe/FeMn/NiFe trilayer structure provide the exchange bias. An adequate understanding of the exchange bias of this trilayer is very important.

We have carried out a systematic investigation of evolution of exchange bias at the top and bottom NiFe layers in a symmetric NiFe(5nm)/FeMn(x)/NiFe(5nm) trilayer structure for FeMn thickness in the range of 3-30 nm, with the help of VSM and MOKE measurements, and its correlation with the structural information derived from X-ray diffraction. Our investigations show that the so called seed layer at the bottom interface show much higher exchange bias in comparison to the pinned layer on top of FeMn layer. The result is significant in that the large exchange bias is often attributed to the technologically important top pinning layer, whereas, in reality the pinning strength of the top NiFe layer could be much lower [4].

2.Experimental

The multilayer thin films of the composition Si/SiO2/Ta(5)/NiFe(5)/ FeMn(x)/NiFe (5)/Al_2O_3 (nm) with x=3,5,7, 10, 15, 20, 25, 30 nm thickness was deposited by rf magnetron sputtering at a base vacuum around 3×10^{-7} Torr. Argon gas pressure was 1×10^{-3} Torr. The deposition rate of all the layers were around 0.1 nm/s. A constant magnetic field of 60 Oe was applied at the time of film deposition to develop the necessary exchange bias. The XRD patterns were recorded on Siemens D5000 diffractometer using Cu Ka radiation. The VSM measurements were carried out on a LDJ 9600 magnetometer and the the MOKE measurements were performed using a home-made MOKE system in the longitudinal mode.

3. Results and Discussion

3.1 X-ray Diffraction

The high angle XRD patterns show that the films under investigation have a (111) texture that becomes stronger with increasing FeMn thickness. The peaks corresponding to FeMn and NiFe are however not very well resolved though the patterns were recorded in the short 2 range of 42-46. The peak at 43.8 in the film with FeMn thickness of 3 nm and the shoulder towards the right correspond to MnFe(111) and NiFe (111) respectively. With increasing FeMn thickness the intensity of the FeMn peak increases and that of the NiFe peak (the shoulder) show a relative decrease since the NiFe thickness remains constant. For low FeMn thickness, the d-value of the (111) peak is lower than the bulk value but the peak shows a systematic shift towards the d-value of (111) peak of bulk FeMn, with increasing FeMn thickness.

3.2 Magnetization by VSM

The magnetization hysteresis loops of the ML films with different FeMn thickness are presented Fig. 1. The 3 nm film shows a single asymmetric hysteresis loop with a small shift from zero field. The thickness of 3 nm for FeMn is apparently insufficient to nduce any exchange bias and the two NiFe layers behave like a single layer and show only a single loop. For FeMn thickness of

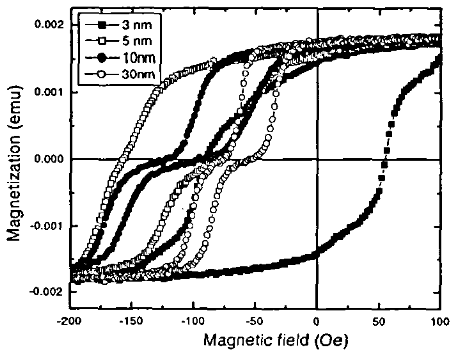

Fig. 1 Magnetization curves of the trilayer films.

5 nm, the hysteresis loops show a clear shift from zero field and now the loops corresponding to the two NiFe layers are evident though not well separated. The two loops show zero field shifts (H_{eb} values) of 85 and 152 Oe. For a thickness of 7 nm and more two well separated hysteresis loops corresponding to the two NiFe layers could be observed.

The zero field shifts or exchange bias H_{eb} for the loop with larger shift increase and reach a maximum value of 175 Oe around a FeMn thickness of 10 nm but show a gradual decrease thereafter. However, exchange bias for the loop with lower shift, shows a maximum value of 85 Oe for the FeMn thickness of 5 nm and decrease thereafter as seen in these curves. The question arises now on which of these loops correspond to the top NiFe layer that usually is the pinned layer in a spin valve structure: The one with stronger exchange bias (larger loop shift) or the one with the smaller shift?

3.3 MOKE measurements

In order to distinguish between the twohysteresis loops and to confirm which of them represent the bottom and top NiFe ayers, we measured MOKE (Magnetooptic Kerr Effect) hysteresis loops of these ML films with different MnFe thickness. MOKE

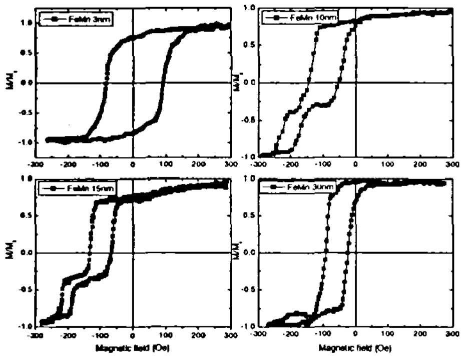

Fig. 2 MOKE hysteresis loops of the trilayer films

or SMOKE, as it is often called on account of its surface probing, is sensitive to a depth of 20- 25 nm only. The top NiFe layer with a thickness of 5 nm is always likely to produce MOKE hysteresis loop but the bottom NiFe layer may not be detected properly by MOKE technique for larger FeMn thickness of the order of 20 nm and above. The MOKE loops recorded for the films with different MnFe thickness are represented in Fig. 2. It can be seen that for FeMn thickness up to 15 nm, the hysteresis loops are identical to the VSM data with two hysteresis loops corresponding to the top and bottom NiFe layers. It may however be noticed that the hysteresis loop with higher exchange bias has become weaker than that of 10 nm film. For FeMn thickness of 25 and 30 nm, the hysteresis loop with higher exchange bias weakens further, showing clearly that it corresponds to the bottom NiFe layer. On account of the increasing thickness of the MnFe layer above 20 and 25 nm, the signal of the bottom NiFe layer is not properly detected by the surface sensitive MOKE technique. Thus the MOKE measurements confirm that the bottom NiFe layer show higher exchange bias in agreement with argument presented above.

3.4 Exchange Bias

Many of the early studies on the multilayers of FeMn/NiFe type, with NiFe on top with no seed layers, have shown no or low exchange bias. Later, several investigations showed that for a multilayer structure with FeMn as antiferromagnetic layer, a (111) seed layer (e.g., NiFe or Cu) is essential for the development of -fcc antiferromagnetic face and the exchange bias [5,6]. In presence of the field applied during growth, the -fcc FeMn phase could start growing by populating the AFM domains with the spin direction closest to the applied field and the NiFe spins, in the seed layer. As a result, this interface between seed NiFe layer (the bottom NiFe layer in the present study) and MnFe could develop good exchange bias. The exchange bias of the top NiFe layer will depend on the extent to which this FM/AFM coupling at the bottom interface is propagated through the MnFe layer to the top FeMn/NiFe interface and also on the thickness of the MnFe layer. It is particularly so in the case of MnFe AFM layers because of the strong dependence of the growth of -fcc FeMn phase on the bottom (111) seed layer. It may be possible that the anti ferromagnetic domains in FeMn with magnetic moments closer to the (111) plane could be getting repopulated during growth in presence of applied magnetic field at the bottom NiFe/FeMn interface to give rise to exchange bias at the bottom.interface [7]. Exchange bias being strongly dependent on the spin structure close to the interface, it is unlikely that similar or better magnetic ordering could be acheived at the top interface after propagating through the MnFe layer to give rise to equal or higher exchange bias at the top interface. Therefore the bottom NiFe layer or the seed layer is likely to show higher exchange bias, provided it has sufficient thickness.

The exchange bias for the top NiFe layer is interestingly only half of that of the bottom interface in the range of FeMn thickness from 5nm to 25 nm. It shows the strong interfacial nature of the exchange anisotropy and exchange bias. Apparently the favorable spin structure at the bottom interface for higher exchange bias is not propagated even up to 5 nm. At the bottom interface, the (111) texture of the bottom NiFe layer induces good (111) spin structure in FeMn at the interface, that helps to enhance the exchange bias. This is however true only up to a few atomic layers. In traversing beyond a certain critical thickness, which is less than 5 nm as is evident from the low exchange bias for upper NiFe layer in films with FeMn thickness of 5nm, the spin structure undergoes a change to reduce the coupling at the upper interface to half. It may be difficult to understand the exact change in spin structure taking place inside multilayer structure over such atomic scale dimensions. However, it is interesting to note that this modified spin structure is almost retained up to a FeMn thickness of 25 nm beyond which it starts decreasing (though there is an initial fall after 5 nm as noted earlier). The decrease in exchange bias beyond 25 nm may be due to the transition of FeMn to the -bcc phase, expected over large thicknesses.

NiFe seed layers of different thickness are used in the FeMn based spin valve structures. It is significant to note that in spin valve structures of NiFe/FeMn/NiFe/NM/FM type, for NiFe seed layer thickness above 4-5 nm, the large exchange bias observed could be due to the seed NiFe layer and not the technologically important pinning NiFe layer on top of the FeMn.

4. Conclusions

The investigations on NiFe/FeMn/NiFe multilayer structure show greater exchange bias for the bottom NiFe layer, which is the so called seed layer, in comparison to the top NiFe layer that is usually the pinned layer in spin valve structure, for 5 nm NiFe seed layer. MOKE hysteresis loop measurements confirm that the NiFe layer with larger exchange bias indeed is the bottom seed layer. The results show that ignoring the seed NiFe layer could lead to wrong assessment of the pinning field strength in NiFe/FeMn based spin valves and serious problems of stability in the devices developed

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