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Exchange Bias Modifications in NiFe/FeMn/NiFe Trilayer by a Nonmagnetic Interlayer

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Modification in exchange bias of a NiFe/FeMn/NiFe trilayer, on introduction of a nonmagnetic Al layer at the top FeMn/NiFe interface, is investigated in multilayers prepared by rf magnetron sputtering. The introduction of Al layer leads to vanishing of bias of the top NiFe layer. But the bias for the bottom NiFe layer increases steadily with increasing Al layer thickness and attains bias (230 Oe) which is greater than that of the trilayer without the Al layer (150 Oe). When the top NiFe layer thickness is varied, exchange bias has highest value at 12 nm thickness for 1 nm thicknes of Al layer. Ion beam etching of the top NiFe layer also leads to an enhancement in bias for the bottom NiFe layer.

Key words : Exchange coupling, Ion implantation, Multilayers, Spin-valve

1. Introduction

Microscopic origin of exchange bias is yet to be understood even after four decades, in which exchange bias manifests as a shift of the magnetic hysteresis loop from zero field. Several models have been proposed for exchange bias over the years and it is often attributed to the presence of interfacial uncompensated spins with a structural origin in surface and interface roughness [1-3]. Recent studies have shown three fold increase in exchange bias on dilution of antiferromagnetic CoO with Mg in MBE grown Co/CoO bilayers [4]. Thus nonmagnetic inclusions appear to have an enhancing effect on the exchange bias.

NiFe/FeMn/NiFe trilayer is present in many spin valve multilayer structures with FeMn antiferromagnetic layer when NiFe is used as the seed (bottom) layer for growth of (111) γ-FeMn phase of FeMn. The trilayer with two antiferromagnet/ferromagnet (AFM/FM) interfaces shows two hysteresis loops with different bias corresponding to the seed and the top NiFe layers. The seed NiFe layer has been observed to show greater bias than the top NiFe layer indicating different spin configuration in the two NiFe/FeMn interfaces [5]. The effect of a nonmagnetic interlayer near one of the interfaces in this trilayer may have effect on the exchange bias of the two NiFe layers. In this study we investigated the effect of a nonmagnetic Al layer between the FeMn and top NiFe layer on bottom exchange bias.

2. Experimental Procedure

Multilayers films with the composition Si/SiO_2/Ta(5)/NiFe(3)/FeMn(8)Al(t)/NiFe(x)/Ta(5) (nm), where t = 0.3. 0.5 ⋯ to 2.0 nm and x = 3,6, ⋯ to 18 nm were prepared by rf magnetron sputtering at a base vacuum around 3×10^{-7} Torr. Argon gas pressure was 1×10^{-3} Torr. The deposition rates 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. No additional field annealing and cooling was carried out. VSM measurements were carried out on a LDJ 9600 magnetometer. A Kaufman type ion source was used to generate Ar ion beam and a beam acceleration voltage of 500V were employed for ion beam etching with different incident angles.

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3. Results and Discussion

The XRD patterns of the multilayered samples showed (111) texture for both FeMn and NiFe layers, necessary for the development of γ-FeMn antiferromagnetic phase and exchange bias [5]. NiFe/FeMn/NiFe trilayer has been observed to show two biased hysteresis loops in the magnetization curves corresponding to the two NiFe layers even for a top NiFe layer thickness of 2 nm [6, 7].

Magnetization curves of the trilayer NiFe(3)/FeMn(10)/NiFe(12) (nm), are shown in Fig. 1, where the two loops are clearly shown with the bias of −90 and −20 Oe, respectively. The relative values of magnetization of the two loops correspond with 1 : 4 ratios of the thickness of the seed and top NiFe layers, indicating higher bias loop is caused by the bottom layer.

On introduction of an Al interlayer of a mere 0.3 nm thickness or more on top of the FeMn layer, the top NiFe layer no more shows any bias, though its magnetization curve persists without any shift from zero field. The presence of Al layer at the top NiFe interface however, has a profound effect on the bias of the bottom NiFe layer. Fig. 2 shows bias variations of the bottom NiFe layer after introduction of Al layer. The exchange bias increases systematically to 230 Oe as Al layer thickness increases from 0.3 nm to 1 nm, and thereafter decreases with increasing Al thickness. However, coercivity is nearly constant for different Al thickness.

Our investigations of the trilayer have shown maximum bias value of only 150 Oe for the seed layer [6, 7]. For Al

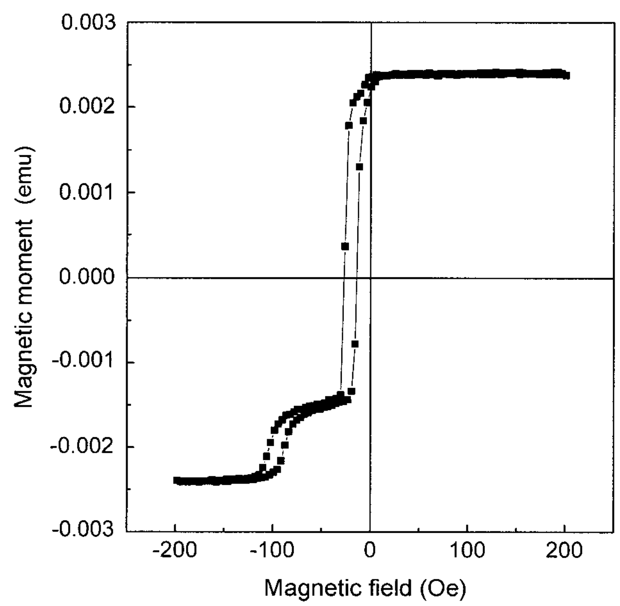

Fig. 1. Magnetization curve of the NiFe(3)/FeMn(10)/NiFe(12) (nm) multilayer.

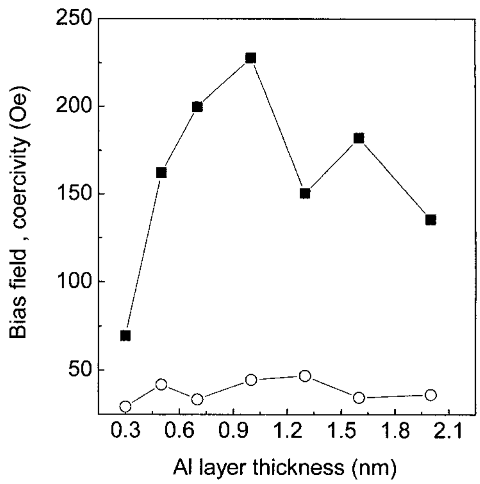

Fig. 2. Variation of exchange bias and coercivity of bottom layer as a function of Al interlayer thickness in NiFe(3)/FeMn(8)/Al(t)/NiFe(12) (nm) multilayer.

interlayer thickness of 1 nm in Fig. 2, the bias is about 230 Oe and thus there is an enhancement in bias. The enhancement of bias with nonmagnetic dilution of antiferromagnetic CoO layer with Mg in the bulk, away from the interfaces, have shown three fold increase in exchange bias in MBE grown Co/CoO bilayers [4]. They have explained their observation of enhancement in bias as related to the possibility that the defects favour formation of domains in AFM and that the domains in the volume of the AFM layer alter the spin structure at the FM/AFM interface leading to small net magnetization and exchange bias. Therefore, nonmagnetic inclusions away from the interface can have substantial influence on exchange bias. In our case, the introduction of Al layer at the top FeMn/NiFe interface may be having somewhat similar effect at the seed interface by inducing domain formations, or modifying crystallites of AFM layer.

Thickness of the top NiFe layer had been observed to have an effect on the exchange bias of the seed NiFe layer studies [5]. In Fig. 3, the exchange bias variations of the bottom NiFe layer in the trilayer are shown as a function of top NiFe layer thicknesses for different Al interlayer thicknesses. At top NiFe layer thickness of 3 nm, relatively low bias values are observed for all Al layer thicknesses. For 0.5 and 1 nm thickness of Al interlayer, high bias values above 150 Oe are observed for top NiFe layer thickness of 6 nm and above. Al interlayer of 1 nm thickness shows highest bias values above 200 Oe for top NiFe thickness of 6 nm and above.

Ar ion beam etching is a low energy process in sub-keV range often employed for dry etching of surfaces in multilayers. The partial etching of the top NiFe layer has

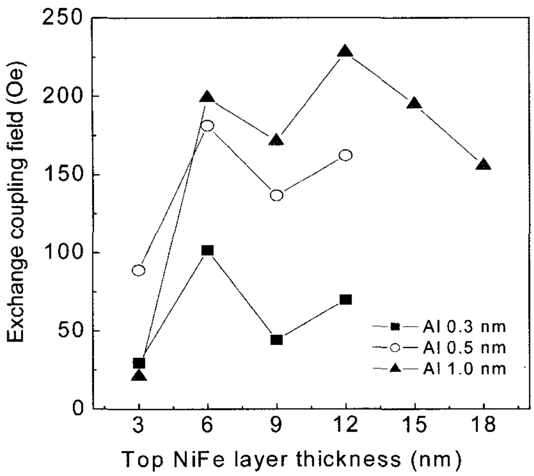

Fig. 3. Exchange bias variations of bottom layer as a function of top NiFe layer thickness for different Al layer thickness.

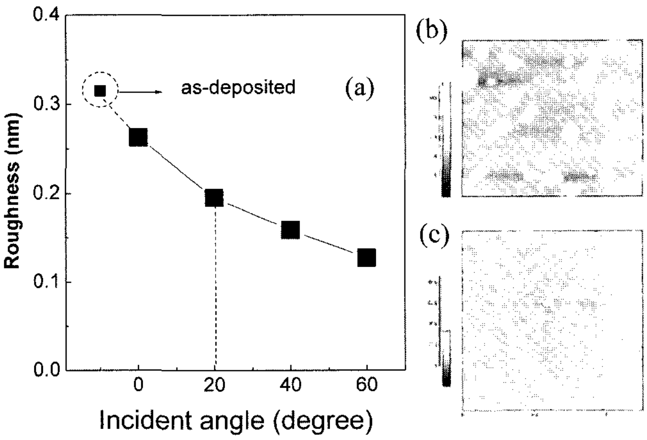

Fig. 4. (a) Dependence of surface roughness on incident angle, and AFM micrographs of (b) as-deposited, (c) etched samples at 20° incident angle.

an influence on internal stress and surface roughness [7]. The incident angle is an important parameter which determines the surface condition after etching. Fig. 4 shows the surface roughness measured by an AFM after etching at different incident angles after 3 nm etching of top NiFe (12 nm). The incident angle of beam is varied from 0 to 60 degree with a step of 20 degree. As the tilt angle increases surface roughness decreases gradually, from 0.26 nm for 0° incident angle to 0.13 nm for 60° angle. This could be understood by the smoothening of the surface due to the increase in incident angle. But it is hard to correlated surface roughness to bias field because exchange bias is an interface phenomenon and is often considered to depend on roughness at interfaces.

The magnetization curves before and after etching less than 1 nm are compared in Fig. 5 for sample with Al

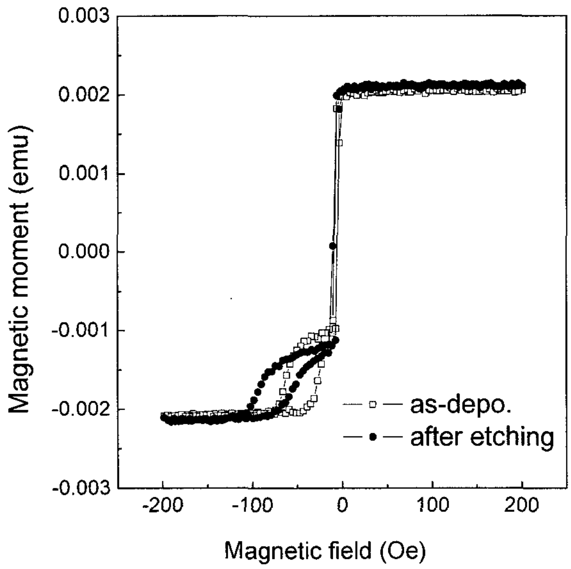

Fig. 5. The magnetization loops of the NiFe(3)/FeMn(8)/Al(0.3)/NiFe(12) (nm) multilayers before and after ion beam etched samples.

interlayer of 0.3 nm at the top NiFe interface. The top NiFe layer of 12 nm shows its own hysteresis loop with large magnetization but with no bias as seen earlier. For the bottom NiFe layer there is a considerable enhancement in bias after etching, from 50 Oe to 70 Oe. Recent studies show that He ion beams in the few keV range have a remarkable effect on the exchange bias in a variety of multilayer systems [8]. The enhancement may be the result of the defects induced in the antiferromagnet as result of bombardment with ions. These defects may serve as energetically favourable pinning sites for magnetic domain formation and increase in the number of domains, which leads to substantial enhancement in bias [9].

4. Conclusion

Introduction of a nonmagnetic Al layer of increasing thickness at the top FeMn/NiFe interface in a NiFe/FeMn/NiFe trilayer leads to vanishing of bias for the top NiFe layer and increase of bias for the seed (bottom) NiFe layer. Ion beam etching of the top NiFe layer also leads to enhancement of bias for the bottom NiFe layer. The study demonstrates the profound influence of nonmagnetic interlayers and ion irradiation on exchange bias. But we need further elaboration to understand the microscopic origin of enhanced exchange bias.

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