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MAGNETORESISTANCE OF NiFeCo/Cu/NiFeCo/FeMn MULTILAYERED THIN FILMS WITH LOW SATURATION FIELD

S. T. Bae*, K.-I. Min, K. H. Shin, and J. Y. Kim*
Div. of Metals, Korea Institute of Science & Technology, Seoul 136-791, Korea.
* Dept. of Electronic Materials Eng., Kwangwoon Univ., Seoul 447-1, Korea.

Abstract-Magnetoresistance of NiFeCo/Cu/NiFeCo/FeMn uncoupled exchange biased sandwiches has been studied. The magnetoresistance change ratio, $\Delta R/R_s$ showed 4.1 % at a saturation field as low as 11 Oe in Si/Ti(50 Å)/NiFeCo(70 Å)/Cu(23 Å)/NiFeCo (70 Å)/FeMn(150 Å)/Cu(50 Å) spin valve structure. In this system, the magnetoresistance was affected by interlayer material and thickness. When Ti and Cu were used as the interlayer material in this structure, maximum magnetoresistance change ratio were 0.32 % and 4.1 %, respectively. 6.1 % MR ratio was obtained in Si/Ti(50 Å)/NiFeCo(70 Å)/Cu(15 Å)/NiFeCo (70 Å)/FeMn(150 Å)/Cu(50 Å) spin valve structure. The magnetoresistance change ratio decreased monotonically as the interlayer thickness increased. It was found that the exchange bias field exerted by FeMn layer to the adjacent NiFeCo layer was ~25 Oe, far smaller than that reported in NiFe/Cu/NiFe/FeMn spin valve structure(Dieny et al., ~400 Oe). The relationship between the film texture and exchange anisotropy has been examined for spin valve structures with Ti, Cu, or non-buffer layer.

I. INTRODUCTION

Since the GMR(Giant Magnetoresistance) effect was firstly observed in $(Fe/Cr)_n$ metallic superlattice by Baibich et al.[1], a great deal of work has been done in various (ferromagnetic/nonmagnetic) multilayers with high magnetoresistance change ratio[2-5]. This effect occurs when the relative orientation of the magnetization of adjacent ferromagnetic layers varies from parallel to antiparallel due to antiferromagnetic coupling of adjacent ferromagnetic layers through the nonmagnetic spacer layer. From the experimental results and theoretical models, the physical origin of the GMR phenomenon is thought to be due to spin dependent scattering induced by random potential between ferromagnetic and nonmagnetic interface[6].

However, from the point of view of the magnetoresistance(MR) application, especially MR head and magnetic flux sensor, saturation fields of these multilayers are too high because of the strong antiferromagnetic coupling between the ferromagnetic layers. Therefore, many research works have focused on the uncoupled sandwich with low saturation field and high magnetoresistance change ratio in respect of MR application. In 1990, a different type of GMR was proposed by Shinjo et al.[7] who studied multilayers like $[NiFe/Cu/Co/Cu]_n$, composed of uncoupled magnetic layers having different coercivities.

They obtained a considerably high magnetoresistance change ratio(9.9 %) with the saturation field as low as 500 Oe at room temperature. In 1991, B. Dieny et al.[8,9] discovered Si/Ta/NiFe/Cu/NiFe/FeMn/Ta spin valve structure, where the two ferromagnetic layers were separated by nonmagnetic (noble metal) layers. In order to vary the relative orientation of the magnetization of each ferromagnet, they constrained one of the ferromagnetic layers by antiferromagnetic layer(for example, FeMn). In this system, they obtained the high magnetoresistance change ratio at a low saturation field. They explained that the magnetoresistance effect in this system due to the antiparallel spin orientation was induced by exchange anisotropy residing at the NiFe/FeMn interface. Because of their high magnetoresistance at a low saturation field, ferromagnetic spin valve multilayers are attractive for many technical applications, such as MR sensors and MR heads for reading from the high density recording media[10].

In this study, we have investigated the magnetoresistance effect in NiFeCo/Cu/NiFeCo

/FeMn uncoupled exchange-biased sandwiches. In this system, we chose the soft magnetic NiFeCo alloy as the ferromagnetic layer, because NiFeCo was expected to exhibit larger MR ratio than NiFe owing to the inclusion of Co atoms[11].

To examine the magnetoresistive characteristics with interlayer thickness, Cu or Ti interlayer thickness was varied from 10 to 60Å. In order to investigate the relationship between the film texture and magnetoresistance, the effect of buffer layers on the magnetoresistance was investigated.

II. EXPERIMENTAL

Samples were prepared by R.F. and D.C. magnetron sputtering on p-type Si(100) substrates with resistivity of 22~38 Ω-cm. NiFeCo alloy thin film was deposited by RF sputtering and FeMn, Ti, and Cu films were deposited by DC sputtering. In order to induce the undirectional anisotropy in the soft magnetic thin films, magnetic field was applied in the substrate holder by $Sm-Co_5$ permanent magnets(Fig.1). Following the previous work[12], the composition of NiFeCo soft magnetic thin film was decided to be $Ni_{66}Fe_{16}Co_{18}$ because of the low magnetostriction and magneto-crystalline anisotorpy. The composition of FeMn exchange biased layer was selected to be $Fe_{50}Mn_{50}$ to induce a strong exchange anisotroy field at the NiFe/FeMn interface.

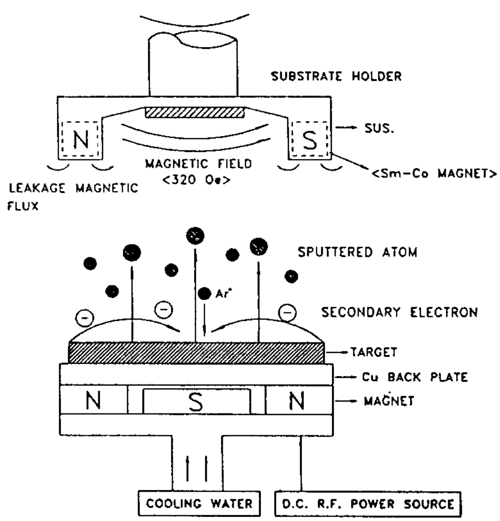

Fig.1 A schematic diagram of magnetron sputtering.

The substrate was fixed on a rotating holder located 75 mm above the targets. The sputtering Ar pressure was kept at 3 mTorr and the substrate temperature during deposition was kept at ambient temperature. The deposition rates of NiFeCo, FeMn, Cu and Ti, measured by long scan profiler, were 18, 36, 24 and 40 Å/min, respectively. The total film thickness was about 400 Å. The composition of NiFeCo and FeMn was analyzed by EPMA(Electron Probe Micro Analysis) and ICP-OES(Inductively Coupled Plasma-Opto Emission Spectroscopy) and the structure of the multilayered thin films was examined by a thin film X-ray diffractometer. The magneoresistance ratio and the magnetization curves of the multilayered structures were measured at room temperature. A vibrating sample magnetometer was used to measure the magnetization curves with a maximum magnetic field of ±100 Oe. The magnetoresistance ratios were measured using a computer controlled four-point probe system by applying a DC magnetic field in the sample plane and perpendicular to the constant DC current. In our experiment, the magnetoresistance change ratio is defined as follows.

$$MR\ ratio(\%) = (R-R_s)/R_s \times 100$$

where R and R_s are resistances at a field and at a saturation field, respectively.

III. RESULTS AND DISCUSSION

The magnetoresistance and the magnetization curves of Si/NiFeCo(70Å)/Cu (23 Å)/NiFeCo(70 Å)/FeMn(150 Å)/Cu(50 Å) were plotted in Fig.2. In this structure, Cu capping layer was introduced in an attempt to minimize surface oxidation of the structure. Fig.2 shows the MR response corresponding to field swept between ±70 Oe and maximum MR ratio of 3.25 % with saturation field as low as 11 Oe. The M-H hysteresis loop of this system consists of two loops. The first one shows the magnetization curve of free NiFeCo soft manetic layer with a coercivity of 6 Oe. The 6 Oe shift of the nominally free NiFeCo layer in this hysteresis loop indicates the presence of a ferromagnetic coupling through the nonmagnetic interlayer[13]. The second one, with a coercivity of 24 Oe and an exchange bias field of 25 Oe, corresponding to the reversal of the magnetization of the NiFeCo layer coupled to the FeMn antiferromagnetic layer. When the external magnetic field is swept from -100 Oe to +100 Oe, the orientation of the magnetizations of the two NiFeCo layers separated by the Cu interlayer varies from parallel below 8 Oe and above 60 Oe to antiparallel between 11 Oe and 54 Oe. The magnetoresistance curve of Fig.2(b) exhibits a sharp increase due to increase of spin-dependent scattering of polarized conduction electrons at 11 Oe [14]. The steep change of resistance in the MR curve corresponds to the switching of the free NiFeCo layer, followed by the switching of the pinned NiFeCo layer. However, magnetoresistnace is very small when the external magnetic field is swept from +100 Oe to -100 Oe. Therefore, the magnetization reversal is asymmetric. This can be attributed to concurrent reversal of both magnetic layers magnetizations due to the small exchange field (~25 Oe) and high anisotropy field (~20 Oe)[13].

Fig.3 shows maximum MR ratios as a function of Ti or Cu interlayer thickness in Si/Ti(50 Å)/NiFeCo(70 Å)/(t_{Ti} or t_{Cu})/NiFeCo(70 Å)/FeMn (150 Å) spin valve structure. The Cu interlayer thikness was varied from 13 Å to 63 Å and the Ti interlayer thickness was varied from 23 Å to 53 Å. Fig3(a) and (b) show that the MR ratio decreases as the interlayer thickness increases in both Ti and Cu cases. When the Ti or Cu was used as an interlayer in Si/Ti(50 Å)/NiFeCo(70 Å)/interlayer (23 Å)/NiFeCo(70 Å)/FeMn/Cu(50 Å) spin valve structure, the MR ratio showed larger in Cu case than Ti Case. From the experimental results and previous work[14], it seems that the flow of electrons emitted from one ferromagnetic layer to the other ferromagnetic layer is very well trasmitted through the Cu layer because of the low electrical resistivity of Cu. However, this transmis-

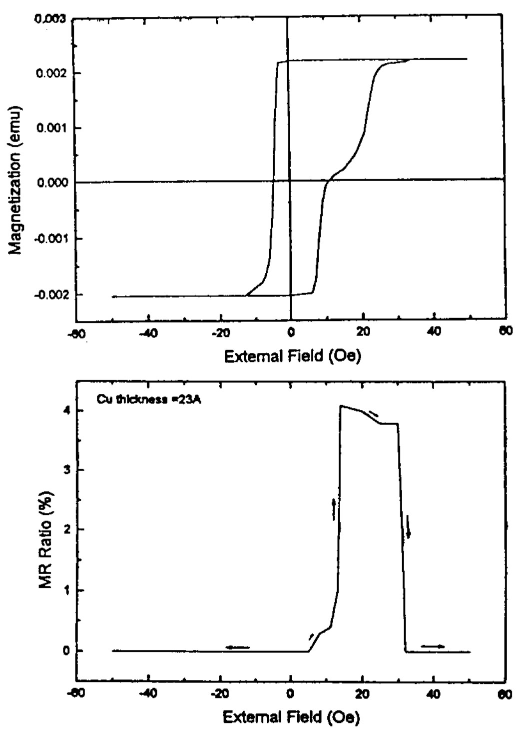

Fig.2 The magnetization and magnetoresistance curves of Si/NiFeCo(70 Å)/Cu(23 Å)/NiFeCo(70 Å)/FeMn(150 Å)/Cu(50Å) spin valve sructure.
(a) magnetization curve. (b) magnetoresistance curve.

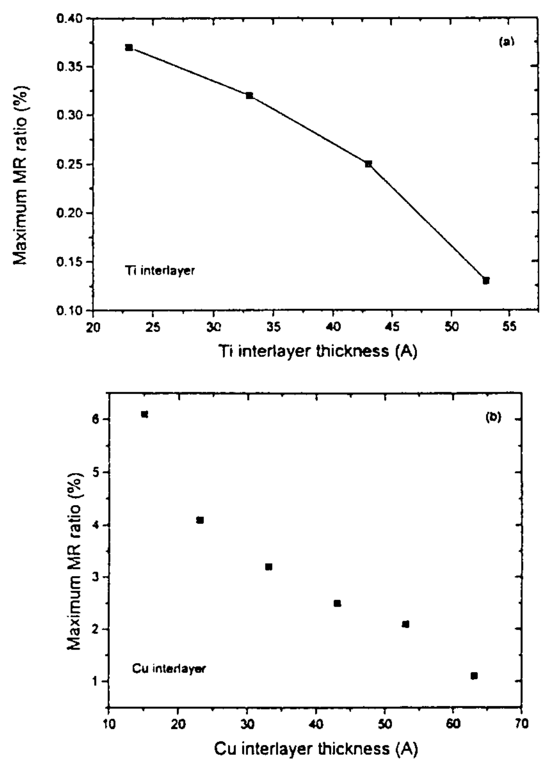

Fig.3 Maximum MR ratio vs interlayer thickness in Si/NiFeCo/interlayer/NiFeCo/FeMn spin valve structures at room temperature. (a) Ti (b) Cu

sion of conduction electrons seems to be severely hindered in the case of Ti interlayer. Fig.3(b) shows maximum MR ratio with Cu interlayer thickness ranging from 15 Å to 63 Å. The magnetoresistance change ratio decreased rapidly and monotonically with increasing Cu interlayer thickness, similar to the behavior reported in NiFe/Cu/NiFe/FeMn spin vlave structure. For 15 Å of Cu, 6.1 % MR ratio can be noticed in Fig.3(b), which is higher value than that reported in NiFe/Cu/NiFe/FeMn spin valve structure. However, it has to be mentioned that two ferromagnetic layers were ferromagnetically coupled, which might be due to pin-holes in the Cu interlayer[13]. Fig. 4 shows the hysteresis loops and magnetoresistance curves of Si/buffer layer(50 Å)/NiFeCo(70 Å)/Cu(23 Å)/NiFeCo(70 Å)/FeMn (150 Å)/Cu(50 Å) samples with Cu, Ti or non-buffer layer. When the Cu was used as a buffer layer, the magnetization curve was slightly shifted from zero magnetic field, which means that the exchange biased field is low. By contrast, the spin valve structures with Ti or non-buffer layer the exchange biased field is somewhat higher. However, it is far smaller than that reported in NiFe/Cu/NiFe/FeMn spin valve structure[9].

As can be seen in Fig.4, the spin valve structure with Cu buffer layer does not show high magnetoresistance effect, while the spin valve structure with Ti or non-buffer layer shows the magnetoresistance change ratios of 4.1 % and 3.25 %, respectively. In the case of Cu buffer layer, because of the low exchange biased field induced at NiFeCo/FeMn interface, magnetic moments of the two NiFeCo layers are always parallel. Therefore, the change of spin dependent scattering did not occur. In contrast to Cu buffer layer, relatively high magnetoresistance change ratio could be obtained in the case of the Ti or non-buffer layer.

In order to understand the different behavior depending on the buffer layer, we examined the film texture of Si/buffer layer/NiFeCo/Cu/NiFeCo/FeMn samples using a thin film X-ray diffractometer. Fig.5 shows the thin film XRD pattern of Si/(Cu, Ti(50 Å) or non-buffer)/NiFeCo(70 Å)/Cu (23 Å)/NiFeCo(70 Å)/FeMn(150 Å)/Cu(50 Å)

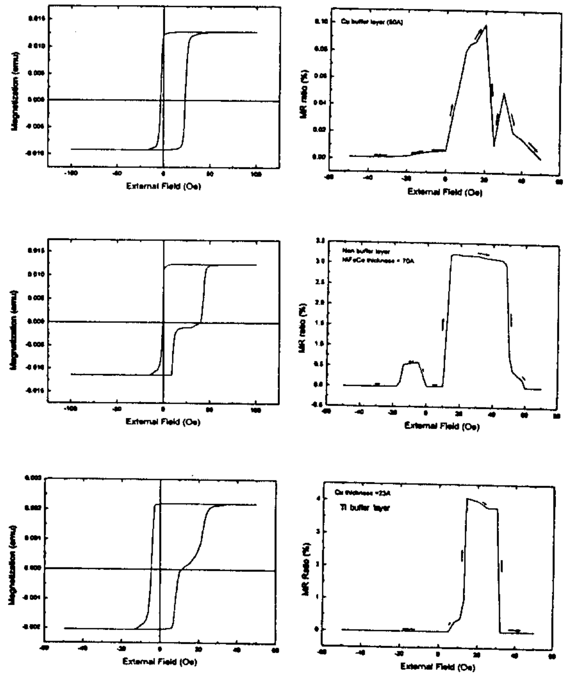

Fig.4 Magnetization curves and magnetoresistance curves in Si/NiFeCo/Cu/NiFeCo/FeMn structures with Ti, Cu or non buffer layer.

multilayered thin films. The sandwiches with Ti or non-buffer layer show fcc(111) peaks from NiFeCo and Cu layers, while the sandwich with Cu buffer layer shows a very weak fcc(111) peak. Therefore, it seems that the sandwich with Cu buffer layer might have α-Mn structure or disordered γ-Mn structure. but it is not clear at this point since the XRD spectra showed no signal from FeMn layer. Nakatani et al.[15] have suggested that the exchange bias field and magnetoresistance might be closely connected with (111) texturing of the sandwiches. This kind of relationship between film texture and exchange bias field is, however, not clear in Figs.4 and 5, since the bias field is smaller but (111) texture is stronger in the case of non-buffer layer than Ti buffer layer. Our recent investigation[16] on the interrelationship between texture, roughness, and exchange bias field suggests that interface roughness must be taken into account, not texture only.

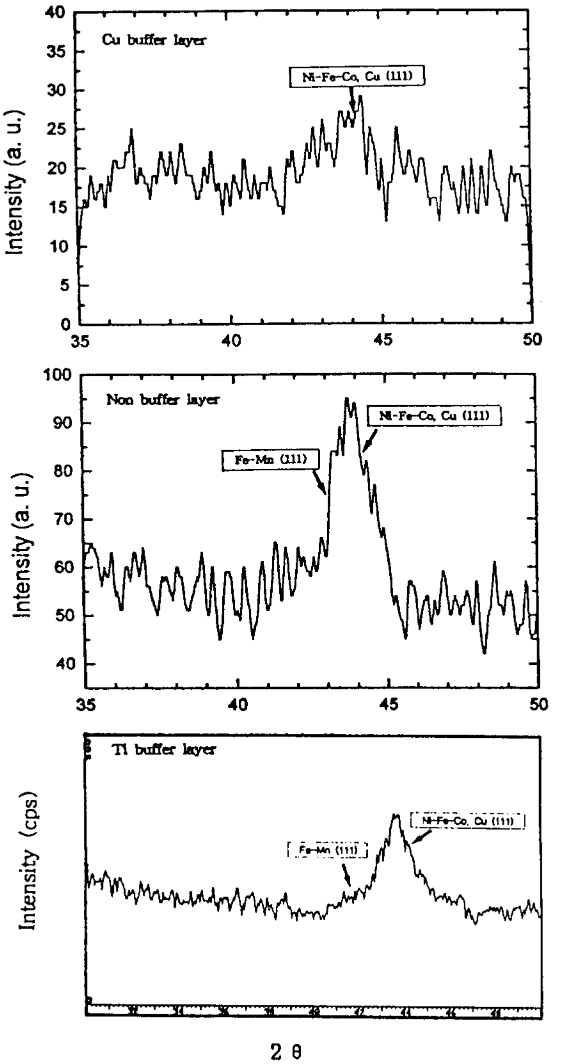

Fig.5 Thin film XRD patterns for Si/buffer layer/NiFeCo(70 Å)/Cu(23Å)/NiFeCo(70Å)/FeMn(150Å)/Cu(50Å).

Ⅳ. CONCLUSIONS

We have investigated the magnetoresistance effect, magnetic properties, and structure of Si/NiFeCo/Cu/NiFeCo/FeMn exchange biased uncoupled sandwiches and obtained the following results.

(1) Magnetoresistance change ratio as large as 6.1 % was obtained in Si/Ti(50 Å)/NiFeCo(70 Å)/Cu(15 Å)/NiFeCo(70 Å)/FeMn(150 Å)/Cu (50 Å) sample, which is larger than that reported in NiFe/Cu/NiFe/FeMn spin valve structure. The magnetoresistance change ratio showed 4.1 % at a saturation field as low as 11 Oe in Si/Ti(50 Å)/NiFeCo(70 Å)/Cu(23 Å)/NiFeCo (70 Å)/FeMn (150 Å)/Cu(50 Å) spin valve structure.

(2) Exchange field in NiFeCo/Cu/NiFeCo/FeMn spin valve structure was small (a few ten Oe) compared with that in NiFe/Cu/NiFe/FeMn spin valve structure (a few hundred Oe).

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