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# Effect of Interface Roughness on Magnetoresistance of [Ni/Mn] Superlattice-Based Spin Valves

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**The effect of interface roughness between [Ni/Mn] superlattice and pinned NiFe layer on magnetoresistance (MR) of [Ni/Mn] superlattice-based spin valve films was investigated. Antiferromagnetic phase structure and interface roughness of [Ni/Mn] superlattice spin valve films were compared in the as-deposited and the annealed samples at 240 °C, respectively. Surface morphology of spin valves was substantially flattened due to the formation of the antiferromatic NiMn phase. In case of Co insertion between Cu and NiFe, the interface roughness and MR ratio in the annealed [Ni/Mn] superlattice and pinned NiFe/Co layer increased more than those in the annealed [Ni/Mn] superlattice and pinned NiFe layer, respectively.**

**Key words : Interface roughness, Antiferromagnetic phase, [Ni/Mn] superlattice-based spin valve, Thermal treatment**

## 1. Introduction

There has been a considerable amount of interest in NiMn alloy film spin valves since they have a high exchange coupling field ($H_{ex}$) and high thermal stability [1, 2]. The $H_{ex}$ in the NiMn/NiFe bilayer is obtained through thermal annealing to promote atomic ordering in the NiMn layer [3-5]. The deterioration of gaint magnetoresistance (GMR) during heat treatment depends on the atomic layer sequence, which includes a pinning layer of antiferromagnetic material. Therefore, the fabrication of [Ni/Mn] superlattice instead of an NiMn alloy film should enhance $H_{ex}$ and thermal stability [6, 7].

In this paper, we report the influence of interface roughness between [Ni/Mn] superlattice and pinned NiFe, and that between [Ni/Mn] superlattice and NiFe/Co layer, on the MR of [Ni/Mn] sperlattice-based spin valve.

## 2. Experimental

The [Ni(2 Å)/Mn(3 Å)]$_{40}$ superlattice was grown on a Corning glass (7059) substrate by means of a 3 inch multi-target dc sputtering system with a base pressure of $2 \times 10^{-6}$ Torr and a working pressure of 5 mTorr. The sandwiched spin-valve films consisting of NiFe(60 Å)/Cu(30 Å)/NiFe (60 Å) on the [Ni/Mn] superlattice were sequentially deposited at the rate of 1.5-2.0 Å/s without a uniaxial deposition field. In order to induce the $H_{ex}$ between the [Ni/Mn] superlattice and the pinned NiFe layer, thermal annealing cycles of 2-4 hrs at 240 °C under a static magnetic field of 250 Oe were applied. The structure phase, the $H_{ex}$ and coercivity ($H_c$) of the [Ni/Mn] superlattice/NiFe films, and the magnetic properties of the spin valve films were measured with X-ray diffraction (XRD) and vibrating sample magnetometer (VSM). MR of the [Ni/Mn] superlattice-based spin valves was measured by a dc four-probe method at room temperature. The surface morphologies of the spin valves were observed using atomic force microscope (AFM), calibrated by standard atomic grating [8].

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## 3. Results and Discussions

Fig. 1(a) and Fig. 1(b) show the $2\theta$ X-ray diffraction patterns of as-deposited [Ni(2 Å)/Mn(3 Å)]$_{40}$ superlattice and the annealed one at 240 °C for 4 hrs, respectively. Due to the annealing treatment, the Ni/Mn superlattice grows preferentially with an NiMn (111) peak ($2\theta = 42.5°$), which is consistent with the appearance of the antiferromagnetic phase. Typical magnetic properties of as-deposited and annealed [Ni/Mn]$_{40}$/NiFe/Cu/NiFe films are shown Fig. 1(c) and Fig. 1(d). The magnetization loops show that the $H_{ex}$ and $H_c$ of the pinned layer are 115 Oe and 95 Oe, respectively.

Fig. 2(a), (b), and (c) show a MR measurement and *M-H* loop of as-deposited [Ni/Mn]$_{40}$/NiFe/Cu/NiFe, the annealed

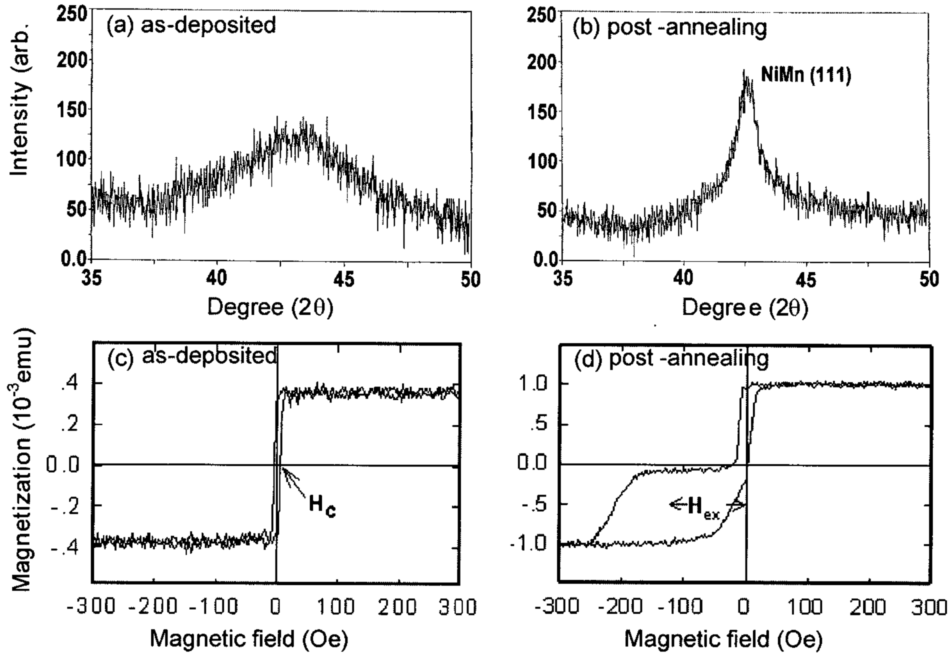


Fig. 1. X-ray diffraction 2$\theta$ scan patterns for the [Ni/Mn] superlattice grown on Corning (7059) glass substrate. (a) As-deposited and (b) annealed [Ni/Mn] superlattice at 240 °C. Magnetization loops of (c) as-deposited and (d) annealed [Ni(2 Å)/Mn(3 Å)]$_{40}$/NiFe(70 Å)/Cu(30 Å)/NiFe(60 Å) spin valves at 240 °C.

one at 240 °C for 4 hrs and 12 hrs, respectively. Here, the measured composition of superlattice was 30 at% Ni. Fig. 2(b) shows that the $H_c$ of the free layer is about 10 Oe, the $H_{ex}$ and $H_c$ of pinned layer are about 125 Oe and 80 Oe, respectively. Fig. 2(c) shows that the $H_{ex}$ and $H_c$ are 305 Oe and 245 Oe, respectively. These values are those of the largest $H_{ex}$ and $H_c$ in [Ni/Mn] superlattice-based spin valve films. Although the good antiferromagnetic phase for [Ni/Mn] superlattice forms through thermal treatment, the MR ratio is as small as 0.43%~0.55% because of the several causes, which are the shunting effect by the metallic multilayers having the thickness of 350 Å, the interdiffusion between NiFe and Cu layer, and the extraction of Mn atom within spin valve films. However, we have found that the

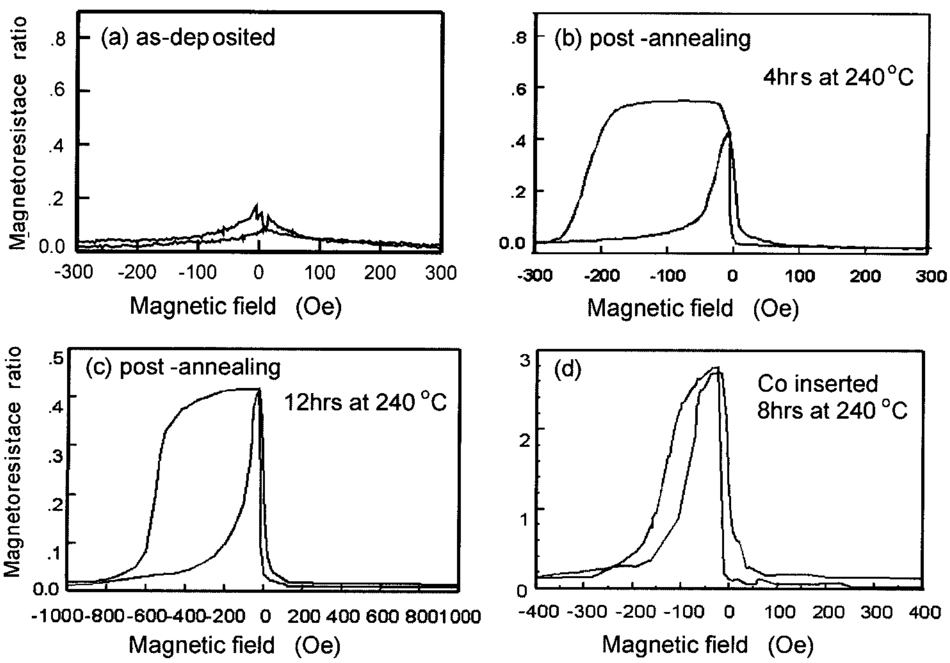


Fig. 2. MR curves of (a) as-deposited, (b) annealed at 240 °C for 4 hrs and (c) 12 hrs for the [Ni(2 Å)/Mn(3 Å)]$_{40}$/NiFe(70 Å)/Cu(30 Å)/NiFe(60 Å) spin valves, and (d) annealed [Ni(2 Å)/Mn(3 Å)]$_{40}$/NiFe(50 Å)/Co(15 Å)/Cu(30 Å)/Co(15 Å)NiFe(100 Å) spin valves at 240 °C.

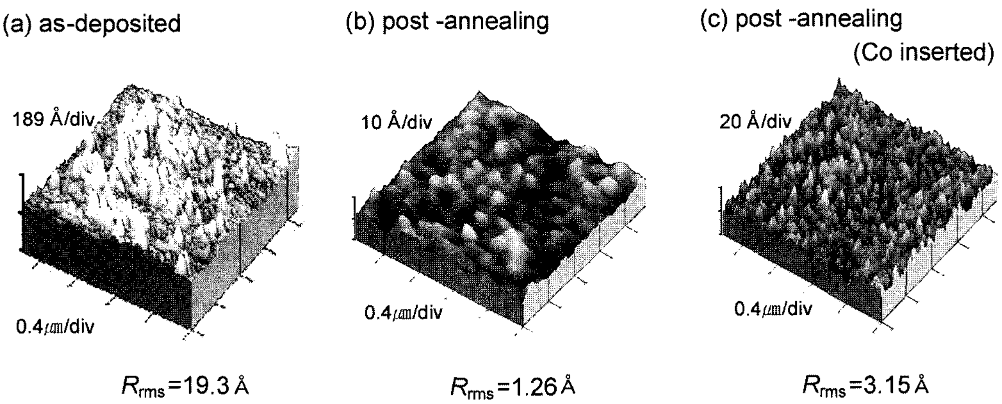


Fig. 3. 3-dimensional AFM image of (a) as-deposited (b) annealed [Ni/Mn] superlattice spin valves and (c) Co inserted spin valves.

MR ratio increases when the thin Co layer is inserted between the NiFe and Cu layer, as shown in Fig. 2(d). In the case of the inserted Co layer, the MR ratio is enhanced to 2.8% increases due to the increase of spin dependent scattering at interface between Co and Cu layer.

The surface morphologies were observed by AFM as shown in Fig. 3. As-deposited spin valve film appears roughly as shown in Fig. 3(a) due to the reduction of mobility when performing deposition at room temperature. The value of rms roughness ($R_{rms}$) is about 19 Å. However after vacuum thermal annealing at 240 °C for 10 hrs, the surface is substantially flattened as shown in Fig. 3(b). The value $R_{rms}$ of post-annealed spin valves rapidly decreases to 1.26 Å. The dominant decrease of $R_{rms}$ may be played an important role in $H_{ex}$ and $H_c$ of the [Ni/Mn] superlattice spin valves having the antiferromagnetic NiMn (111) phase, as shown in Fig. 1(b) and (d). In case of Co insertion between Cu and NiFe, the increase with $R_{rms}$ of 3.15 Å, indicating a relatively larger roughness of the interface in the annealed [Ni/Mn] superlattice and NiFe layer, is shown in Fig. 3(c). The slightly large roughness leads to the reduction of $H_{ex}$ (115 Oe) and $H_c$ (25 Oe) due to the increased slope of roughness of the line depth profiles in AFM analysis [9]. The reduction of the $H_{ex}$ and $H_c$ in the annealed [Ni/Mn] superlattice-based spin valves is attributed to the value of the slope of roughness, because the high value could both increase the magnetostatic energy and decrease the antiferromagnetic domain size [10]. From Fig. 3, it can be seen that after thermal treatment the MR ratio for the Co-inserted [Ni/Mn] superlattice spin valves is on an average 2~3% higher than other spin valves due to the difference roughness of surface and interface, as confirmed by AFM measurement.

## 4. Conclusions

[Ni/Mn] superlattice-based spin valves having high thermal stabilities after a thermal treatment at 240 °C showed a fct (face centered tetragonal) structure, which is consistent with the appearance of the antiferromagnetic phase. The surface morphology of the annealed spin valves is substantially flattened due to atomic ordering with the formation of the antiferromagnetic NiMn (111) phase. The interface roughness and $H_{ex}$ in the annealed [Ni/Mn] superlattice and pinned NiFe/Co layer increased and decreased more than those in the annealed [Ni/Mn] superlattice and pinned NiFe layer, respectively.

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