

## Magnetoresistance in Hybrid Type YBCO-NiO/NiFe/Cu/NiFe Film Structure

S. S. Lee\*, J. R. Rhee<sup>1</sup>, D. G. Hwang and K. Rhie<sup>2</sup>

*Dept. of Physics, Sangji University, Wonju 220-702, Korea*

<sup>1</sup>*Dept. of Physics, Sookmyung Women's University, Seoul 140-742, Korea*

<sup>2</sup>*Dept. of Physics, Korea University, Chochiwon 339-700, Korea*

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The magnetoresistance properties of NiO/NiFe/Cu/NiFe spin valve film deposited on MgO(100) substrate with YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub>(YBCO) film were investigated at room temperature and at 77 K. The magnetoresistance (MR) curves of the hybrid superconductor-magnetoresistor film structure showed an exchange coupling field of 300 Oe and an inverse magnetoresistance ratio of -6.5%. The magnetization configurations of the two magnetic layers in the NiO spin valve were antiparallel due to an increment in the conduction electron flow to superconductor YBCO film. This sample showed an inverse MR ratio.

**Key words :** NiO/NiFe/Cu/NiFe spin-valve, hybrid type, superconductor YBCO film, inverse MR ratio

### 1. Introduction

Since the discovery of high- $T_c$  superconductor (HTS), there has been studied a hybrid type device of superconductor-semiconductor or a heterostructure device of superconductor-ferroelectric for the semiconductor industry or electric information storage application. On the other side, the hybrid type structure of HTS-giant magnetoresistance (GMR) can be expected a complex and peculiar experimental results because of the diamagnetic property of superconductor and the GMR effect [1-4]. To apply the nonvolatile MRAM device or a new magnetic read head sensor having a very small power loss by the sense current [5, 6], it is necessary to study magnetoresistance properties of the hybrid type HTS-GMR multilayer. Generally, GMR finds its origin in the spin-dependence of electron scattering in magnetic layers or at their interface. However, the other side, it has been shown that the GMR in sandwiches, which ferromagnetic layers are separated by semiconductors or metallic nonmagnetic layers, can be reversed to obtain an inverse magnetoresistance (IMR) [7, 8]. In this present work, we reported that the negative or inverse MR effect could be observed in the hybrid type YBa<sub>2</sub>Cu<sub>3</sub>O<sub>6</sub>(YBCO)-NiO/NiFe/Cu/NiFe film structure, and explained this peculiar result.

### 2. Experimental Procedure

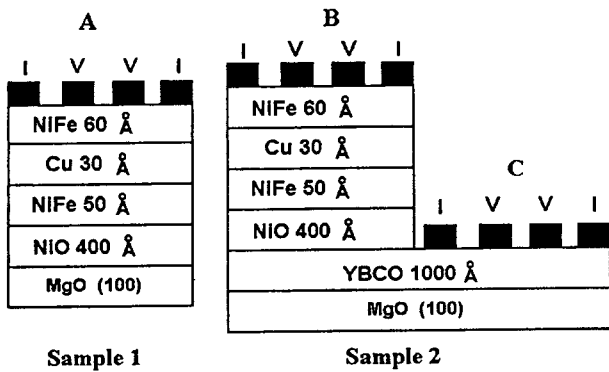
We fabricated the high- $T_c$  superconducting YBCO film (2000 Å) on MgO(100) at 710 °C using a hollow cathode

dc sputtering deposition technique [8]. NiO-based NiFe/Cu/NiFe spin valve films were prepared at room temperature by rf sputtering (NiO) and dc sputtering (NiFe, Cu) using a sintered NiO powder target and a pure metallic 3-inch targets, respectively. The base pressure was  $1 \times 10^{-6}$  Torr prior to deposition. The sputtering argon pressure was 1.3 mTorr. The growth rates of NiO(300 Å)/NiFe(50 Å)/Cu(30 Å)/NiFe(60 Å) were controlled by deposition time. The growth rates were typically 5 Å/min for NiO, 1 Å/s for Cu, and 2 Å/s for NiFe. During the deposition time, the uniaxial anisotropy field of 350 Oe applied in film plane. The exchange coupling field ( $H_{ex}$ ) and MR ratio defined by magnetoresistance curves measured at room temperature and 77 K, respectively. The critical temperature ( $T_c$ ) was measured from resistance-temperature curve. The surface morphology of hybrid HTS-GMR films was observed by using an atomic force microscope (AFM).

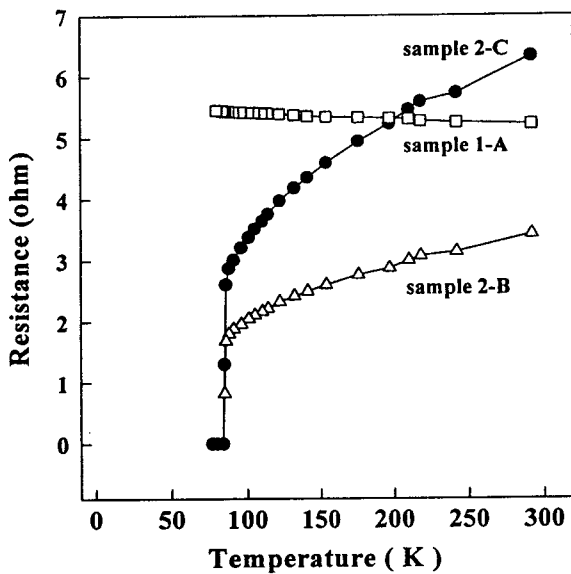
### 3. Results and Discussion

The four probe electrodes for three different samples are shown in Fig. 1. Sample 1-A is the typical spin valve structure of NiO(400 Å)/NiFe(50 Å)/Cu(30 Å)/NiFe(60 Å) deposited on MgO(100) single crystal substrate. The sample 2 was separated into two regions, one is MgO(100)/YBCO(2000 Å)/NiO spin valve film (sample 2-B) and the other one is YBCO film (sample 2-C). Fig. 2. shows the resistance-temperature (R-T) curves of three different samples. Sample 1-A has a metallic-semiconducting mixed phase due to the semiconducting phase at interface of NiO/NiFe and the metallic phase of Cu/NiFe bilayers. Sample 2-

\*Tel: +82-33-730-0415, e-mail: sslee@chiak.sangji.ac.kr

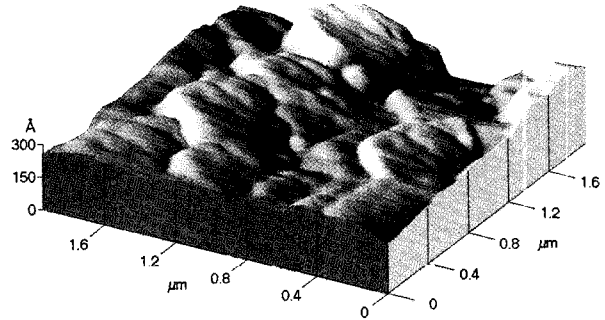


**Fig. 1.** Multilayer structures of sample 1-A: NiFe/Cu/NiFe/NiO/MgO(100), sample 2-B: NiFe/Cu/NiFe/NiO/YBCO/MgO(100), and sample 2-C: YBCO/MgO(100).



**Fig. 2.** Resistance versus temperature curves of sample 1-A : NiFe/Cu/NiFe/NiO/MgO(100) (open square), sample 2-B: NiFe/Cu/NiFe/NiO-YBCO/MgO(100) (open triangle), and sample 2-C: YBCO/MgO(100) (solid circle).

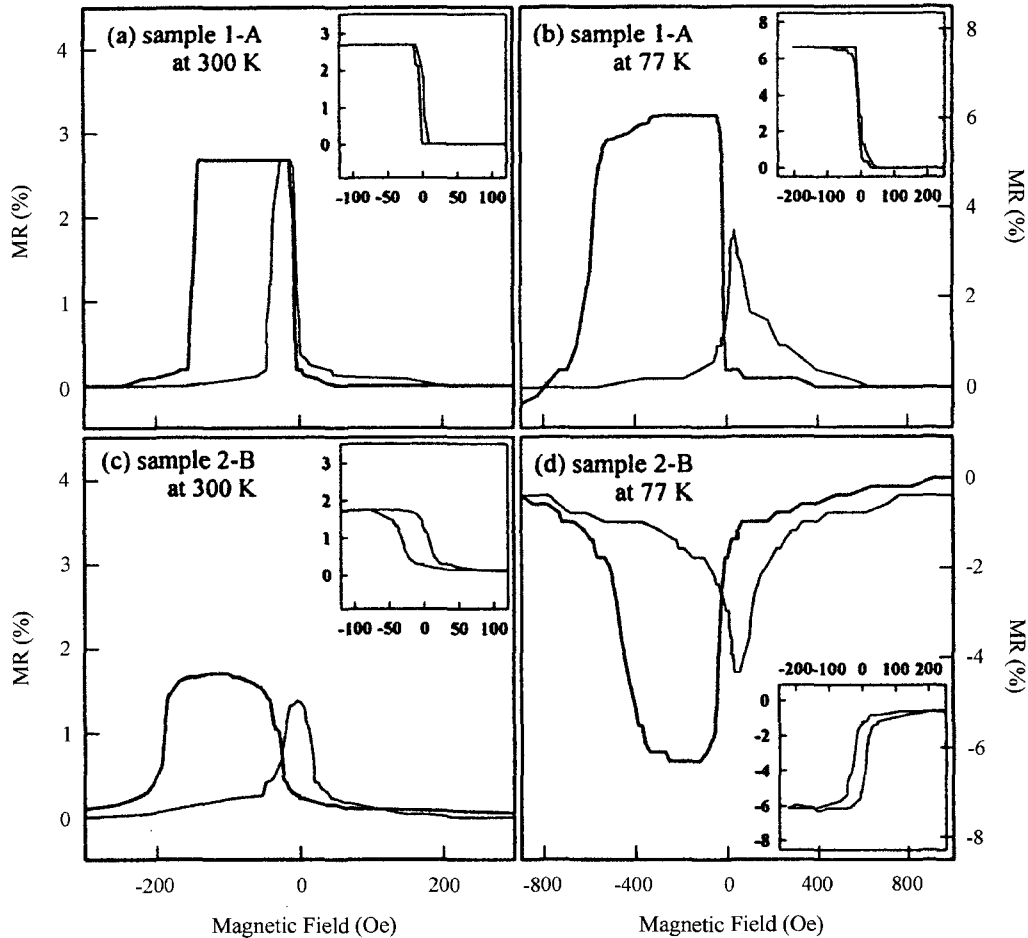
B has an incomplete superconducting phase because of antiferromagnetic NiO insulating barrier, and sample 2-C has a superconducting phase having a critical temperature of 85 K and critical current density of  $2 \times 10^{-5}$  A/cm<sup>2</sup> at 77 K. The R-T curve of sample 2-B also shows that the tunneling current pass through NiO between YBCO film and NiFe/Cu/NiFe sandwiches. The surface morphology having a height of 100~200 Å and a width of a few thousand Å is due to the surface morphology of YBCO films having the rms roughness value of below 100 Å. The surface roughness is smaller than the NiO layer thickness of 400 Å, but the YBCO films can not be completely covered by NiO films. Fig. 3 shows 3-dimensional AFM image for the sample 2-B. From R-T curve and surface morphology of sample 2-B, we can explain that the conduction electron flow of current is a part of tunneling current through NiO antifer-



**Fig. 3.** 3-dimensional AFM image for the sample 2-B: MgO(100)/YBCO(2000 Å)/NiO(400 Å)/NiFe(50 Å)/Cu(30 Å)/NiFe(50 Å).

romagnetic layer of 400 Å.

The major and minor MR curves of three samples are shown in Fig. 4. These are measured at room temperature (300 K) and LN<sub>2</sub> temperature (77 K), respectively. The minor loops as shown in inset of Fig. 4 represent soft magnetic behavior of the free NiFe layers of NiO spin valves and YBCO-NiO spin valves, respectively. In case of sample 1-A as shown in Fig. 4(b), the MR ratio and  $H_{ex}$  are increased to 6.5% and 300 Oe at 77 K. This is because the spin-dependent scattering was increased by enhancement of magnetic properties (such as coercivity and exchanging bias field) at low temperature. Fig. 4(c) shows that the MR ratio at room temperature is smaller and the shape of MR curve less square than those of Fig. 4(a). As existing the YBCO-intercalating layer with a few hundred rms roughness, the shape and the magnitude of the MR curves and the  $H_{ex}$ -value are changed. However, the hybrid HTS-GMR film (sample 2-B) shows an  $H_{ex}$  of 300 Oe and a inverse MR ratio of -6.5% at 77 K (Fig. 4(d)). These peculiar phenomena occur the abruptly change of conduction electron flow to YBCO superconductor through NiO insulating, which is insufficient thickness to cover the YBCO layer, having randomly percolation path at transition temperature. It can be explained that when the magnetization configurations of two magnetic layers in the NiO spin-valve films were anti-parallel, due to an increment in the conduction electron flow to superconducting YBCO film, the MR ratio had an inverse value. According to the AFM image, tunneling current through NiO and the random percolation path between NiO spin-valve and YBCO film are exist. When the magnetization configurations in NiO spin valves are parallel, the value of the sheet resistance of NiFe/Cu/NiFe is similar to that of YBCO films. The conduction current flows into two parts of hybrid HTS-GMR multilayers. Therefore, this result implies that not only the large sensing current of GMR heads can be reduced by the insertion of superconductor layer, but also only the inversely enhanced MR ratio can be obtained by controlling of the thickness and the interfacial roughness of NiO layer in the hybrid type HTS-GMR multilayers.



**Fig. 4.** Magnetoresistance ratio (MR) versus magnetic field curves of sample 1-A: NiFe/Cu/NiFe/NiO/ MgO(100) at (a) 300 K and (b) 77 K, sample 2-B: NiFe/Cu/NiFe/NiO/YBCO/MgO(100) at (c) 300 K and (d) 77 K. The minor loops are shown in inset.

#### 4. Conclusions

The NiO/NiFe/Cu/NiFe spin valve films were fabricated on MgO(100) substrate covered with MgO(100)/YBCO film. The magnetoresistance properties of hybrid type HTS-GMR. MR curves of hybrid type HTS-GMR film structure showed an exchange coupling field of 300 Oe and an inverse MR ratio. The MR ratio of -6.5% occur to the abrupt increment in the conduction electron flow to superconducting YBCO film. The existence of the random percolation path between NiO spin valve and YBCO film expects that the magnitude of GMR ratio can be controlled by the NiO thickness of hybrid type HTS-GMR, which it is very useful for applications.

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