Journal of Magnetics 8(2), 89-92 (2003)

Large Tunneling Magnetoresistance of a Ramp-type Junction with a $SrTiO_3$ Tunneling Barrier

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(Received 16 December 2002)

The tunneling magnetoresistance (TMR) of a ramp-edge type junction with $SrTiO_3$ barrier layer has been studied. The samples with a structure of glass/NiO(600 Å)/Co(100 Å)/$SrTiO_3$(400 Å)/$SrTiO_3$(20~100 Å)/NiFe(100 Å) were prepared by the sputtering and etched by the electron cyclotron (ECR) argon ion milling. Nonlinear *I-V* characteristics were obtained from a ramp-type tunneling junctions, having the dominant difference between two different external magnetic fields (±100 Oe) perpendicular to the junction edge line. In the $SrTiO_3$ barrier thickness of 40 Å, the TMR was 52.7% at a bias voltage of -50 mV. The bias voltage dependence of resistance and TMR in a ramp-type tunneling junction was similar with those of the layered TMR junction.

Key words : Ramp-edge type junction, Tunneling magnetoresistance (TMR), $SrTiO_3$ tunneling barrier, *I-V* characteristics

1. Introduction

For low-scale magneto-electronics, planner tunnel junctions are well established and already allow for the fabrication of complex superconductor electronic circuits. Ramp-type junctions with normal conducting interlayers were fabricated in the early 1980s in order to increase the density of integration in electronic circuits. Ramp-type junctions have several merits, such as solvable boundary problem at the slope interface, usage of edge domain wall effects, and ease of scale down to the sub-micron range [1, 2]. However, for ramp-type TMR junctions, some peculiar MR properties have to be taken into account [3], which arise from the asymmetric tunneling processes at the junction line boundary and the characteristics of the *I-V* response [4, 5]. In this study, we fabricated ramp-type magnetic tunneling junctions with a $SrTiO_3$ tunneling barrier and observed the *I-V* curves that shows a high TMR properties.

2. Experimentals

After the depositions of NiO, Co, and $SrTiO_3$ layers with rf and dc magnetic sputtering, the entire layers of half region of NiO(600 Å)/Co(100 Å)/$SrTiO_3$(400 Å) multilayer were etched by the ECR argon ion milling at an angle of 15° [6]. Subsequently, a $SrTiO_3$ tunneling barrier of 20 Å~100 Å thickness and NiFe top electrode of 100 Å thickness were deposited. The final ramp-type junction was made after the lift-off process for the electrodes, as shown in Fig. 1(c). The detailed sample preparation procedure for a ramp-edge type tunneling junction are described elsewhere [3]. Figure 1(a) illustrates a cross-sectional view of the ramp edge line from the side. The height and the angle for the milled step are 2500 Å and 15°, respectively. The ramp slope was formed smoothly; thus, the value of the effective junction area must be $37\,\mu\text{m} \times 100\,\text{Å}/\sin 15^0 \approx 1.58\,\mu\text{m}^2$. Figure 1(b) is the schematic of tunneling process with a $SrTiO_3$ barrier between the free NiFe layer and the wedge-pinned NiO/Co/$SrTiO_3$ multilayers. The experimental results will be discussed on the basis of Fig. 1(b). Figure 1(c) is the schematic view of a ramp-type structure having four electrodes for the measurement of *I-V* and TMR curves.

The transport properties were characterized by measuring the *I-V* response curves at RT (room temperature). In these measurements, a constant voltage was applied across the junction, and the current that flowed from the Co to the NiFe layers was measured. During the *I-V*

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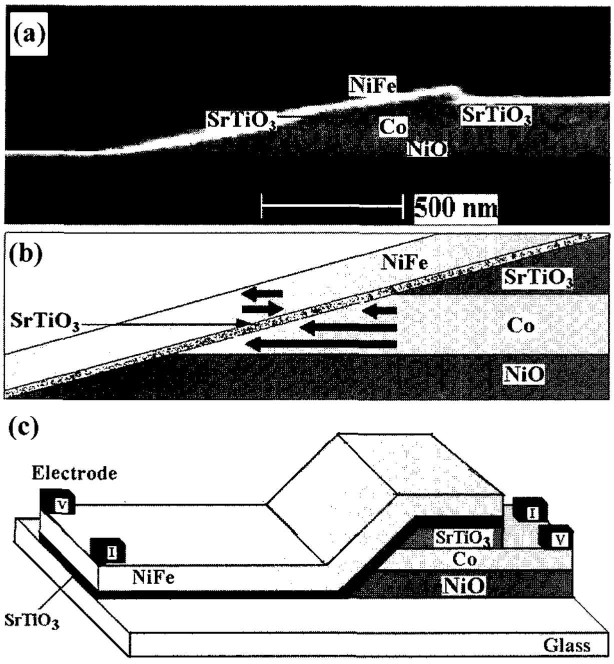

Fig. 1. (a) A cross-sectional view of SEM image of ramp-edge junction line. (b) The schematic of tunneling process with a $SrTiO_3$ barrier between the free NiFe layer and the wedge-pinned $NiO/Co/SrTiO_3$ layers. (c) The schematic view of ramp-type structure having four electrodes for the measurement of *I-V* and TMR curves.

measurement, the magnetic field was applied in the plane of the film and perpendicular to the ramp-type junction line. Both the TMR curves with a dc bias voltage of 50 mV and the junction resistance *R* including normalized TMR ratio versus dc bias voltage curves at RT for the ramp edge tunneling junction were measured using the dc four probe method in magnetic field up to 500 Oe.

3. Results and Discussion

The morphological and the stoichiometric properties of the $SrTiO_3$ layers were characterized by using atomic force microscopy, X-ray diffraction, and energy dispersive x-ray analysis on thick films. The $SrTiO_3$ layer was almost amorphous and maintained an atomic ratio of a sintered powder target. The surface and value of rms roughness of $SrTiO_3$ layer were flat and 1.8 Å, respectively.

Figures 2(a) and (b) show *I-V* characteristic curves of ramp-type tunneling junctions with the $SrTiO_3$ barrier thickness of 20 Å and 100 Å, respectively. The minimum resistances of ramp-type junction with the barrier thickness of 20 Å and 100 Å were about 5.6 kΩ and 180 MΩ, respectively. The application of external magnetic field did not show any effects on the *I-V* characteristics, indicates the absence of TMR properties.

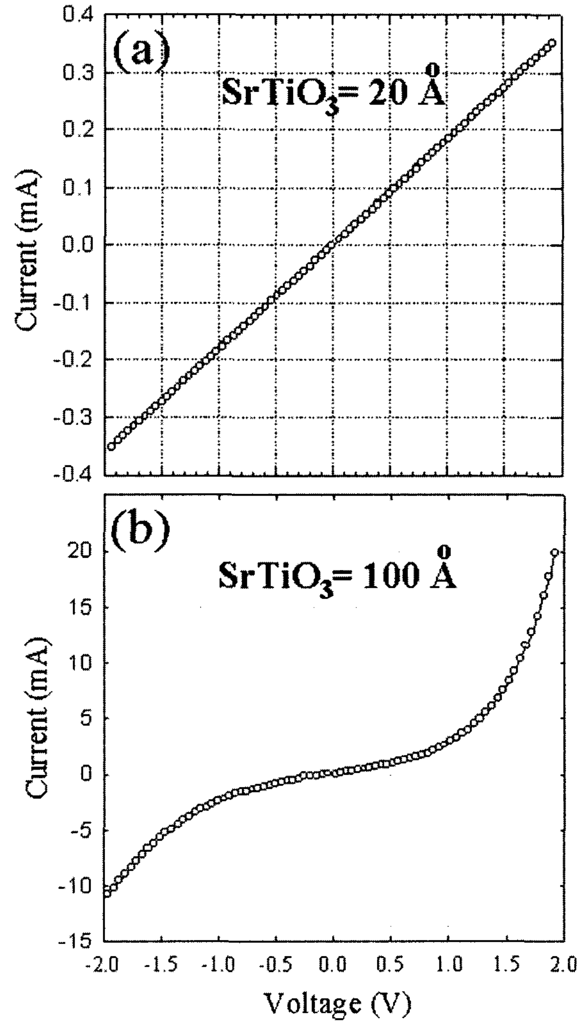

Fig. 2. *I-V* curves of ramp-type tunneling junctions for the various thickness of $SrTiO_3$ barrier: (a) 20 Å and (b) 100 Å. The resistances at the bias voltage of 1.0 V with the barrier thickness of (a) 20 Å and (b) 100 Å were about 5.6 kΩ and 180 MΩ, respectively.

Figure 3(a) presents the *I-V* characteristics of a ramp-type tunneling junction with 40 Å thick $SrTiO_3$ tunneling barrier. In the case of zero field (H_a=0 Oe), we observed a nonlinear curve with tunneling junction resistance and junction area of about 2 MΩ ~ 4 MΩ and about 1.58 μm^2, respectively, which is quite similar value compared to that of a conventional plasma Al_2O_3 oxidized barrier based on layer-by-layer magnetic tunnel junctions at the same junction area of 12 μm^2 [7]. The *I-V* characteristics were studied with an applied magnetic field up to ±500 Oe perpendicular to the ramp edge line and along the film plane. The direction of an applied field and a ramp junction shape is shown in set of Fig. 3(a). The I-V characteristic curves under the positive (+100 Oe) negative (-100 Oe) field are distinctly different from each other.

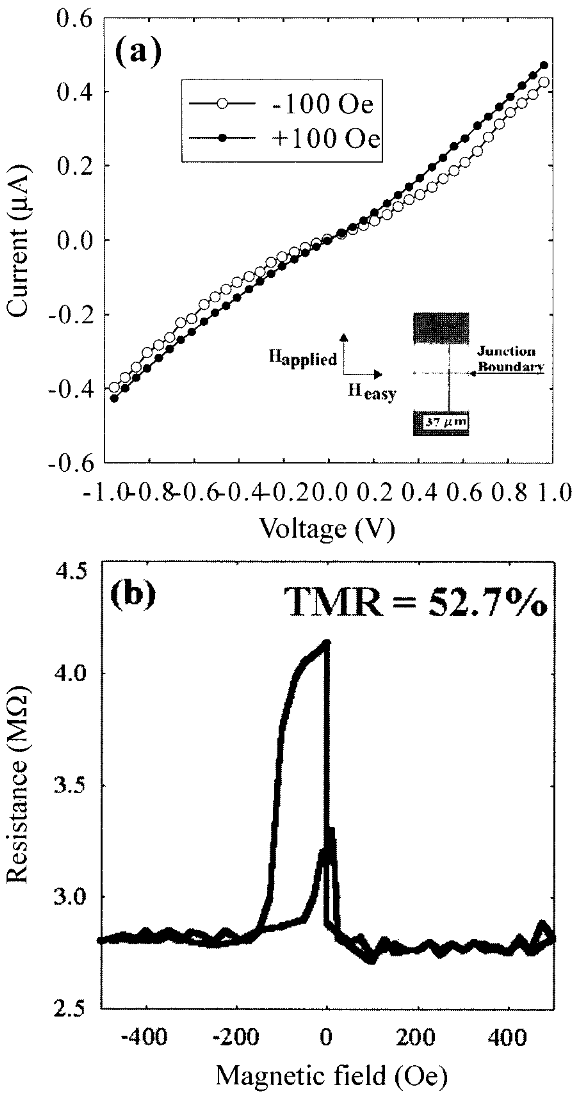

Fig. 3. (a) *I-V* characteristics of ramp-type tunneling junction with 20 Å thick $SrTiO_3$ barrier: two applied magnetic fields of H_a=-100 Oe (open circles) and H_a=+100 Oe (closed circles) perpendicular to the ramp edge line. The direction of an applied field and a ramp junction shape of an optical image is shown in set. (b) TMR curve of ramp-type tunneling junction with a $SrTiO_3$ tunneling barrier at a bias voltage of -50 mV.

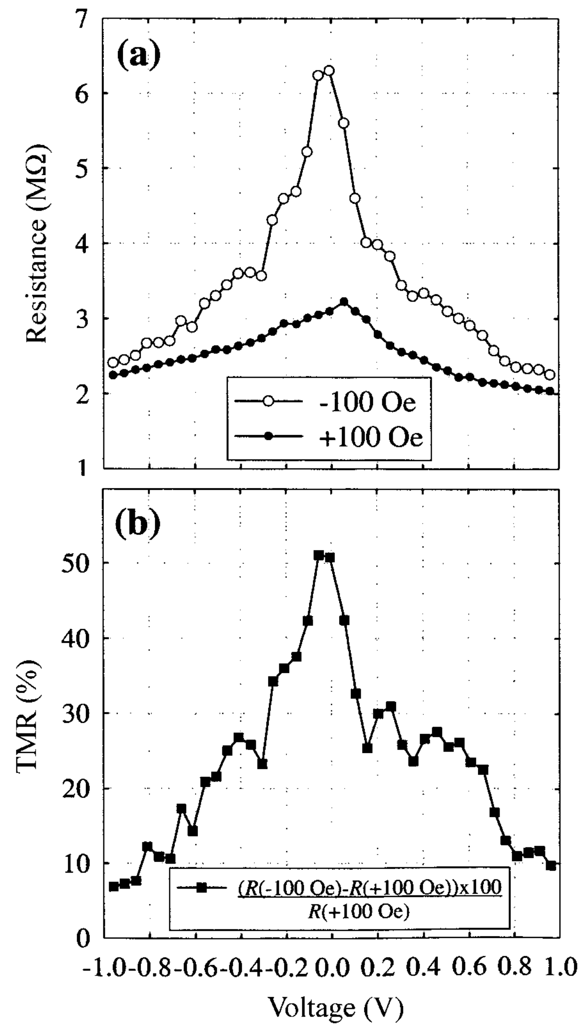

Fig. 4. (a) Bias voltage dependence of resistance from 0 to ±1.0 V for a ramp-type tunneling junction with a $SrTiO_3$ tunneling barrier: H_a=-100 Oe (open circles) and H_a=+100 Oe (solid circles). (b) Bias voltage dependence of TMR for the same *I-V* curves as that shown Fig. 3(a). The TMR is calculated by the equation of $(R_{ap}-R_p) \times 100/R_p$ from (a) *R-V* curve.

Both the curves are nonlinear and bias field makes a lot of effect on the *I-V* curve. The bias voltage dependence of resistance and TMR in a ramp-type tunneling junction can be drawn from Figure 3(a), and it is presented in Figure 4(a) and (b), respectively. The TMR amplitude is up to 52.7% at the bias voltage of -50 mV, as shown in Fig. 3(b). This TMR value for a ramp-type tunneling junction is very high. This high positive TMR value is compared with the earlier group's results for the spin inversion across tunnel junction using the $SrTiO_3$ barrier with negative TMR. Spin inversion arises across the tunnel junction when the tunneling $SrTiO_3$ barrier converts spin during the tunneling process [8].

However, this very large TMR property for a ramp-type tunneling junction may be used for application device. One possibility for the higher TMR property is an effect of asymmetric tunneling junction process between the NiFe-free layer and the wedge-pinned $NiO/Co/SrTiO_3$ layers having various exchange bias distributions caused by the slope angle of 15^0, as shown in Figure 1(b). The influence of the spin-polarized tunnel current with very sharp tunneling edge changes the magnetization abruptly in some of the domains of the Co layer pinned between the pinning NiO layer and the insulating $SrTiO_3$ layer. Another possibility for asymmetric tunneling barrier is related to the charge accumulation at the sharp and wedged interfaces.

Resistance-dc bias voltage curves throughout the measured voltage range up to ±1.0 V are shown in Figure 4(a). The decrease of resistance for the antiparallel (AP) alignment (-100 Oe) of the magnetization of the two electrodes is larger than that for the parallel (P) alignment (+100 Oe) with the increasing applied dc bias voltage. The resistance and TMR dependence of bias voltage in a ramp-type tunneling junction were similar to those of conventional TMR junctions [9, 10] except that small saw-tooth-like peaks as shown in the Figure 4(b) are observed as bias increases. These results can explained to several factors due to an asymmetric geometric tunneling structure, such as unstable edge domains, pinholes of $SrTiO_3$ tunneling barrier, magnetic impurities at interface, and damaged high-resistivity Co layers [11, 12].

Summary

A new planar tunneling structure having a ramp-type tunneling junction was fabricated and its transport properties were investigated. We presented the *I-V* curves with two different applied fields, which generated a large TMR. The asymmetric bias voltage dependence of TMR is observed, indicates asymmetric spin-dependent tunneling process through the ramp edge. It exhibited an asymmetric spin-dependent tunneling process based on the unstable bias voltage dependence and a large TMR of 52.7%. The origins of a large TMR for a ramp-type junction with a $SrTiO_3$ tunneling barrier may be an effect of asymmetric tunneling junction process between the NiFe-free layer and the wedge-pinned $NiO/Co/SrTiO_3$ layers with a local charge accumulation at the sharp and wedged interfaces.

Acknowledgments

This work was supported by the National Program for Tera-level Nano-devices of the Ministry of Science and Technology (MOST) and by the Vision 21 Research Program of the Korea Institute of Science and Technology (KIST).

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