MR BEHAVIOR IN TUNNELING JUNCTIONS WITH A NONMAGNETIC METAL LAYER BETWEEN BARRIER AND ELECTRODE

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Abstract— **The influence of a nonmagnetic metal (Cu) layer between the barrier and the electrode in ferromagnetic tunneling junctions on magnetoresistance has been investigated. MR decreases with increasing the Cu layer thickness (t_{Cu}), however, the variations in MR at 77K with temperature and bias voltage become smaller with increasing t_{Cu}.**

Index terms—**Bias voltage dependence, Ferromagnetic tunneling junction, Non magnetic metal layer, Tunneling magnetoresistance.**

INTRODUCTION

Since the discovery of magnetoresistance (MR) above 20 % at room temperature for ferromagnetic tunneling junctions [1], a lot of studies on tunneling MR have been performed to develop magnetic heads, sensors or memories. On the other hand, there are many problems for applications; in particular, the difficulty in preparing a good quality tunneling barrier without pinholes or defects for reproducible and large MR, the drastic decrease of MR with bias voltage (V_{bias}) [2]. The V_{bias} dependence of MR was reported to be attributed to magnon excitations at interfaces between the insulating barrier and ferromagnetic electrode [3]. We consider that inserting a nonmagnetic metal layer between the barrier and the electrode modifies the magnon excitations at interfaces influencing the V_{bias} dependence of MR. In this study, we prepared tunneling junctions with a nonmagnetic metal (Cu) layer inserted between the barrier and the electrode, and we have found that variations in MR with temperature and V_{bias} are diminished by inserting Cu.

EXPERIMENTAL PROCEDURE

A multitarget-type ion beam sputtering apparatus was used for sample preparation [4]. A typical layer structure is Fe(1000 Å)/Al(12 Å)-O/Cu(t_{Cu} Å)/Co(30 Å)/NiFe(150 Å)/FeMn(400 Å), where t_{Cu} is the thickness of a thin Cu layer inserted between the barrier and the top electrode and the magnetization of top electrodes Co and NiFe is pinned by the antiferromagnetic FeMn layer, as shown in Fig. 1. The samples were deposited on thermally oxidized Si substrates at room temperature. Metallic masks were used to produce the cross stripe configuration. The junction area was 0.5 mm x 0.5 mm and for each change of masks the vacuum chamber was opened to air. As the bottom electrode a 1000 Å thick Fe layer was first deposited at a beam voltage V_{Beam} of 800 V. Then, the Al-oxide insulating barrier was fabricated after breaking vacuum and changing the mask. A 12 Å thin Al metallic layer was deposited on the Fe layer at V_{Beam} = 800 V, and oxidized for t_{ox} minutes by exposing the Al surface to ionized $Ar+O_2$ beam at V_{Beam} = 100 V from an assist ion source. The oxidization time, t_{ox} is defined as the time to expose Al to the $Ar+O_2$ beam. As the top electrode, 30 Å Co, 150 Å NiFe and 400 Å FeMn were continuously deposited at V_{Beam} = 600 V for Co, 800 V for NiFe and FeMn, respectively. A thin Cu layer was deposited at V_{Beam} = 600 V on the Al-oxide insulating barrier before sputtering the top electrodes. In this study, we made several tunneling junctions with t_{Cu} = 0~12 Å. MR curves and I-V characteristics were measured at room temperature and 77 K by a four-point-probe method. Junction resistance R_J and barrier height ϕ increase with increasing t_{ox}, as described in a previous paper [4]. For small t_{ox}, the geometrical enhancement of MR was observed due to small R_J, and an unoxidized Al metal layer may remain under the Al-oxide barrier. For large t_{ox}, the bottom electrode is considered to be oxidized. We found that the largest MR was obtained for t_{ox} = 15 min.

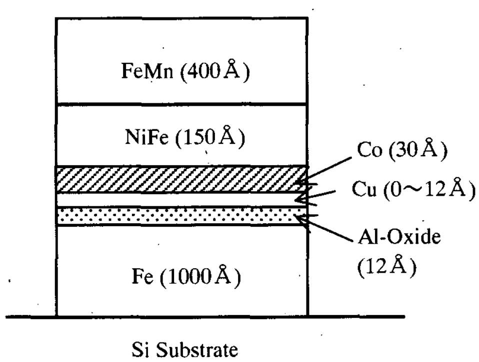

Fig. 1 Illustration of the cross sectional view of a typical tunneling junction.

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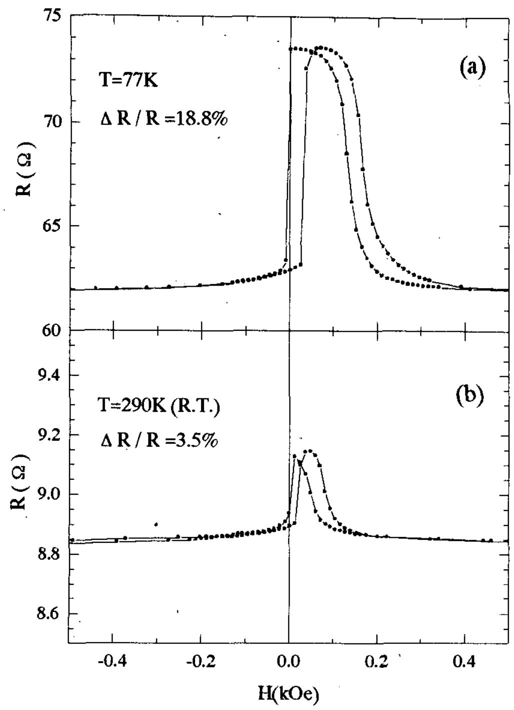

Fig. 2 MR curves for a Fe(1000 Å)/Al(12 Å)-O/Co(30 Å)/NiFe(150 Å) /FeMn(400 Å) junction at (a) T=77 K and (b) room temperature.

RESULTS AND DISCUSSION

The examples of MR curves at 77 K and room temperature (RT) for t_{Cu} = 0 Å and t_{ox} = 15 min. are shown in Fig. 2. The MR curves show typical spin valve type behavior: the MR maximum is observed for antiparallel alignment of the magnetization vectors on top and bottom electrodes. At RT, however, there is no plateau at the MR maximum, suggesting that the antiparallel alignment is not perfect. Typical MR values are approximately 20 % and 5 % at 77 K and RT, respectively. The magnitude of MR at RT is small, and the temperature dependence of MR is large. The barrier height ϕ and width L are calculated to be 0.2~0.4 eV and 20~30 Å, respectively, by fitting the I-V characteristics at 77 K to Simmons' formula [5]. ϕ is small compared to the generally known value for Al_2O_3 [6]. The strong temperature dependence of MR and the low barrier height suggest that the barrier quality is not good enough. As shown in Fig. 3, a cross sectional TEM photograph indicates a fairly uniform oxide layer. The thickness (about 30 Å) of the oxide layer estimated from TEM is consistent with L estimated from the I-V characteristics. L is considerably lager than the thickness (12 Å) of as-deposited Al metal layer, suggesting the oxidization of Fe surface.

Figure 4 shows the t_{Cu} dependence of MR at V_{bias} = 1 mV. MR decreases with increasing t_{Cu} at both 77K and RT.

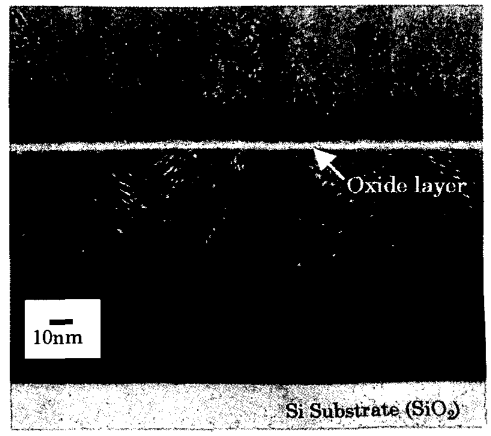

Fig. 3 Cross sectional TEM photograph of tunnel junctions Fe(1000 Å)/Al(12 Å)-O/Co(30 Å)/NiFe(150 Å)/FeMn(400 Å). A white stripe area corresponds to an Al-oxide layer.

The decrease in MR with t_{Cu} is faster than those reported by Parkin *et al.* [7] and J. S. Moodera [8]. The t_{Cu} dependence of MR at 77K is described approximately as $\exp(-t_{Cu}/\lambda)$ with λ = 6 Å. The value of λ is similar to that reported at RT by J. J. Sun and P. P. Freitas [9], although the measurement temperature is different. The t_{Cu} dependence of MR at RT becomes smaller than that at 77K, indicating that the temperature dependence of MR is diminished by inserting Cu. Figure 5 shows the V_{bias} dependence of MR at 77K for various t_{Cu}. MR decreases with increasing V_{bias} in all the cases. MR for t_{Cu}=0 decreases to half of the initial value at approximately 100mV of V_{bias}. The V_{bias} dependence of MR is stronger than those reported previously by some groups [2][9], which may be caused by the formation of Fe oxide. However, the decrease in MR becomes smaller with

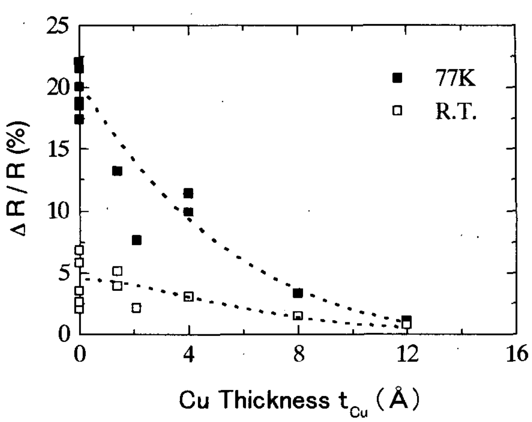

Fig. 4 Cu thickness t_{Cu} dependence of MR for Fe(1000 Å)/ Al(12 Å)-O/ Cu(t_{Cu} Å)/Co(30 Å)/NiFe(150 Å)/FeMn(400 Å) at T = 77 K and room temperature. MR at 77K can be fitted to exponential curve MR×exp ($-t_{Cu}/\lambda$) with λ=6 Å .

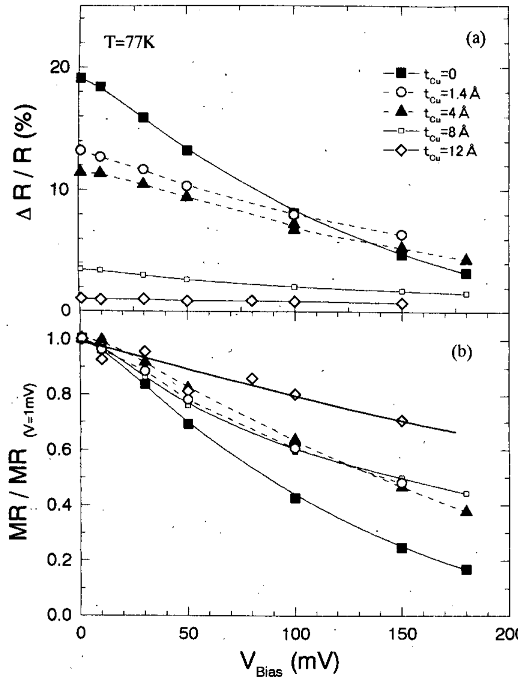

Fig. 5 Bias voltage V_{bias} dependence of (a) the MR ratio, ΔR/R and (b) normalized MR by the value at V_{bias} = 1 mV for various t_{Cu} in Fe(1000 Å)/Al(12 Å)-O/Cu(t_{Cu} Å)/Co(30 Å)/ NiFe(150 Å)/FeMn(400 Å) at T= 77 K.

increasing t_{Cu}. When V_{bias} is higher than 150 mV, particularly, MR for t_{Cu} = 1.4 and 4 Å are larger than that for t_{Cu} = 0. Figure 5(b) shows the V_{bias} dependence of the MR at 77K normalized by the value at V_{bias} = 1 mV, indicating clearly that the V_{bias} dependence of MR becomes smaller as t_{Cu} increases. The similar behavior of V_{bias} dependence has also been obtained at RT. We have found that the variations in MR with temperature and V_{bias} dependence are diminished by inserting Cu.

Recently J. J. Sun and P. P. Freitas [9] reported that the V_{bias} dependence of MR was almost not affected by inserting Cu. The origin for the difference from the present result is not clear, but the influence of Cu may depend on the barrier quality.

Conclusion

We prepared tunneling junctions with a nonmagnetic metal (Cu) layer between the barrier and the top electrode. MR decreases with increasing t_{Cu}. Interestingly, however, the variations in MR with temperature and V_{bias} are diminished by inserting Cu, in comparison to those for t_{Cu} = 0. This may be related to the modification of the magnon excitations at the interfaces. However, the temperature and V_{bias} dependence is rather strong for the present samples and the effect of Cu may depend on the barrier quality. In order to elucidate this point, further studies using the samples with higher-quality barriers are now in progress.

Acknowledgment

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