한국표면공학회지
Journal of the Korean Institute of Surface Engineering
Vol. 34, No. 5, Oct. 2001
<연구논문>

Tunnel junction-Mangnetorsistance in Co–Al-O_x–NiFe with oxidation conditions of Al thickness.

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Abstract

Ferromagnets (FM) -Al-O_x-Ferromagnets (FM) tunneling junctions were evaluated by changing the fabricating conditions of an Al-O_x layer. The junction composed of a thicker Al-O_x shows the low resistance and the stable MR ratio about 16 % in a wide range of oxidation time. For the junctions with the thinner Al-O_x, they showed a fast increase of the barrier width as an increase of an oxidation time and exhibited a strong bias dependence. As oxidation time increased, the coercivity (H_c) of bottom Co layer increased gradually due to the local oxidation of Co bottom layer at a interface. However, the small formation of Co oxide did not largely influence on the deterioration of MR ratio.

Introduction

Since the tunneling junction magnetoresistenace (defined as the change in junction resistance in an applied magnetic field normalized to the peak resistance value, TMR) was found by Juillere[1], The TMR junctions were steadily improved for the requirement of a smaller device cell. In order to obtain the stable high MR ratio from a small device, a significant progress have been done on the tailoring of the magnetic behavior of the device, on the maximization of the tunneling spin-polarization factors and on the optimization of the fabrication of the insulating barrier (usually, oxide or nitride). The latter directly can affect on the resistance of the junctions in an application for a memory cell and a magnetic head in a hard disk drive. For achieving a high stable resistance, a lot of trials have been done on the modification of oxide barrier and on various oxidation methods[2, 3]. But, the effects of a barrier and an interfacial state on the TMR are not fully understood. In this study, we fabricated Co/Al-O_x/Ni-Fe tunnel junctions with various thickness of oxide barrier and characterized the TMR properties. The fabrication of Al oxide layer was performed by changing an oxidation time of various thickness of Al layer, which could affect the properties of oxide barrier and the interface between Al-O_x and a bottom Co layer.

Experimentals

The tunnel junction layers were prepared by using a conventional D.C and R.F magnetron sputter with a base pressure of 7×10^{-7} torr. Films

were deposited on the Corning 7059 glass at room temperature. The structures of tunnel junctions were Co 10 nm/Al-O_x t nm/ Ni-Fe 12 nm and Co10 nm/Al-O_x t nm/ Co 3 nm/ Ni-Fe 12 nm. Metal mask was used to confine the junction area of 0.2 mm ×0.2 mm and two vacuum break steps were required for changing mask types, which may cause the deterioration an interface in junctions.

Al thickness was changed from 1.5 nm to 2.5 nm. The oxidation step was performed in Ar+O_2 (3:1) mixed gas, dc power of 40 W and various oxidation times. The MR and the I-V properties were characterized by using a conventional four-point probe. The magnetic properties were evaluated by VSM. The chemical composition of a junction was characterized by using an Auger microscope. The barrier height and width were obtained from the I-V characteristics and fitted to Simmon's formula.

Results and dicussion

Figure 1 shows the variation of TMR ratio of tunnel junctions, composed of different Al thickness, as a function of oxidation time. The saturation time of an oxidation increases gradually with increasing the Al thickness. Because the optimum oxidation condition can result in the maximum value of MR ratio, the highest MR can be obtained at the optimum oxidation time with a respective to Al thickness, such as 40 sec for 1.5 nm, 100 sec for 2.0 nm and 120 sec for 2.5 nm. The right side of a peak may indicate the existence of an unreacted Al in the Al oxide layer. The other side of a peak

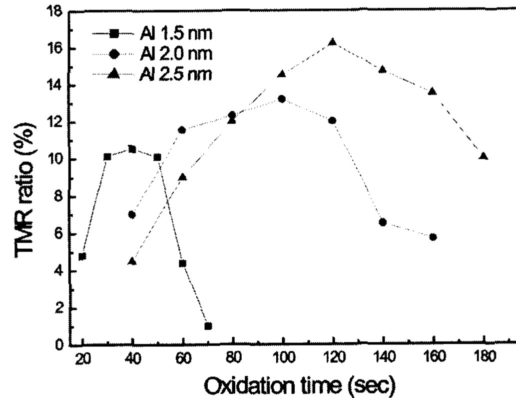

Fig. 1 Variation of TMR ratio with oxidation time in a Co 10 nm/Al-O_x t nm/ Co 3nm/Ni-Fe12 nm. Al-O_x is determined by an Al thickness and oxidation time.

value may suggest the local oxidation of a bottom Co layer. The junctions with Al layer of 2.5 nm exhibit the highest TMR ratio of 16.5 % for an oxidation time of 120 sec. The maximum TMR ratio gradually with increasing with increasing a Al thickness, which is consistent with others' results[4]. We also investigated the barrier thickness and interface clearness of the junction by using TEM. Fig. 2 shows the relative clearness of an interface of bottom Co layer and a rough interface of an upper interface of Al oxide layer. The

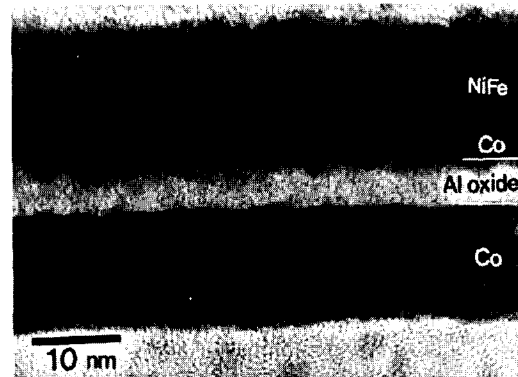

Fig. 2 TEM image of Co10 nm/ Al 2.5 nm-oxidation 120 s/ Co 1.5 nm/ $Ni_{80}Fe_{20}$ 14 nm junction.

roughness of Al oxide may come from the nonuniform oxidation of Al layer. We could confirm the barrier thickness of 3.5 nm in a junction with Al thickness of 2.5 nm.

The figure 3 shows the resistance of the junctions with various thickness of Al layer as a function of an oxidation time. The thinner Al exhibits the larger increase of resistance. In contrast, the increase of resistance is not steep in junctions with Al of 2.5 nm, which is because the oxidized Al film, has a higher density of Al layer, plays a role as a diffusion barrier of oxygen ion and exhibits a high junction resistance. Thus, the thick oxide barrier can be expected to be from a thicker Al layer. For a thinner Al, the increase of a barrier thickness is difficult theoretically because the bottom Co has to be oxidized after the Al layer is consumed to be oxidized, which can deteriorate the TMR ratio. From above results, it suggests that the higher barrier can be formed in a junction with a thicker Al. However, in real tunnel junctions, the junctions with the thinner Al have a higher barrier width than the thicker. As shown in Fig 4, the junction with 2 nm Al shows the larger

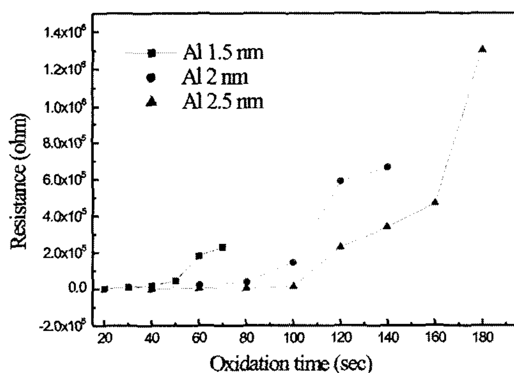

Fig. 3 Variation of resistance as a function of Al thickness and oxidation time in Co 10 nm-Al-O_x t nm-Co 3 nm-Ni-Fe 12 nm tunnel junctions.

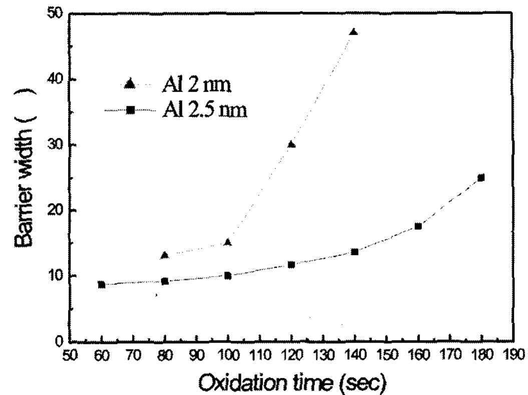

Fig. 4 Variation of barrier width as a function of oxidation time in tunnel junction Co 10 nm-Al-O_x t nm-Co 3 nm-Ni-Fe 12 nm.

barrier width than that with 2.5 nm, which is consistent with the resistance variation in Fig. 3. These results may be explained that it is highly possible for the thinner Al layer to be oxidized for a short oxidation time without formation of any other defaults theoretically[5].

Figure 5 shows the coercivity (H_c) variation of the Co bottom electrode with oxidation time. There were no interlayer coupling in Co (10 nm) Al-O (2.5 nm)/Co (3 nm)/Ni-Fe (13 nm) tunnel junction. In the Co bottom electrode, the gradual increase of H_c with oxidation time, which may

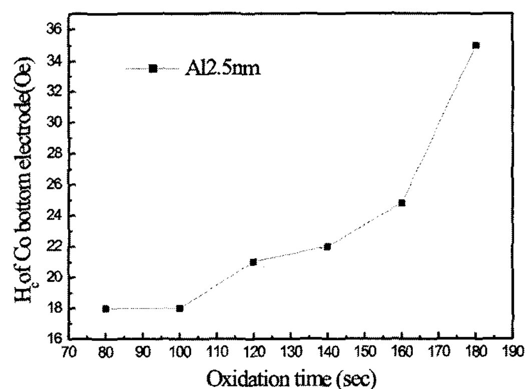

Fig. 5 Increase of coercivity (H_c) of a Co bottom electrode with increasing oxidation time.

result from the existence of CoO. The formation of CoO in bottom layer starts before the Al is fully oxidized[4]. The local oxidized Co region at interface may prevent the spin of Co from rotating along the external field. The other possibility is the magnetic ordered CoO. It has been reported that CoO of 2 nm may induced the increase of H_c in a Co layer at room temperature[6]. The paramagnetic property of Co oxide causes the spin scattering of tunnel current. But, if the CoO shows the antiferromagnetic property, a spin scattering at CoO can be ignored because of the magnetic ordering in CoO[7]. Because of a low intensity and a slight shift of a binding energy, We could not confirm the existence CoO by using X-ray photoemission spectroscope. However, the content of oxygen at interface between the Co and Al-O_x increases with increasing oxidation time as shown Fig. 6. The higher signal of oxygen was obtained at the interface between Al-O_x and bottom Co layer of a TMR junction with a long oxidation time. This may suggest that the longer oxidation time affect the high possibility of CoO formation in a bottom layer. We also found that a possibility of the formation of CoO gradually increase with increasing an oxidation time.

In summary, the variation of resistance in the junctions with various thickness of Al layer is correlated with TMR ratio. The junction with the thick Al of 2.5nm shows the stable and high TMR ratio of 16.5%. With increasing oxidation time, the H_c of a bottom Co layer increase gradually. It is thought to be the formation of antiferromagnetic CoO in Co layer. Because the scattering at the small amount of CoO in interface on the TMR ratio is not strong, we considered carefully a present CoO as a magnetic ordered phase.

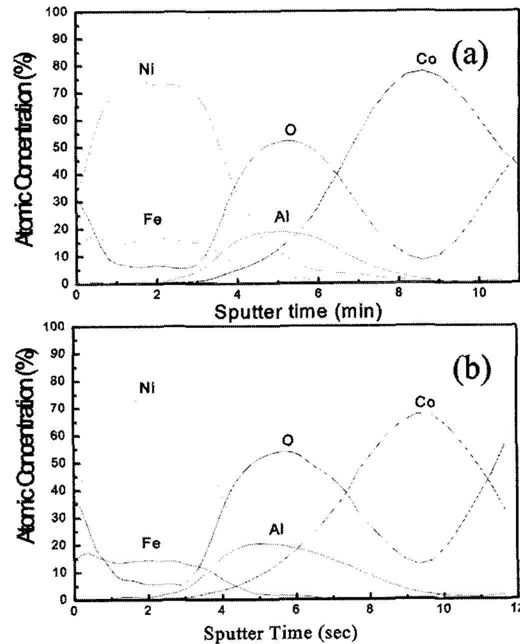

Fig. 6 Distributions of element concentration in a film depth. (a) tunnel junction with proper oxidized of Al, (b) a tunnel junction with over oxidized of Al.

Acknowledgments

We gratefully acknowledge the financial support from the Korea Research Foundation (KRF-99-042-E00106 E5105).

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