C-03

Effects of Tunnel Barrier Roughness on Magnetoresistance of Magnetic Tunnel Junctions

터널장벽 표면거칠기가 자기터널접합의 자기저항에 미치는 효과

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1. Introduction

Magnetic tunnel junction (MTJ) devices using tunneling magnetoresistance (TMR) have been studied extensively due to their application in high density magnetic read heads and nonvolatile magnetic random access memory (MRAM) [1]. MTJ consist of two ferromagnetic (FM) electrodes separated by a tunnel barrier that exhibits TMR due to spin polarized tunneling [2]. The bottom FM electrode is an important factor to draw the desirable performance of MTJ cells. Of several microstructural features related with the bottom electrode, the surface roughness is considered one of the most critical ones.

In this study, MTJs with different surface roughness of the bottom electrode were prepared. We investigated the dependence of TMR ratio and resistance-area product (*RA*) on plasma oxidation time, and tunnel barrier thickness dependence of *RA*, so we presented the deposition condition for optimum MTJ preparation, the dependence of MTJ characteristics on different tunnel barrier roughness, and the tunneling characteristics of these junction devices through current-voltage (*I-V*) curves.

2. Experimental Procedure

MTJ devices consisting of Si/SiO_2/Ta/Ru/IrMn/CoFe/Ru/CoFe/Al-O/CoFe/NiFe/Ru, varying surface roughness of the bottom electrode by surface treatment using ion-beam, were deposited on oxidized Si (100) substrates by a 7-target dc and rf magnetron sputtering system under base pressure below 2.0×10^{-8} Torr and Ar pressure of 2 mTorr. A magnetic field of 100 Oe was applied to induce the uniaxial magnetic anisotropy in FM layer. The junctions were fabricated by photolithographic patterning procedure and ion beam etching. A series of annealing was applied under a static magnetic field of 1 kOe in vacuum furnace with a base pressure 8.0×10^{-7} Torr. The insulating layer was formed by depositing 8 Å thick Al layer followed by rf plasma oxidation in a load lock chamber under base pressure 1.2×10^{-7} Torr, varying oxidation time and oxidation power. TMR ratio and resistance were measured using four-point probe station. The cross-sectional view of MTJs with various oxidation time were analyzed using transmission electron micrograph (TEM).

3. Results and Discussion

MTJs of structure Si/SiO_2/Ta40/Ru10/IrMn15/CoFe2/Ru1/CoFe2/AlO_x/CoFe3/NiFe7/Ru6 (in nm) with different surface roughness of bottom electrode were prepared. To get resistance of below *RA* 10 k$\Omega\mu m^2$, oxidation time of 10 s for 8 Å thick Al layer was required. In this case, thickness of Al_2O_3 barrier layer was 12.5 ~ 14 Å. For the 13 Å thick Al_2O_3 tunnel barrier, TMR ratios of optimized MTJ with uniform tunnel barrier were about 45% and 32% at 100 mV and 400 mV, respectively. The barrier thickness and barrier height showed 12.3 Å and 3.07 eV, respectively, which obtained by fitting *I-V* curves to the Simmon's model [3]. These values agree with real tunnel barrier thickness within an error range.

For MTJ of rough tunnel barrier with 12 Å RMS surface roughness, the *I-V* curve and TMR ratio versus bias voltage curve were linear and asymmetric, respectively. *RA* was 2.2 kΩμm^2 and TMR ratio was about 4% at 100 mV. It showed that it was difficult to achieve the optimum TMR ratio and *RA*. In contrast, MTJ of uniform tunnel barrier with 3 Å RMS surface roughness shows *RA* of 14 kΩμm^2 and TMR ratio of 40%. The *I-V* curve and TMR ratio versus bias voltage curve were non-linear and symmetric, respectively. The barrier thicknesses of MTJs with rough and uniform tunnel barriers show 11.8 Å and 12.3 Å, the barrier heights show 4.65 eV and 3.07 eV, respectively.

As MTJs have uniform tunnel barrier, TMR ratio and resistance were higher, while interlayer coupling field (H_{int}) was decreased. For a MTJ with the rough surface (with more than 10 Å RMS surface roughness), *RA* is greatly reduced. Figure 1 shows the cross-sectional TEM image of MTJs with rough tunnel barrier (a) and uniform tunnel barrier (b). The rough surface of bottom electrode possibly makes the preferential conduction channels activated through the barrier, shunting the conduction to spin-independent path. The high TMR ratio and its low variation with bias are crucial for stably sensing a signal from an MRAM, and the smooth surface of bottom electrode is a basic requirement for them. We have obtained the multilayer films with smooth surfaces through a CMP (chemical mechanical polishing) process.

4. Conclusions

By measuring the rf plasma oxidation time dependence of TMR ratio and *RA* for MTJs, oxidation time of 10 s for 8 Å thick Al layer was required to obtain resistance of below 10 kΩμm^2. By measuring the dependence of *RA* on Al_2O_3 tunnel barrier, Al_2O_3 barrier thickness was about 12.5 ~ 14 Å to obtain *RA* of about 10 kΩμm^2. The optimized MTJ with 13 Å thick Al_2O_3 tunnel barrier showed TMR ratio of 45% at bias voltage 100 mV. The barrier thickness and barrier height showed 12.3 Å and 3.07 eV, respectively, which obtained by fitting the *I-V* curves to the Simmon's model. These values agree with real tunnel barrier thickness within an error range. As MTJs have uniform tunnel barrier with smooth surface of bottom electrode, TMR ratio and resistance were higher, while interlayer coupling field (H_{int}) was decreased. The *I-V* curve and TMR ratio versus bias voltage curve of MTJ with rough tunnel barrier were linear and asymmetric, respectively, but in case of MTJ with uniform tunnel barrier, these curves were non-linear and symmetric, respectively. It was confirmed that the smooth surface of bottom electrode was a basic requirement for MTJ.

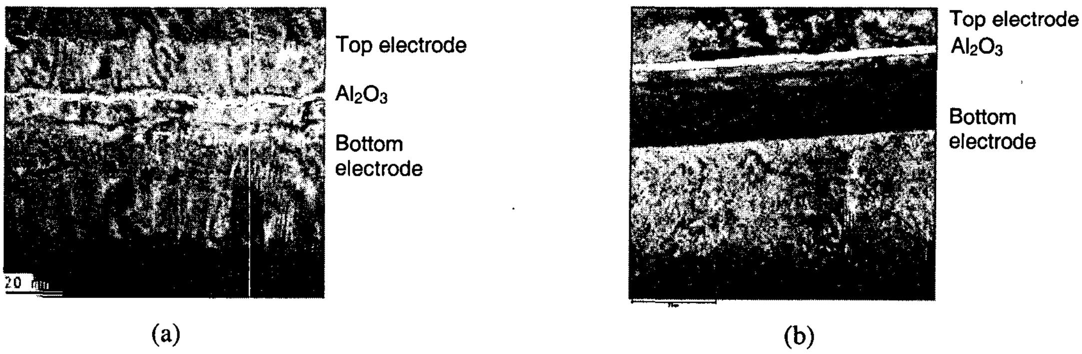

Fig. 5. TEM cross-sectional view of TMR devices with (a) rough tunnel barrier and (b) uniform tunnel barrier.

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