C-04

# Magnetization Switching Characteristic of MTJs with Synthetic Antiferromagnet Free Layers Consisting of Amorphous CoFeSiB

## 비정질 CoFeSiB 합성형 반강자성 자유층을 갖는 MTJs의 자화스위칭 특성

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### 1. Introduction

Magnetic tunnel junctions (MTJs) have a large potential for use in high areal density read head and magnetic random access memory (MRAM) applications because they exhibit large tunneling magnetoresistance (TMR) ratios [1]. MTJs generally consist of hard magnet (reference)/insulator/soft magnet (sensing) structure, so the interactions between two ferromagnetic (FM) layers are very important. Because, the interactions between hard and soft magnet have influence on the reversal (switching) of two FM layer. These characteristics are especially important for a high density MRAM with submicrometer-sized MTJ cells. To reduce $H_{sw}$, the synthetic antiferromagnet (SAF) free layer structure had been demonstrated. A SAF structure can reduce the both magnetostatic coupling between the pinned and free layers and magnetostatic energy in the free layer separated by nonmagnetic space layer [2]. On the other hand, according to the Stonei-Wohlfarth's single domain model, $H_{sw}$ depends on the saturation magnetization ($M_s$) and shape anisotropy [3]. To get low $H_{sw}$, the $M_s$ and shape anisotropy must be small, but lower aspect ratio produce multidomain structures which are not suitable to MRAM.

From these points of view, we introduced amorphous FM CoFeSiB to the SAF free layer in the MTJs. We use the anisotropy of the material itself. This is because, if the materials anisotropy constant ($K_u$) is high, we can get lower aspect ratio without struggle. The main purpose of this study is to investigate the switching characteristics of SAF free layer structures comprising CoFeSiB layers.

### 2. Experimental Procedure

Tunnel junctions consisting of Si/$SiO_2$/Ta45/Ru9.5/IrMn10/CoFe7/$AlO_x$/CoFeSiB($t$)/Ru0.5/CoFeSiB(7-$t$)/Ru60 (in nm) were prepared by a six-target rf magnetron sputtering system under base pressure below $5\times10^{-8}$ Torr. A magnetic field of 100 Oe was applied during deposition to induce the uniaxial magnetic anisotropy in FM layer. Tunnel barriers were formed by oxidizing 1.0 nm thick Al layers under rf plasma environment in a load lock chamber. The junctions were fabricated by a photolithographic patterning procedure and ion beam etching. We varied the sample size from 10 to 100 μm with fixed aspect ratio to 1. Annealing was done *in situ* at 200 ℃ in $5\times10^{-4}$ Torr vacuum under applied field of 300 Oe for 2 hr. The magnetic properties and crystalline texture of the film were characterized by vibrating sample magnetometer (VSM) and x-ray diffraction (XRD), respectively. The magnetic and electric properties of MTJs were measured by a 2-point probe station. Micromagnetic Modeling based on the Landau-Lisfschitz-Gilbert (LLG) equation were carried out on SAF free layer MTJs to investigate the effect of size variation and material properties on their magnetization transfer behaviors. The local equilibrium of magnetization was obtained by integrating this equation.

### 3. Results and Discussion

We made the Ta5/CoFeSiB$t_1$/Ru1.0/CoFeSiB$t_2$/Ta5 (nm) SAF structures to confirm the magnetic properties using a VSM. A well-defined anisotropy and an antiparallel alignment during the magnetization reversal is occurred in

$t_1$=1.5 and $t_2$=5.5 nm, as shown in Fig. 1. The calculated exchange energy ($J_{ex}$) is -0.003 erg/cm$^3$ by applying $H_s$=50 Oe, $M_1$=$M_2$=560 emu/cm$^3$, $t_1$=1.5 nm, and $t_2$=5.5 nm and this result much lower than CoFe and CoFeB SAF structure. To investigate the SAF characteristics on the magneto-transfer curve, we made single and SAF free layer in the MTJs Fig.2 showed $H_c$ and TMR ratio in our SAF and single structure as a function of the junction size. $H_c$ and TMR ratio are inversely proportional to the junction size. For all range of the sample size, CoFeSiB single-layered exhibited both higher TMR ratio and $H_c$ than those with SAF free layer. We speculated that the reasons of exhibiting relatively lower TMR ratio and $H_c$ of SAF free layer MTJs were due to a lower magnetostatic energy in the free layer separated by nonmagnetic space layer. To confirm our speculation, the micromagnetic modeling was carried out on SAF free layer MTJs to investigate the effect of size variation on their magnetization transfer behaviors. Our CoFeSiB SAF structure has low $J_{ex}$ than CoFe and CoFeB SAF structures, resulting in the size dependent $H_{sw}$, as shown in Fig. 3. The most interesting results, nevertheless of this undesirable size dependence of $H_{sw}$, the CoFeSiB SAF structure showed lower $H_c$ than other SAF structure, because of low $M_s$ and high $K_u$.

## 4. Conclusions

We have investigated both the magnetic switching and TMR ratio for MTJs of CoFeSiB single and SAF free layers with micrometer size by experiment and submicrometer size by simulation. MTJs of CoFeSiB SAF free layer show lower TMR ratio and $H_c$ than those of single free layer due to a low net magnetic moment or magnetostatic energy. The CoFeSiB SAF structure has lower $J_{ex}$, thus size dependence of the switching field occurs. But the CoFeSiB characteristics such as low $M_s$ and high $K_u$ were proven to be beneficial for the switching characteristics such as reducing the $H_c$ in micrometer to submicrometer ranges.

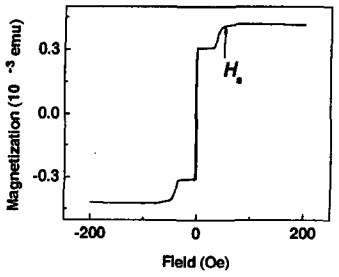


Fig. 1. Magnetization curve of synthetic antiferromagnetic srtucture. Structure is Ta5/CoFeSiB1.5/Ru1.0/CoFeSiB5.5/Ta5 (in nm).

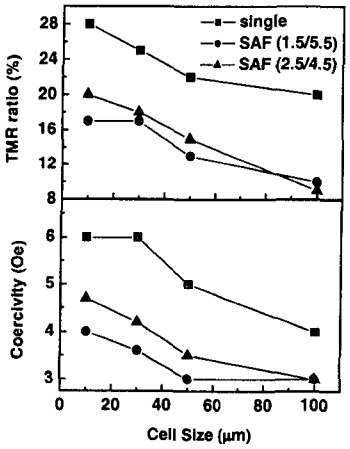


Fig. 2. TMR ratio and $H_c$ as a function of the cell size for MTJs with the CoFeSiB single and SAF free layer.

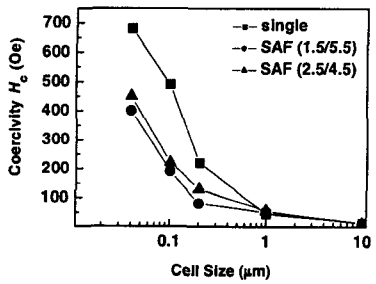


Fig. 3. Submicrometer cell size dependence of $H_c$ for MTJs by micromagnetic simulation.


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