Voltage-induced Nonvolatile Change of Magnetic Anisotropy of CoFeB Ultrathin Films Stacked with Multivalent Oxides

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1. Introduction

The manipulation of magnetization achieved solely by the application of an electric field may further reduce the power consumption in nonvolatile magnetic memories. Recently a purely-electrical manipulation of magnetization of ultrathin ferromagnetic metals at room temperature, based on the voltage control of the ferromagnetic/oxide interface magnetic anisotropy energy (MAE) was reported for Fe or CoFeB/MgO systems [1-2], even though only a volatile change of anisotropy was attainable. One of the possible ways to attain a nonvolatile change of interface anisotropy might be replacing MgO with multivalent oxides, like TiOx which have been widely used as the active layer for restive random access memories (ReRAMs). Since the MAE at ferromagnetic /oxide interface is quite sensitive to a change of the interface structures like oxygen-ferromagnetic metal bond density [2-3], it is possible to expect the change of MAE by modulating the stoichiometry of oxides. Considering the fast switching of TiOx-based ReRAMs, the local redox reactions in TiOx would possibly very fast (> GHz) operations. In this study we demonstrate a nonvolatile change of magnetic anisotropy with Ta/CoFeB/TiO_x stacks by applying voltage bias.

2. Experimental

After the thermally oxidation of Si wafer to form ~100 nm-thick SiO_2, a 2 nm-thick-Y_2O_3 was rf-sputtered on the substrate, followed by the deposition of ~ 0.5 nm-thick Ti layer. After a short oxidation of Ti in oxygen ambient at room temperature, 1.3 nm-thick $Co_{0.6}Fe_{0.2}B_{0.2}$ and 6.5 nm-thick Ta were sequentially deposited. These stacks were patterned into a Hall bar to characterize the magnetization behaviors while applying a voltage bias between the Hall bar and the Si substrate. The advantage of this back-gate structure is that we can employ thermally-grown SiO_2 as a reliable dielectric barrier layer.

3. Results and Discussion

First we investigated the impact of oxygen deficiency of TiOx layer on the MAE at CoFeB/TiOx interface, by comparing the magnetization curves under perpendicular magnetic field for the two kinds of samples without applying voltage bias. The only difference between those two samples is that the deposited Ti layer was exposed to oxygen ambient before CoFeB deposition, or not. The significant difference of the observed saturation field should be attributed to the difference of the oxygen deficiency of TiOx layer. The impact of the oxidizing condition tuning of oxides on the interface MAE has been already studied for Ta/CoFeB/MgO [2] and Pt/Co/AlOx [3], therefore this result seems reasonable. From Fig. 1 it is indicated that oxygen deficiency in TiOx reduces the MAE at CoFeB/TiOx interface probably because some of the oxygen-ferromagnetic bonds are replaced by metallic bonds at the metal-rich interface.

Next the nonvolatile control of the magnetization by applying voltage bias was demonstrated by using Ta/CoFeB/TiOx/Y_2O_3 stacks. The electrical stress with a constant electric field ~ ± 3 MV/cm was applied for 15 minutes, and soon after releasing the electrical stress, the magnetization loop was measured under perpendicular magnetic field. Note that magnetization curves were measured without applying the electric field. The positive electric field direction is defined as the application of the positive bias on Si back-gate. The electrical stress application and the magnetization measurement at zero bias were repeated for several times while changing the polarity of the electrical stress at each step (+3 MV/cm stress→measurement at 0 MV/cm→-3 MV/cm stress → measurement at 0 MV/cm →…). As a result, it was observed that the saturation magnetization field after releasing the electrical stress changes at each step, as shown in **Fig. 2**. This small but clear manipulation of the saturation field is nonvolatile, and attributable to the positively-charged oxygen vacancy motion in the ultrathin TiOx layer. The increase of saturation field after the positive bias application is explicable by considering the more oxygen vacancy accumulation nearby the CoFeB/TiOx interface, which should reduce the MAE. The mechanism is possibly be similar with the reported non-volatile change of MAE at Co/GdOx interface [4].

4. Conclusions

We demonstrated the voltage-induced nonvolatile change of magnetic anisotropy of Ta/CoFeB/TiOx systems. This change is attributable to the oxygen vacancy motion in TiOx layer to modulate the MAE at CoFeB/TiOx interface.

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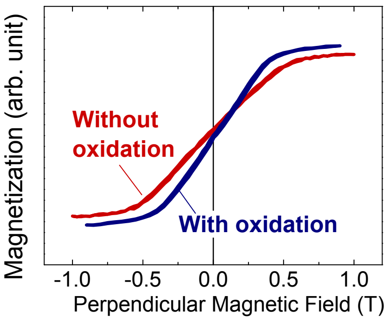

Fig. 1. Difference of magnetization behavior of Ta/CoFeB/TiOx/Y_2O_3/SiO_2/Si stacks with or without exposure of TiOx to oxygen just after the deposition of Ti.

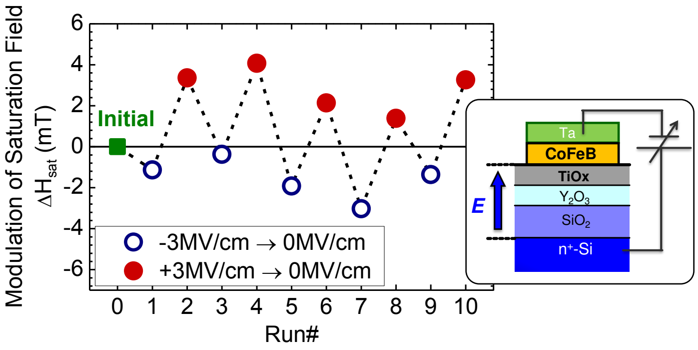

Fig. 2. Nonvolatile switching behavior of saturation magnetic field after ±3 MV/cm electrical stress observed for Ta/CoFeB/TiOx/Y_2O_3/SiO_2/Si stacks.