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Voltage-Induced Nonvolatile Change of Magnetic Anisotropy in TiOx/CoFeB/Ta Stack

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Abstract

Voltage-induced nonvolatile change of magnetic anisotropy was demonstrated with TiOx/CoFeB/Ta stacks. We observed a nonvolatile manipulation of MAE, which was attributable to the motion of oxygen vacancies in TiOx. Our results indicate a possible application of this phenomenon to a new nonvolatile memory.

1. Introduction

Recently, the voltage control of magnetic anisotropy at oxide/ferromagnetic interface has been reported at room temperature [1,2], which attracts much attention because of the possibility to manipulate the magnetization with less power consumption. The change of magnetic anisotropy energy is caused by the electron density modulation at the interface, so this change is volatile. One of the ways to attain nonvolatility is to utilize the oxides which exhibit nonvolatile switching of electrical properties due to the drift of oxygen vacancy by applying an electric field [3]. Since the interface magnetic anisotropy energy (MAE) should be sensitive to oxygen-ferromagnetic bonds, it is expected that MAE will change with the amount of oxygen vacancy accumulated at the interface by applying an electric field. The expected nonvolatile switching is schematically drawn in **Fig. 1 (a)**. In this paper, we demonstrate the nonvolatile change of magnetic anisotropy with TiOx/CoFeB/Ta structures.

2. Experimental

On thermal SiO_2 (100 nm-thick) grown on a Si wafer, 2 nm-thick Al_2O_3 was rf-sputtered. Then 2 nm-thick Ti was sputtered and oxidized in 10-Pa O_2 atmosphere at room temperature. After that 1.3 nm-thick $Co_{0.6}Fe_{0.2}B_{0.2}$ and 6.5 nm-thick Ta were sequentially deposited. This stack was patterned into a Hall bar to characterize the magnetization behavior while applying a voltage bias between the Hall bar and the Si substrate as shown in **Fig. 1 (b)**. We applied electric fields with different magnitude (±1.5, ±3, and ±5 MV/cm) for a period of time from 1 to 300 sec, and characterized the magnetization behavior under perpendicular magnetic field just after releasing the electric fields. To investigate the Ti chemical states, Ti $2p_{3/2}$ core-level photoelectron spectra were measured with AlKα x-ray (1487 eV).

3. Experimental Results

First, we investigated the impact of TiOx-oxidizing conditions on the magnetic properties of the stack. In **Fig.2 (a)**, Ti $2p_{3/2}$ core-level photoelectron spectra are compared for the stacks with oxidized- and non-oxidized Ti (not exposed to O_2) layers. The peak corresponding to dioxides was clearly observed for the sample with O_2 exposure, whereas metallic Ti or TiO peaks were dominant for the spectrum of the sample without O_2 exposure. In correspondent with the difference of Ti $2p_{3/2}$ spectra, the change of magnetization behavior was observed as shown in **Fig.2 (b)**, which means that the MAE at CoFeB/oxidized-Ti interface is stronger than that at CoFeB/non-oxidized Ti interface. This result seems reasonable considering the previous studies on the effects of oxidizing condition tuning on MAE for Ta/CoFeB/MgO [4] and Pt/Co/AlO_x [5].

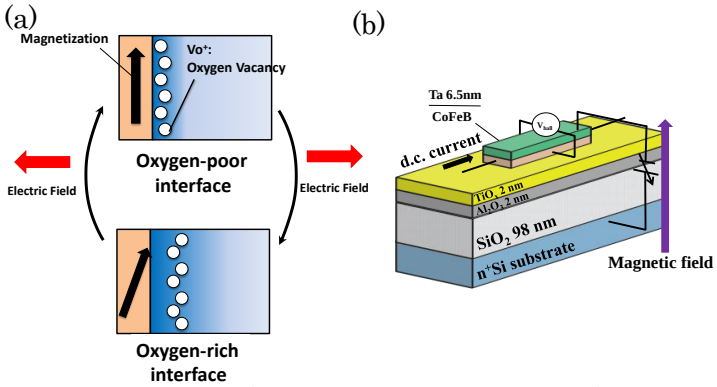

Fig.1 (a)The concept of voltage-induced nonvolatile change of magnetic anisotropy. Accumulated oxygen vacancy at the interface affects the magnetization. (b) Schematic of our experimental stack.

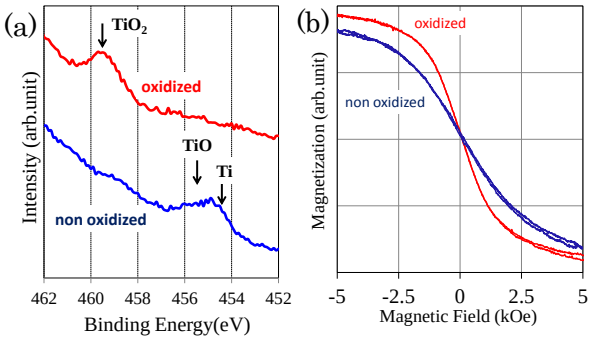

Fig.2 (a) Ti XPS $2p_{3/2}$ core-level spectra of the stacks with oxidized or non oxidized Ti. (b) The difference of magnetization curves corresponding to Ti oxidation condition.

Next, the voltage-induced non-volatile change of magnetic anisotropy was demonstrated, as shown in **Fig. 3**. The electrical stress with a constant electric field ~ ± 5 MV/cm was applied intermittently, with the stress time of 300 sec, and soon after releasing the electrical stress, the magnetization was characterized under perpendicular

magnetic field. Note that magnetization curves were measured without applying the electric field. The positive electric field direction was 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. As a result, it was observed that the saturation magnetization field after releasing the electrical stress changed at each step. This change of the saturation field was nonvolatile, and possibly 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 may be similar with the reported nonvolatile change of MAE at Co/GdOx interface [6], and quite different from the charge-induced one [1,2,4]. These results suggest the possible application of this phenomenon to novel nonvolatile memory devices.

The magnitude of nonvolatile change of the saturation magnetic field by changing the polarity of the electrical stress, ΔH_{sat}^{*}, rapidly increases with the magnitude of the applied electric field, as shown in **Fig. 4**, which clearly shows this nonvolatile change is voltage-induced one. ΔH_{sat}^{*} reaches ~ 12 mT for the case of 5 MV/cm, which corresponds to the change of interface anisotropy energy ~ 10 μJ/m^2, assuming *Ms* and effective thickness of CoFeB as 1.1 Wb/m^2 and 0.9 nm, respectively. In this figure, the rsult for Al_2O_3/CoFeB/Ta stack, without inserting TiOx layer, is also shown for a comparison. Only a tiny ΔH_{sat}^{*} was observed for this stack. This result indicates that an appropriate choice of the interface oxide will improve the value of ΔH_{sat}^{*}.

Finally, the effects of electrical stress time, from 1 to 300 sec, on ΔH_{sat}^{*} was investigated, to discuss the switching speed of this phenomenon. As shown in **Fig. 5 (a)**, ΔH_{sat}^{*} was not dependent on stress-time significantly. Even though we have not examined the shorter pulsed voltage, we expect a very fast operation will be attainable, taking account of the ultrathin Ti layer thickness and reported very fast operation of TiOx-based ReRAM devices [1,7]. For the device application of this phenomenon, another technological issue will be the improvement of the nonvolatility. As shown in **Fig. 5 (b)**, the Hall voltage under a given magnetic field was observed to be almost constant after releasing the electrical stress, but gradually decayed with a half-life period of several thousands of seconds. The improvement of the nonvolatility by tuning the process conditions is our next challenge.

4. Conclusion

Voltage-induced nonvolatile change of magnetic anisotropy was demonstrated. We observed a nonvolatile manipulation of MAE by introducing TiO_x at the interface with CoFeB layer.

References

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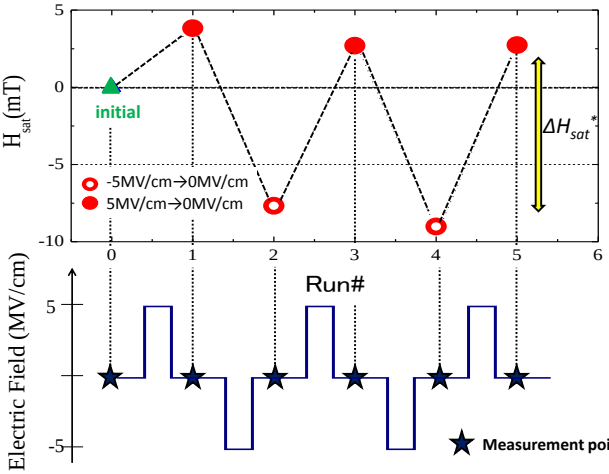

Fig.3 Nonvolatile switching behavior of saturation magnetic field after ± 5 MV/cm electrical stress. We defined ΔH_{sat}^{*} as the difference between H_{sat} after releasing positive and negative biases.

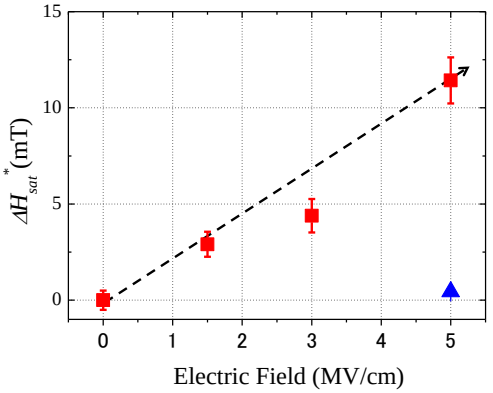

Fig.4 Stress electric field dependence of ΔH_{sat}^{*}, indicating that nonvolatile behavior was induced by electrical stress. Blue triangle is the case of Al_2O_3/CoFeB/Ta stack without Ti, which shows negligibly small change.

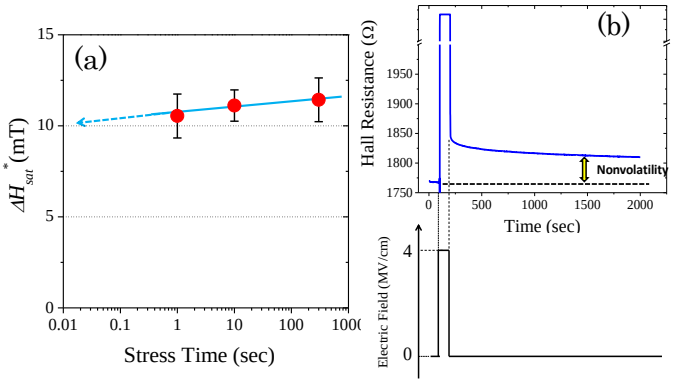

Fig.5 (a) Stress time(1~300sec) dependence of ΔH_{sat}^{*}.The magnitude does not decrease significantly by shortening stress time. (b) Time dependent decay of Hall resistance obtained at 200 mT. The half life period may be several thousands of seconds.