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Observation of Spin-Orbit Torque Induced Magnetization Switching in Gd-Fe Perpendicular Magnetized Wire with In-Plane Exchange Bias Field

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Abstract

We fabricated a Ta/Gd-Fe/$Ir_{22}Mn_{78}$/$Co_{90}Fe_{10}$/Ta multilayered magnetic wire and investigated current-induced magnetization switching in the wire. The magnetization switching was observed by a current even in zero magnetic field. Moreover, we successfully observed the periodical magnetization switching in zero magnetic field. It indicates that the present wire is one of the candidates to realize the magnetic random access memory with low power consumption.

1. Introduction

Magnetization switching using spin orbit torque (SOT) has been paid much attention because it is available for Magnetic Random Access Memory (MRAM). The critical current density of current-induced magnetization switching (CIMS) using SOT is lower than that using spin transfer torque (STT), which indicates that SOT has the advantage over STT from the viewpoint of power consumption [1]. However, in the case of CIMS using SOT, it is necessary to apply the external in-plane magnetic field. If there is not an in-plane magnetic field, a magnetization keeps on rotating and its direction is not determined. The in-plane magnetic field is a barrier against the rotation to determine a magnetization direction (up or down) [2]. To fabricate the memory device using SOT-CIMS, the in-plane magnetic field should be eliminated. In this study, in order to achieve SOT-CISM in zero magnetic field, we fabricated Ta/Gd-Fe/IrMn/CoFe multilayered magnetic wire, where Ta layer generates SOT in the next Gd-Fe layer and IrMn/CoFe cap layer has exchange bias field to Gd-Fe layer corresponding to the effective in-plane magnetic field. Since the switching current of SOT-CIMS is proportional to the magnetization of ferromagnetic layer, the magnetic materials with low saturation magnetization is suitable for low power operation of SOT-CIMS [3]. The Gd-Fe alloy is a ferrimagnetic material which has low saturation magnetization. In this study, therefore, we investigate SOT-CIMS in zero magnetic field using Gd-Fe alloy film.

2. Experimental

The Gd-Fe alloy was fabricated by DC magnetron co-sputtering using Gd and Fe targets. The Ta, IrMn, and CoFe were also fabricated by DC magnetron sputtering. The Ta (6 nm)/Gd-Fe (8 nm)/IrMn (2 nm)/CoFe (2 nm)/Ta (3.5 nm) multilayer film was deposited on a thermally oxidized Si substrate shown in Fig. 1. The 5-μm-wide Hall bars were fabricated by the electron beam lithography and a lift-off process as shown in Fig. 2. The SOT-CIMS was observed by using anomalous Hall effect (AHE) in the in-plane magnetic field H_X. AHE measurements were carried out after applying a field of 3 kOe to align the magnetization of CoFe layer.

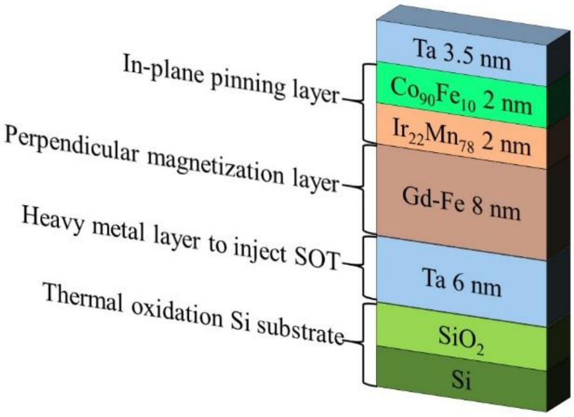

Fig. 1 Schematic diagram of the film structure.

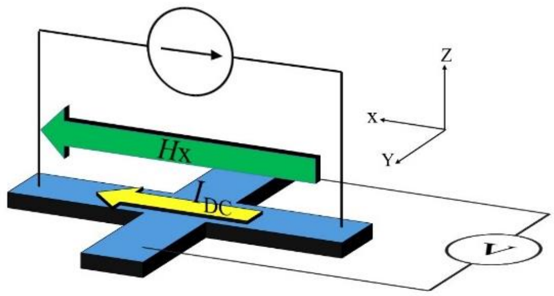

Fig. 2 Experimental setup.

3. Results and Discussion

Figure 3(a) shows the Hall resistance (R_H) in Ta/Gd-Fe/IrMn/CoFe multilayered wire as a function of current under the in-plane magnetic field (H_X = 100 Oe). The R_H greatly changes at the critical current around ± 3 mA. This result indicates that the CIMS was occurred by SOT generated from the Ta layer. The critical current of CIMS increased as the external in-plane field decreases.

However, even when the external field was decreased to zero, we could observe the magnetization switching at 5 mA as shown in Fig. 3(b). It is noted that the R_H change is not sharp. It means that the magnetization switching was partially occurred in the case of CIMS in the zero magnetic field.

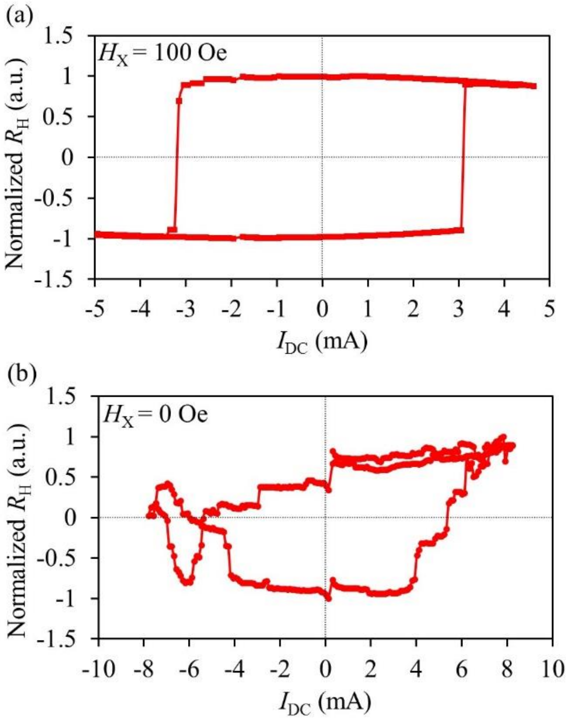

Fig. 3 R_H -I_{DC} loop of Ta/Gd-Fe/IrMn/CoFe multilayered wire in H_X = 100 Oe (a) and in H_X = 0 Oe (b).

To investigate the device operation, we applied the 1 sec pulse current of ±5 mA or ±8 mA periodically in H_X = -40 Oe and in the zero magnetic field, respectively. Figure 4(a) shows the Hall voltage (V_H) in Ta/Gd-Fe/IrMn/CoFe multilayered wire as a function of time under the in-plane magnetic field (H_X = -40 Oe) when the periodical pulse current was applied. The red and blue backgrounds in Fig. 4(a) show the period of time for applying the positive current (+5 mA) and the negative pulse (-5 mA) to switch the magnetization, respectively. The gray background between red and blue shows the period of time for applying the sense current (0.05 mA) to measure the V_H. The V_H repeatedly changed between positive and negative values in response to the pulse current application. This means the SOT-CIMS was occurred by the 1 sec pulse currents of ±5 mA.

Figure 4(b) shows the Hall voltage (V_H) as a function of time in Ta/Gd-Fe/IrMn/CoFe multilayered wire without external in-plane magnetic field (H_X= 0 Oe). As shown in Fig. 4(b), the V_H was clearly changed by the pulse current (±8 mA). However, the value of $|V_H|$ measured by the sense current after applying the negative pulse current are extremely small compared to that after applying the positive pulse current. It is probably due to the partial magnetization switching. Then we increased the pulse current from ±5 mA to ±8 mA. Although the magnitude of V_H by CIMS is small, we successfully observed magnetization switching in the zero magnetic field by using the 1 sec pulse current of ±8 mA. It indicates that 1 bit information can be written in Ta/Gd-Fe/IrMn/CoFe multilayered wire by SOT under zero magnetic field.

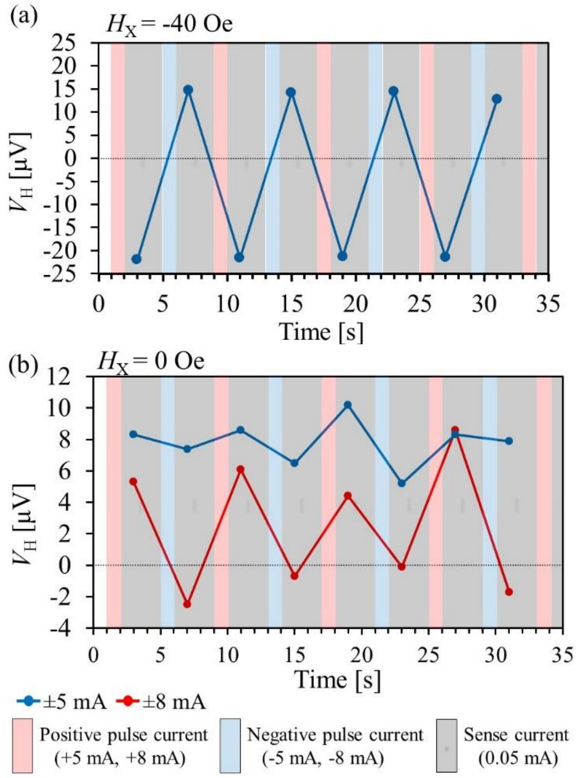

Fig. 4 Hall voltage (V_H) as a function of time under periodical pulse current in H_X = -40 Oe (a) and in H_X = 0 Oe (b).

4. Conclusions

We fabricated a Ta/Gd-Fe/IrMn/CoFe/Ta multilayered magnetic wire with in-plane bias field from IrMn for spin orbit torque induced magnetization switching. The magnetization switching was demonstrated even without the external magnetic field. Furthermore, we successfully observed the periodical magnetization switching in the present wire under zero magnetic field. It indicates that the Ta/Gd-Fe/IrMn/CoFe/Ta multilayered magnetic wire can be applied for memory devices.

Acknowledgements

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