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Highly Sensitive Magnetic Field Sensor Devices Based on Magnetic Tunnel Junctions with CoFeSiB Electrode

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Abstract

Magnetic tunnel junctions (MTJs) with CoFeSiB/Ru/CoFeB free layer were fabricated. CoFeSiB thickness dependences of magnetic properties and TMR effect were systematically investigated. We have observed a linear response to external magnetic field and have achieved a very high sensitivity of 115%/Oe in MTJs by optimization of CoFeSiB thickness. This sensitivity is the highest value to date among single MTJ devices.

1. Introduction

The discovery of the large tunnel magneto-resistance (TMR) effect in magnetic tunnel junctions (MTJs) with (001)-oriented MgO barriers enabled us to design highly sensitive magnetic field sensors. MTJs with low power consumption and small device size makes them leading candidate for the novel magnetic field sensor devices [1]. Detection of bio-magnetic field is important for our health because disease of heart and brain can be diagnosed. A high sensitivity and a linear response to external field are necessary for bio-magnetic field sensor applications. The sensitivity of MTJs is defined as TMR ratio/2H_k, where H_k is the magnetic anisotropy field of the free layers [2]. We have to develop MTJs with high sensitivity of more than 100%/Oe in order to detect a small bio-magnetic field such as brain field (ca. 10^{-9} Oe). In our previous work, we have fabricated MTJs with CoFeSiB (30)/Ru (t_{Ru})/CoFeB (3) free layers and optimized the thickness of Ru spacer ($t_{CoFeSiB}$). As a result, we could observe the sensitivity of 39%/Oe at t_{Ru} = 0.4 nm [3].

Reduction of H_k is expected in CoFeSiB/Ru/CoFeB free layers by increasing CoFeSiB thickness. In this work, we systematically investigated the CoFeSiB layer thickness dependence of magnetic property and TMR effect in MTJs with CoFeSiB/Ru/CoFeB free layers to improve the sensitivity.

2. Experimental procedure

The films were deposited onto thermally oxidized Si wafers using ultrahigh vacuum magnetron sputtering system (P_{base} < 3.0 × 10^{-6} Pa). Ar pressure for preparation of all films was 0.1 Pa. The stacking structure of MTJ films were Si, SiO_2 subs. /Ta (5)/Ru (10)/Ta (5)/$Co_{70.5}Fe_{4.5}Si_{15}B_{10}$ ($t_{CoFeSiB}$ = 30, 50, 70, 100)/ Ru (0.4)/$Co_{40}Fe_{40}B_{20}$ (3)/MgO (2.5)/ $Co_{40}Fe_{40}B_{20}$ (3)/Ru (0.9)/$Co_{75}Fe_{25}$ (5)/$Ir_{22}Mn_{78}$ (10)/Ta (5)/Ru (8) (in nm). The MTJ devices were fabricated using photolithography and Argon ion milling. Ar ion milling was stopped in the middle of the MgO barrier layer, and the top pinned layers were patterned into 80×40, 40×20, 20×10 μm^2 rectangles.

The MTJs were annealed at 350°C for 1 hour in a vacuum furnace after micro fabrication (first annealing). This first annealing was carried out with a magnetic field of 200 Oe to induce the magnetic anisotropy and obtain a high TMR ratio. The MTJs were annealed again at 260°C for 15 min in the atmosphere with 90° rotated field of 100 Oe, which is applied to the magnetic hard axis direction of the bottom free layer and easy axis direction of top pinned layer (second annealing). The second annealing induced the rotation of the easy axis of top pinned layer. The scanning transmission electron microscope (STEM) image was measured in MTJ with CoFeSiB thickness = 100 nm after first anneal by Toray Research Center, Inc. The magneto-resistance properties were measured at RT by using the DC four prove method with applied magnetic field swept with a 0.1 Oe step. The direction of the magnetic field was the same as the second annealing.

3. Experimental results

Fig. 1(a) shows CoFeSiB thickness dependence of twice coercive field (2H_c) of easy axis. A coercive field value of MTJ is close to that of CoFeSiB single film by increasing CoFeSiB thickness. This result suggests that magnetization switching of CoFeSiB is dominant in CoFeSiB/Ru/CoFeB free layers by increasing CoFeSiB thickness. Fig. 1(b) shows CoFeSiB thickness dependence of TMR ratio. A TMR ratio of ca. 200% was observed regardless of CoFeSiB thickness.

Fig. 2 (a) shows BF-STEM image and Fig.2 (b) shows HAADF-STEM image. We confirmed that Ru in the CoFeSiB /Ru/CoFeB free layer was continuous film, CoFeSiB kept amorphous structure, and CoFeB/MgO/CoFeB was (001)-oriented polycrystalline structure after first annealing from those STEM-images.

Fig. 3 shows the magnified views of magneto-resistance curves around zero field in MTJs with each CoFeSiB thickness. A magnetic anisotropy field (H_k) and coercive field (H_c) decreased by increasing CoFeSiB thickness.

Fig. 4 shows CoFeSiB thickness dependence of sensitivity of MTJs. Sensitivity was improved by increasing CoFeSiB thickness and highest sensitivity of 115%/Oe was observed in MTJ with 100 nm thick CoFeSiB. This sensitivity is the highest value among single MTJ devices.

4. Summary

MTJs with CoFeSiB/Ru/CoFeB free layers were fabricated and we systematically investigated CoFeSiB thickness dependence of magnetic property of free layers and TMR effect. A coercive field decreased by increasing CoFeSiB thickness and a TMR ratio of ca. 200% was observed regardless of CoFeSiB thickness. Finally, a very high sensitivity of 115%/Oe was observed at CoFeSiB thickness = 100 nm after second anneal. The MTJ with high sensitivity over 100%/Oe can detect small magnetic field of 10^{-9} Oe. We have greatly advanced measurement of bio-magnetic field by MTJ sensor devices.

Acknowledgements

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References

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Figures

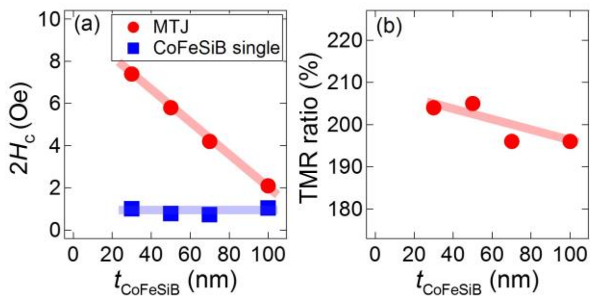

Fig. 1 CoFeSiB thickness ($t_{CoFeSiB}$) dependence of (a) twice coercive field ($2H_c$) of easy axis and (b) TMR ratio.

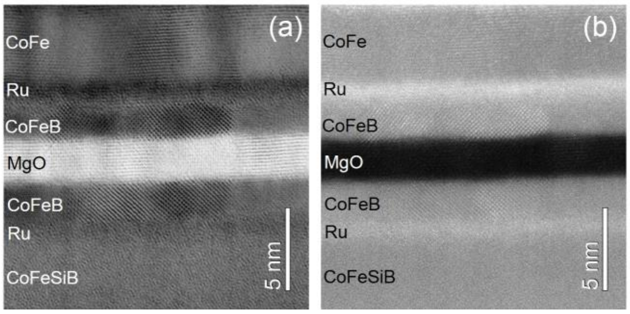

Fig. 2 STEM image (a) BF-STEM image, (b) HAADF-STEM image

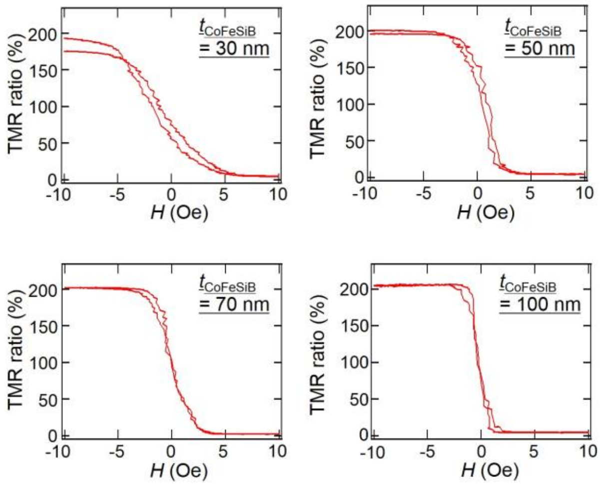

Fig. 3 Magnified vies of magneto-resistance curves in MTJ with each CoFeSiB thickness.

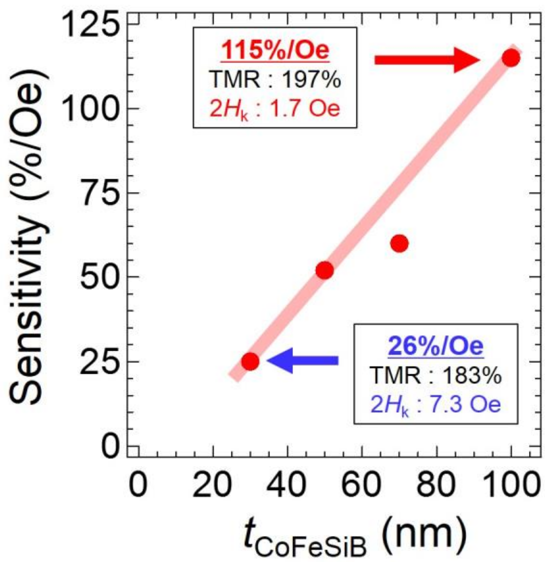

Fig. 4 CoFeSiB thickness dependence of sensitivity