A-8-1 (Invited)

Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp454-455

Switching current and thermal stability of perpendicular magnetic tunnel junction with MgO/CoFeB/Ta/CoFeB/MgO recording structure scaling down to 1X nm

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Abstract

We review characteristics of CoFeB-MgO magnetic tunnel junction with perpendicular easy axis (p-MTJ) at a reduced dimensions down to 1X nm. CoFeB-MgO p-MTJ with double-interface shows higher thermal stability down to 1X nm than that with single-interface. Intrinsic critical current of 24 μA and thermal stability factor of 58 are achieved at a junction diameter of 20 nm in double CoFeB-MgO interface structure.

1. Introduction

CoFeB-MgO based magnetic tunnel junction with perpendicular easy axis (p-MTJ) is attracting great attention as a building block in spintronics based very large scale integrated circuits[1] and spin-transfer-torque magnetoresistive random access memory (STT-MRAM), because high tunnel magnetoresistance (TMR) ratio, a relatively high thermal stability factor Δ, and low intrinsic critical current of 49 μA were demonstrated at a junction diameter (D) of 40 nm.[2] A fast switching[3] and low write error rate[4] by STT were also reported in CoFeB-MgO p-MTJs. These features made it possible to demonstrate several types of spintronics based VLSIs[5-8] and STT-MRAMs[9-11] by using CoFeB-MgO p-MTJs. For further development of the spintronics based VLSIs and STT-MRAMs, it is required to miniaturize MTJ size while maintaining high performances. In this study, we report characteristics of the p-MTJs with double CoFeB-MgO interface structure and single CoFeB-MgO interface structure scaling down to D of 1X nm.

2. Experimental procedure

Stack structures shown in Fig. 1 are deposited on thermally oxidized Si substrate by dc/rf magnetron sputtering. The stacks are processed into circular p-MTJs by electron beam lithography, reactive ion etching, and Ar ion milling. The fabricated MTJs are annealed at 300°C for 1 hour in vacuum under perpendicular magnetic field of 0.4 T. Resistance and area product (RA) is determined by fitting a linear function to the relationship between conductance at parallel state and junction area measured by scanning electron microscope for the MTJs with nominal D of 30 – 80 nm. D of each MTJ is determined by the RA value and R of each MTJ.

3. Results

Figure 2 shows TMR ratio for the p-MTJs with double- and single-interface structure as a function of D. Both structures show virtually the same TMR ratio in the studied D range. However, minor resistance versus magnetic field curves (R-H curves) with single-interface structure show no hysteresis at D of 1X nm whereas that with double-interface structure shows square shape with bi-stable state at H = 0 (not shown).[12]

Switching probability as a function of applied pulse magnetic field amplitude with duration of 1 s is measured to evaluate Δ.[13] Δ for both structures is plotted with respect to D in Fig. 3. Higher Δ is observed in double-interface structure than single-interface structure, which is consistent with previous study.[13] Double-interface structure shows almost constant Δ down to D of 30 nm, below which it starts to decreases. The results indicate that nucleation size of double-interface structure is ~ 30 nm. Note that the D dependence of Δ can be explained by magnetic properties of blanket film with correction of demagnetization factor.

Finally, I_{C0} is evaluated for double-interface structure with D of 20 nm. To evaluate I_{C0}, we measure switching probability with respect to pulse current amplitude with duration of 0.1 s as shown in Fig. 4.[13] From a fit of theoretical equation to the results,[14] $I_{C0}^{P(AP)}$ are determined to be 27 μA and -21 μA where superscripts of I_{C0} denotes magnetization configuration before switching.

Our present result indicates that Δ of 58, and average $|I_{C0}|$ of 24 μA can be achieved by using double-interface structure at D of 20 nm.

4. Conclusions

We investigate junction size dependence of properties of magnetic tunnel junctions with double- and single-interface structure scaling down to 1X nm. Double-interface structure shows higher thermal stability factor than single-interface structure. At a junction diameter of 20 nm, thermal stability factor of 58 and average absolute intrinsic critical current of 24 μA are achieved in double-interface structure.

Acknowledgements

The work was supported by the FIRST program of JSPS, R&D for Next-Generation Information Technology of MEXT, and R&D Subsidiary Program for Promotion of Academia-industry Cooperation of METI. The authors wish to thank I. Morita, Y. Iwami, T. Hirata, H. Iwanuma, Y. Kawato, K. Goto, and C. Igarashi for technical support.

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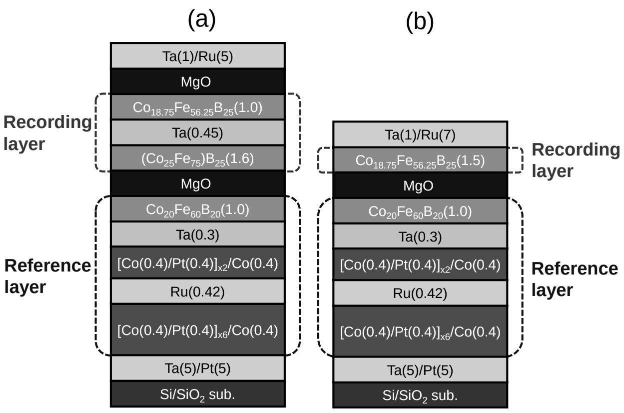

Fig. 1 Schematic of stack structures employed in this study. (a) double CoFeB-MgO interface structure, (b) single CoFeB-MgO interface structure.

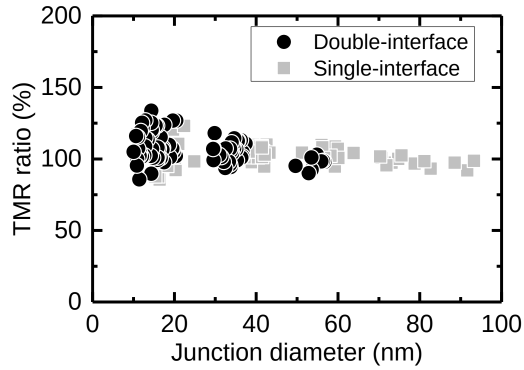

Fig. 2 Tunnel magnetoresistance ratio of magnetic tunnel junctions with double- and single-interface structure as a function of junction diameter.

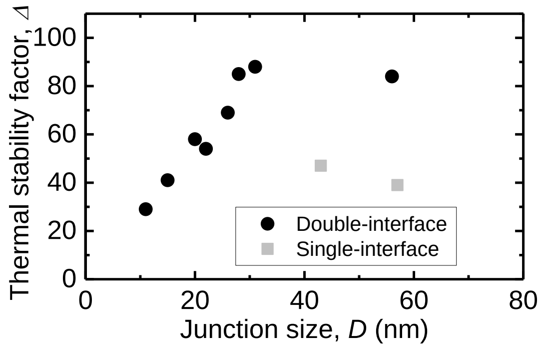

Fig. 3 Thermal stability factor of double- and single-interface structure as a function of junction diameter..

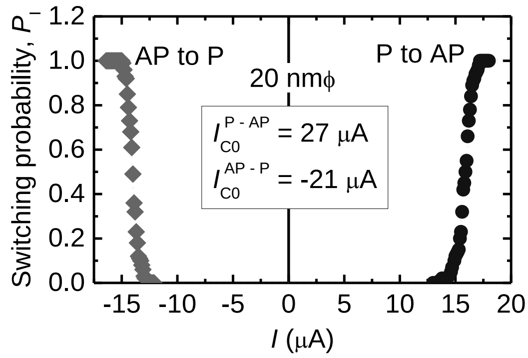

Fig. 4 Switching probability as a function of applied pulse current amplitude with duration of 0.1 s for double-interface structure with junction diameter of 20 nm.