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Microfabrication and magnetoelectric properties of amorphous magnetic-tunnel-junctions with Co–Fe–B/Al–O/Co–Fe–B hardcore structure

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Abstract

Both single-barrier magnetic tunnel junctions (SBMTJs) and double-barrier magnetic tunnel junctions (DBMTJs) with an amorphous hardcore structure of $Co_{60}Fe_{20}B_{20}$/Al–O/$Co_{60}Fe_{20}B_{20}$ were microfabricated. A high TMR ratio of 102.2% at 4.2 K was observed in the SBMTJs after annealing at 265 °C for 1 h. High TMR ratio of 56.2%, low junction resistance-area product RS of 4.6 k$\Omega\,\mu m^2$, small coercivity $H_C = 25$ Oe, and relatively large bias-voltage-at-half-maximum TMR with the value $V_{1/2}$ greater than 500 mV at room temperature (RT) had been achieved in such Co–Fe–B SBMTJs. Whereas, high TMR ratio of 60% at RT and 89% at 30 K, low junction resistance-area product RS of 7.8 k$\Omega\,\mu m^2$ at RT and 8.3 k$\Omega\,\mu m^2$ at 30 K, low coercivity $H_C = 8.5$ Oe at RT and $H_C = 14$ Oe at 30 K, and relatively large bias-voltage-at-half-maximum TMR with the value $V_{1/2}$ greater than 1150 mV at RT had been achieved in the Co–Fe–B DBMTJs. Temperature dependence of the TMR ratio, resistance, and coercivity from 4.2 K to RT, and applied voltage dependence of the TMR ratio and resistance at RT for such amorphous MTJs were also investigated.

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1. Introduction

A high TMR ratio combined with a low junction resistance and a comparatively small switching field based on the non-single crystal magnetic-tunnel-junctions (MTJs) with single-barrier (SB) and double-barrier (DB) layers are continually desirable because they can provide greater signal level, lower power consumption, high speed, and larger design margin for developing magnetoresistance devices such as novel magnetic random access memory (MRAM), TMR-read heads for ultra-high density magnetic storage, and other magnetic sensors [1–4]. Although many investigations on new junction materials and structures for improving TMR ratio have been achieved in recent years [5–10], fabrication of good-quality poly-crystal or amorphous MTJs is still a key challenge for the actual device applications with low cost.

In this work, we showed an optimized SBMTJs and DBMTJs using the amorphous $Co_{60}Fe_{20}B_{20}$/Al–O/$Co_{60}Fe_{20}B_{20}$ hardcore structure as the three key layers because the amorphous thin Al–O barrier layer was easily formed. A high TMR ratio of 102.2% at 4.2 K and 56.2% at RT for the SBMTJs, whereas a high TMR ratio of 89% at 30 K and 60% at RT for the DBMTJs were achieved. Then, the temperature dependence of the TMR ratio, resistance, and coercivity from 4.2 K to RT, and applied voltage dependence of the TMR ratio and resistance at RT and 4.2 K for such SBMTJs and DBMTJs were investigated.

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2. Experimental method

The SBMTJs and the DBMTJs with the amorphous hardcore structure of $Co_{60}Fe_{20}B_{20}$/Al–O/$Co_{60}Fe_{20}B_{20}$ on the Si(1 0 0)/SiO_2 substrate were microfabricated, respectively, using an ULVAC TMR R&D Magnetron Sputtering System (MPS-4000-HC7) combined with the optical lithography and Ar ion-beam etching techniques. All the deposition processes were done at a base pressure of below 1.0×10^{-6} Pa and an Ar plasma sputtering pressure of 0.07 Pa without breaking vacuum in any process. The Al-oxide barrier was formed by inductively coupled plasma (ICP) oxidizing the thin Al-layer in a mixture of oxygen and argon at a pressure of 1.0 Pa in a separate chamber. An in-plane magnetic field of about 100 Oe was applied to define the uniaxial magnetic anisotropy of the magnetic layers. The TMR curves between 4.2 and 300 K with a DC bias voltage of between 1 and 1500 mV for the MTJs were measured with a physical properties measurement system (PPMS).

3. Results and discussion

Fig. 1 shows the TMR curves measured at 4.2 K for a typical SBMTJ with the layer structure of Ta(5)/Cu(30)/$Ni_{79}Fe_{21}$(5)/$Ir_{22}Mn_{78}$(12)/$Co_{60}Fe_{20}B_{20}$(4)/Al(0.8)-oxide/$Co_{60}Fe_{20}B_{20}$(4)/Cu(30)/Ta(5) [layer thickness unit: nm] after annealing at 265 °C for one hour. A high TMR ratio of 102.2% at 4.2 K and 56.2% at RT was observed. The value of effective spin-polarization of $Co_{60}Fe_{20}B_{20}$ at 4.2 K, $P = 58.1\%$, can be deduced from the Jullière's formula [11], due to which there is no contribution to TMR ratio from the amorphous Al–O band structure besides both $Co_{60}Fe_{20}B_{20}$ electrodes [12]. Such effective spin polarization in the amorphous alloy of $Co_{60}Fe_{20}B_{20}$ is higher than the experimental data of 50–52% for the $Co_{50}Fe_{50}$, $Co_{60}Fe_{40}$, and $Co_{84}Fe_{16}$ alloys, measured at 0.2 K by Parkin et al. [13], and $Co_{75}Fe_{25}$ measured at 4.2 K by Han et al. [5] Further more, low-junction resistance-area product RS of 4.6 kΩ μm^2, small coercivity $H_C = 25$ Oe, and relatively large bias-voltage-at-half-maximum TMR with the value $V_{1/2}$ greater than 500 mV at RT had been achieved in such Co–Fe–B SBMTJs.

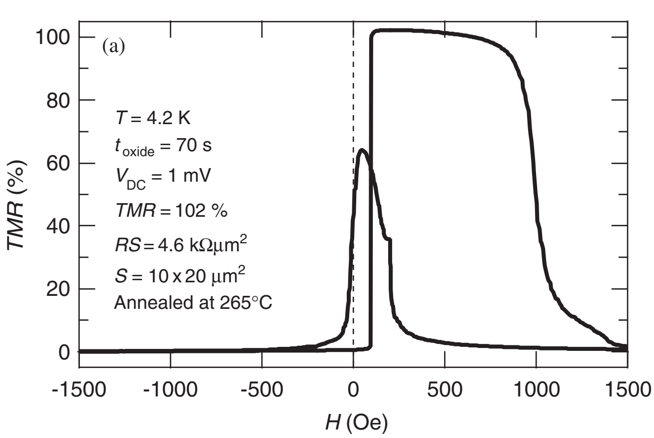

Fig. 1. A typical TMR curves measured at 4.2 K for an amorphous Co–Fe–B SBMTJ with the size of $10 \times 20\,\mu m^2$ after annealing.

Fig. 2 shows the temperature dependence of the TMR ratio, junction resistances R_{AP} and R_P, which are corresponding to the antiparallel and parallel magnetization configurations of the $Co_{60}Fe_{20}B_{20}$ electrodes, the switching fields of H_S^1 and H_S^2 for two back and forth magnetoresistance curves, and the coercivity H_C of the free layer, which was defined as $H_C = (H_S^1 - H_S^2)/2$ for the same SBMTJ after annealing. It showed that the TMR ratio, the junction resistances, the coercivity H_C and switching fields H_S of the free layer decrease with increasing temperature from 4.2 K to RT. The temperature dependence of the TMR ratio and resistances can be explained using the theory and formulas based on the magnon- and phonon-assistant tunnelling model developed by Zhang et al. [14–16].

Fig. 3 shows the TMR curves measured in an external magnetic field of 5000 Oe at 4.2 K and RT for a typical DBMTJ with the layer structure of Ru(5)/Cu(10)/$Ni_{79}Fe_{21}$(5)/$Ir_{22}Mn_{78}$(12)/$Co_{75}Fe_{25}$(4)/Ru(0.9)/$Co_{60}Fe_{20}B_{20}$(4)/Al(1.0)-oxide/$Co_{60}Fe_{20}B_{20}$(4)/Al(1.0)-Oxide/$Co_{60}Fe_{20}B_{20}$(4)/Ru(0.9)/$Co_{75}Fe_{25}$(4)/$Ir_{22}Mn_{78}$(12)/$Ni_{79}Fe_{21}$(5)/Ru(5) after

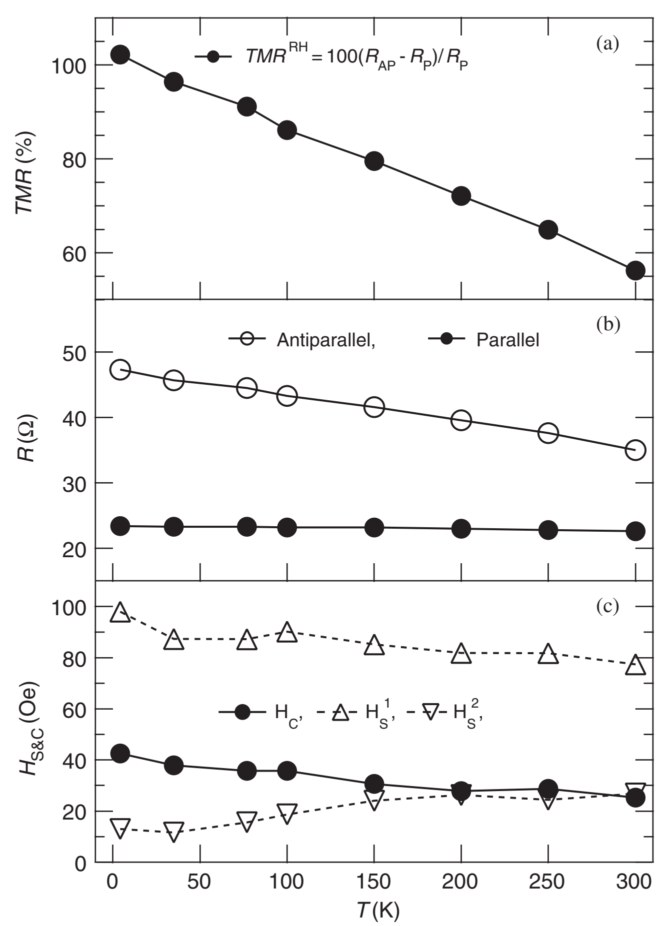

Fig. 2. Temperature dependence of the TMR ratio, junction resistances R_{AP} and R_P, the switching fields of H_S^1 and H_S^2 and the coercivity H_C of the free layer for the same SBMTJ after annealing.