Temperature dependence of spin-dependent tunneling conductance for the parallel configuration of Co_2MnSi MTJs with high spin polarization

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A highly efficient spin source is essential for spintronic devices. We recently showed that controlling defects through the film composition is critical to retain the half-metallicity of ternary Heusler alloy Co_2MnSi (CMS) and quaternary alloy $Co_2(Mn,Fe)Si$ (CMFS) [1−3]. As a result, we demonstrated a giant TMR ratio of up to 2610% at 4.2 K (429% at 290 K) for CMS/MgO/CMS MTJs (CMS MTJs) and CMFS MTJs [1,3]. The purpose of the present study was to clarify the key mechanisms that determine the temperature dependence of the spin-dependent tunneling conductance G (= I/V), in particular, for the parallel configuration (P), G_P of CMS MTJs.

The preparation of fully epitaxial CMS MTJs with various values of α in $Co_2Mn_\alpha Si$ electrodes has been described elsewhere [1]. G_P was measured by a dc four-probe method at temperatures from 4.2 to 290 K at a small bias voltage of 2 mV. The TMR ratio was defined as TMR = $(G_P-G_{AP})/G_{AP}$.

Figure 1 plots the T dependence of the normalized G_P of CoFe-buffered CMS MTJs with various Mn compositions α in $Co_2Mn_\alpha Si_{0.84}$ electrodes. The TMR ratios at 4.2 K of these MTJs significantly increased with increasing α from 574% for Mn-deficient α = 0.73 to 2011% for α = 1.30 [3]. G_P of these MTJs decreased with increasing T in a T range from T_1 (~25 K) to T_2 (~220 K). Then, it increased for $T > T_2$. Furthermore, the degree of the decrease in the normalized G_P at T_2 became larger for the MTJ that showed the larger TMR at 4.2 K. In contrast, the normalized G_P of a CoFe/MgO/CoFe MTJ (CoFe MTJ) that showed a lower TMR of 382% at 4.2 K (258% at 290 K) slightly increased with increasing T from 4.2 K to around 100 K and then increased with T from around 100 K to 290 K. The T dependence of G_P of the CoFe MTJ can be explained by the Zhang's model in which a spin-flip, inelastic tunneling process via thermally excited magnon is taken into account [4]. Note that the Zhang's term provides an increase in G_P (and G_{AP}) with increasing T.

To understand the T dependence of G_P of CMS MTJs with α from 0.73 to 1.30 that showed high TMR ratios ranging from 574% to 2011%, we take into consideration two tunneling processes; one is the Zhang's term [4] and another is the Shang's term [5]. In the latter term, only spin-conserved elastic tunneling process is taken into account but the T dependence of spin polarization (SP) is introduced. Given this understanding, the $G_P(T)$ for the CMS MTJs were fitted with the conductance at T = 0, and the additional terms from the Shang's process and the Zhang's process. This analysis is reasonable because the contribution to G_P from the Zhang's term decreases for MTJs with higher SP, resulting in a relative increase in the contribution of the Shang's term to $G_P(T)$ for MTJs with higher SP. These fittings for the CMS MTJs well reproduced the experimental $G_P(T)$ with reasonable values of the parameters involved in the fitting. In conclusion, it was clarified that the characteristic T dependence of CMS MTJs showing giant TMR ratios is highly influenced by the half-metallicity of the CMS electrodes.

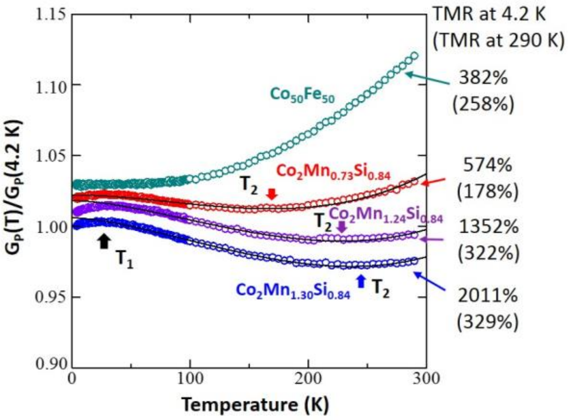

Fig. 1. T dependence of the normalized tunneling conductance for the parallel configuration of CoFe-buffered CMS MTJS with various Mn compositions α in $Co_2Mn_\alpha Si_{0.84}$ electrodes (α = 0.73, 1.24, 1.30). As a reference, $G_P(T)$ for a CoFe MTJ is also plotted. The solid lines are fitted curves. The second to fourth curves from the bottom have respective offsets of 0.01 to 0.03 in the normalized G_P.

References

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