Temperature dependence of spin-dependent tunneling resistances of Co_2MnSi and $Co_2(Mn,Fe)Si$ MTJs showing high tunneling magnetoresistances

Bing Hu, Hongxi Liu, Takeshi Kawami, Kidist Moges, Tetsuya Uemura, and Masafumi Yamamoto
Graduate School of Science and Technology, Hokkaido University, Sapporo 060-0814, Japan

We recently demonstrated that the suppression of Co antisites at nominal Mn/Fe sites is critical to obtaining half-metallic quaternary CMFS [1] in a similar way as in ternary alloy Co_2MnSi [2-4]. The purpose of the present study was to investigate how the temperature (T) dependence of the spin-dependent tunneling resistances in CMS/MgO/CMS MTJs (CMS MTJs) and CMFS MTJs is correlated with the half-metallicy of CMS and CMFS electrodes.

The preparation of fully epitaxial CMS MTJs with various values of α in $Co_2Mn_\alpha Si$ electrodes and CMFS MTJs with various values of α' and β' in $Co_2Mn_{\alpha'}Fe_{\beta'}Si$ electrodes has been reported in Refs. [1-3]. In this study, we focused on the tunneling resistance for the parallel (P) magnetization configuration, R_P, which was measured by a dc four-probe method at temperatures from 4.2 to 290 K.

Figure 1 plots the T dependence of the normalized R_P of the MgO-buffered CMS MTJs with various Mn compositions α in $Co_2Mn_\alpha Si_{1.0}$ electrodes. The TMR ratios at 4.2 K of these MTJs significantly increased with increasing α from 355% for α = 0.79 to 1035% for α = 1.29 [2]. R_P of α = 0.79 MTJ didn't show any increase with increasing T but decreased as T increased for $T > T_2$ of about 100 K. This decrease in R_P with increasing T can be explained by a model by Zhang et al. [5], in which magnon-assisted tunneling is taken into account under the assumption of T-independent spin polarization at the Fermi level (E_F). On the other hand, R_P of α = 1.0 and 1.29 increased as T increased for $T_1 < T < T_2$. Note that the appearance of the increase in R_P was observed for CMS MTJs with almost Mn-stoichiometric or Mn-rich CMS electrodes featuring reduced Co_{Mn} antisites.

Figure 2 plots the T dependence of R_P for CMFS MTJs having $Co_2Mn_{1.24}Fe_{0.16}Si_{0.84}$ and $Co_2Mn_{1.0}Fe_{0.40}Si_{0.84}$ electrodes, respectively. The former MTJ showed a giant TMR ratio of 2500% at 4.2 K (429% at 290 K) and the latter showed a lower TMR ratio of 1920% at 4.2 K (328% at 290 K). Note that the relative increase in R_P was larger for the MTJ that showed the higher TMR ratio. This correlation observed for both CMS MTJs and CMFS MTJs suggests that the increase in R_P with increasing T occurred for MTJs having electrodes being close to be half-metallic, resulting in the minority-spin density of states at E_F at the ground state being greatly reduced. Then, spin fluctuation at finite temperatures reduces the spin polarization, leading to the increase in R_P at finite temperatures.

In summary, we observed the clear increase in R_P for MTJs having CMS or CMFS electrodes being close to be half-metallic.

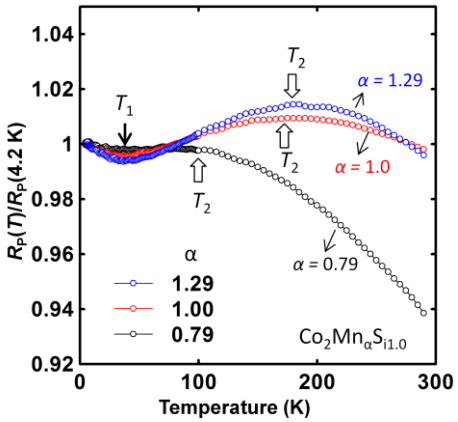

Fig. 1. T dependence of R_P for MgO-buffered CMS MTJs with α = 0.79, 1.0, and 1.29 in $Co_2Mn_\alpha Si_{1.0}$ electrodes.

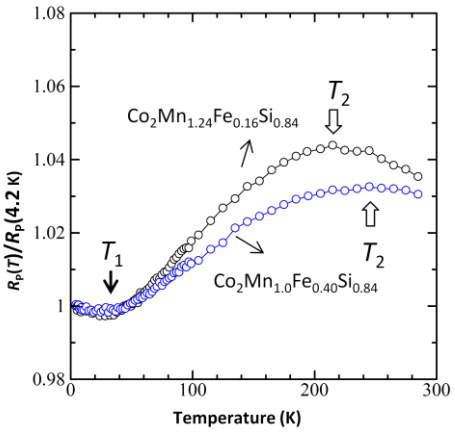

Fig. 2. T dependence of R_P for CoFe-buffered CMFS MTJs with $Co_2Mn_{1.24}Fe_{0.16}Si_{0.84}$ and $Co_2Mn_{1.0}Fe_{0.40}Si_{0.84}$ electrodes.

Reference

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