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Influence of interface termination layer on temperature dependence of tunneling magnetoresistance of Co_2MnSi/MgO-based magnetic tunnel junctions

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We have recently demonstrated giant tunneling magnetoresistance (TMR) ratios (β) of up to 1995% at 4.2 K and up to 354% at 290 K for epitaxial Co_2MnSi (CMS)/MgO/CMS magnetic tunnel junctions (MTJs).[1] If we use parameter $\gamma = \beta(4.2\ K)/\beta(290\ K)$ to represent the degree of temperature (T) dependence of β, γ for the CMS MTJs that showed a high β of 1910% at 4.2 K was 5.4, resulting in a lower β of 354% at 290 K than the 604% at RT for a CoFeB/MgO/CoFeB MTJ that exhibited a much lower β of 1144% at 5 K (γ = 1.9).[2] The purpose of the present study was to investigate the possible origin of the strong T dependence of β of CMS/MgO-based MTJs. In this study, we prepared epitaxial MTJs having a CMS electrode in combination with a $Co_{50}Fe_{50}$ (CoFe) electrode and a MgO barrier and prepared three kinds of MTJ layer structures on MgO(001) substrates: (1) MTJ-1: (from the lower side) CoFe/MgO/CMS (3 nm), (2) MTJ-2: CoFe-buffer/CMS (3 nm)/MgO/CoFe (3 nm), and (3) MTJ-3: CoFe/MgO/ultrathin CoFe inserted layer (1.1 nm)/CMS (3 nm). We used Mn-rich CMS electrodes[3,4] having a film composition of $Co_2Mn_{1.29}Si_{1.0}$ for MTJ-1 and a film composition of $Co_2Mn_{1.35}Si_{0.88}$ for MTJ-2 and MTJ-3.

Figure 1 shows β as a function of T from 4.2 K to 290 K for these three kinds of MTJs. We first compare the T dependence of β for MTJ-1 and MTJ-2. It has been experimentally shown that harmful Co_{Mn} antisites are strongly suppressed for Mn-rich CMS electrodes,[1,3,4] suggesting that the bare tunneling spin polarizations that are determined by the majority- and minority-spin density of states at the Fermi level are close for the Mn-rich CMS electrodes having the almost identical film compositions used in this study. Then, the higher β value at 4.2 K for MTJ-1 than MTJ-2 has been attributed to the enhanced coherent tunneling contribution arising from the larger misfit dislocation spacing for MTJ-1.[4] According to the theory by Zhang *et al.*,[5] if the bare tunneling spin polarizations and the properties of thermally excited magnons are close for MTJ-1 and MTJ-2, γ should be close. Note that, however, MTJ-1 showed much stronger T dependence of β (γ = 3.3) than MTJ-2 (γ =2.6), resulting in a slightly lower β of 311% at 290 K for MTJ-1 than the 340% for MTJ-2 although the latter exhibited a markedly lower β at 4.2 K.

To clarify the origin of the difference in the T dependence of β, we investigated the interface structure of these MTJs by high-resolution Z-contrasted scanning transmission electron microscopy. We found that the termination layer at the CMS/MgO interface for MTJ-2 mainly consisted of MnMn/O termination layer[6] which has been theoretically predicted to be thermodynamically unstable.[7] On the other hand, we found that the termination layer for MTJ-1 consisted of coexisting MnMn/O and CoCo/O terminations with one monolayer steps probably caused by the very flat interface in MTJ-1. Given the observation of CoCo/O terminations coexisted with MnMn/O terminations, we attribute the stronger T dependence of MTJ-1 to the theoretically predicted strong spin fluctuation of Co atoms in the Co plane of CMS in the interfacial region with a MgO barrier.[8]

To further evidence this understanding, we prepared MTJ-3 in which an ultrathin CoFe layer (1.1 nm) was inserted between the MgO barrier and the upper CMS electrode. Most importantly, the T dependence of β was significantly weakened (γ =2.5). This resulted in a much higher β of 448% at 290 K. The markedly enhanced β at RT for MTJ-3 can be explained by the elimination of the CMS/MgO interface, including in particular, the CoCo/O termination, observed in MTJ-1.

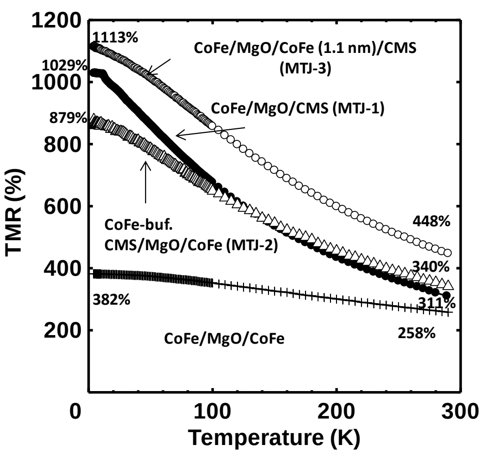

Fig. 1. TMR ratios as a function of T from 4.2 K to 290 K for a CoFe/MgO/CMS (MTJ-1), a CoFe-buffered CMS/MgO/CoFe (MTJ-2) and a CoFe/MgO/CoFe (1.1 nm)/CMS (MTJ-3). For comparison, TMR ratios as a function of T for an identically fabricated CoFe/MgO/CoFe are plotted.

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