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Highly spin-polarized tunneling in Heusler-alloy-based magnetic tunnel junctions with a Co_2MnSi upper electrode and a MgO barrier

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1. Introduction

One Co-based Heusler alloy in particular, Co_2MnSi (CMS), has attracted much interest as a promising ferromagnetic electrode material for spintronic devices [1－5] because of its theoretically predicted half-metallic nature and its high Curie temperature of 985 K. We recently fabricated fully epitaxial CMS/MgO/CMS magnetic tunnel junctions (MTJs) with various Mn compositions α ($0.67 \leq \alpha \leq 1.38$) in $Co_2Mn_\alpha Si$ electrodes. With a Mn-rich composition $\alpha = 1.29$ in $Co_2Mn_\alpha Si$ electrodes, the MTJs exhibited high tunnel magnetoresistance (TMR) ratios of up to 1135% at 4.2 K and 236% at room temperature (RT) [6, 7]. The higher TMR ratios for α above 1.0 were explained by a decreased density of minority-spin in-gap states around the Fermi level (E_F) caused by the suppression of harmful Co_{Mn} antisites [6－8]. However, the reason for the low TMR ratio of 236% at RT in contrast to the high TMR ratio of 1135% at 4.2 K is still not fully understood. The purpose of the present study is to further investigate the key factors influencing the TMR characteristics of MTJs with potentially half-metallic CMS electrodes and a MgO barrier. To do this, we prepared CMS-based MTJs with a simplified layer structure in which a CMS electrode was used as one of the electrodes, i.e., the upper electrode in this study.

2. Experimental

The fabricated MTJ layer structure was as follows: MgO buffer (10 nm)/$Co_{50}Fe_{50}$ (CoFe) (30 nm)/MgO barrier (2-3 nm)/CMS (3 nm)/Ru (0.8 nm)/$Co_{90}Fe_{10}$ (2 nm)/IrMn (10 nm)/Ru cap (5 nm), grown on a single-crystalline MgO(001) substrate. The CMS upper electrodes were deposited by magnetron co-sputtering from a nearly stoichiometric CMS target and a Mn target to systematically vary α in the $Co_2Mn_\alpha Si$ electrodes. The film composition of the prepared CMS electrodes was determined to be $Co_2Mn_\alpha Si_\gamma$ ($\gamma = 1.0 \pm 0.06$) by inductively coupled plasma analysis.

3. Results and discussion

Figure 1 shows typical magnetoresistance curves at RT and 4.2 K for a fabricated fully epitaxial, exchange-biased CoFe/MgO/CMS MTJ with $\alpha = 1.29$ in the $Co_2Mn_\alpha Si$ upper electrode. The junction size was 10 μm × 10 μm. The bias voltages were 1 mV at 4.2 K and 5 mV at RT. The MTJ exhibited clear exchange-biased TMR characteristics with high TMR ratios of 1049% at 4.2 K and 335% at RT. The value at RT is significantly higher than our previously reported value of 236% at RT for MgO-buffered CMS/MgO/CMS MTJs with $\alpha = 1.29$ in the $Co_2Mn_\alpha Si$ electrodes [6, 7]. Figure 2 shows the α dependence of the TMR ratios at 4.2 K and RT for fully epitaxial CoFe/MgO/CMS MTJs with various α in the $Co_2Mn_\alpha Si$ upper electrodes. The TMR ratio at 4.2 K increased with increasing α from 0.80 to 1.29. Notably, the TMR ratio at 4.2 K increased even in the α range beyond 1.0, where α of 1.0 corresponds to an almost stoichiometric film composition of CMS. This feature is similar to that obtained for the MgO-buffered CMS/MgO/CMS MTJs [6, 7]. The high TMR ratio of 1049% at 4.2 K was obtained for α of 1.29. The TMR ratio at RT also increased with increasing α from 0.80 to 1.13 but was almost independent of α with increasing α from 1.13 to 1.38.

The higher TMR ratio of 335% at RT for CoFe/MgO/CMS MTJs compared to that of 236% at RT for MgO-buffered CMS/MgO/CMS MTJs indicates the reduced tunnel conductance for the antiparallel magnetization alignment in the CoFe/MgO/CMS MTJs at RT. This is probably due to a reduced density of minority-spin interface states at the interface between the lower electrode and MgO barrier in the CoFe/MgO/CMS MTJs. Another reason for the increased TMR ratio at RT for CoFe/MgO/CMS MTJs would be the improved structural quality of the MgO barrier deposited on the CoFe lower electrode and that of the CMS upper electrode in the CoFe/MgO/CMS trilayers. The improved structural quality probably results in a reduced density of minority-spin in-gap states in the interior region of the upper CMS electrode and enhanced coherent tunneling contribution. The fact that the TMR ratio at RT is almost completely independent of α beyond 1.13 suggests that minority-spin interface states at the upper interface along with thermally excited magnons play a critical role in spin-dependent tunneling at RT. The marked increase in the TMR ratio with increasing α up to 1.29 at 4.2 K suggests that the role of thermally excited magnons is suppressed and that the minority-spin in-gap states in the interior region of the upper CMS electrode play a critical role at 4.2 K.

4. Summary

High tunnel magnetoresistance ratios of 1049% at 4.2 K and 335% at RT were demonstrated for Heusler-alloy-based magnetic tunnel junctions with a Co_2MnSi upper electrode and a MgO barrier. The key factors influencing the spin-dependent tunneling characteristics were discussed.

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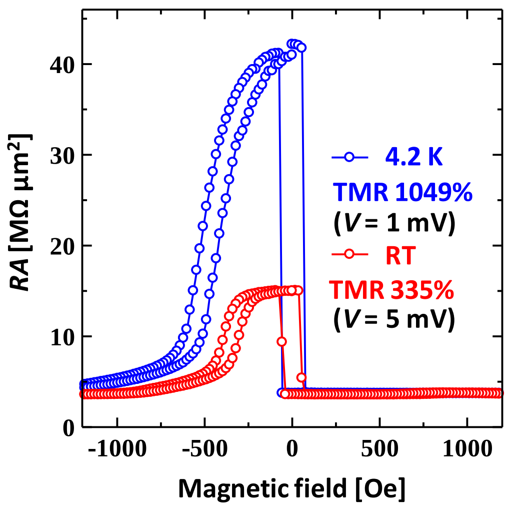

Fig. 1. TMR curves at 4.2 K and RT for a $Co_{50}Fe_{50}$/MgO/CMS MTJ with a Mn composition α = 1.29 in the $Co_2Mn_\alpha Si$ upper electrode.

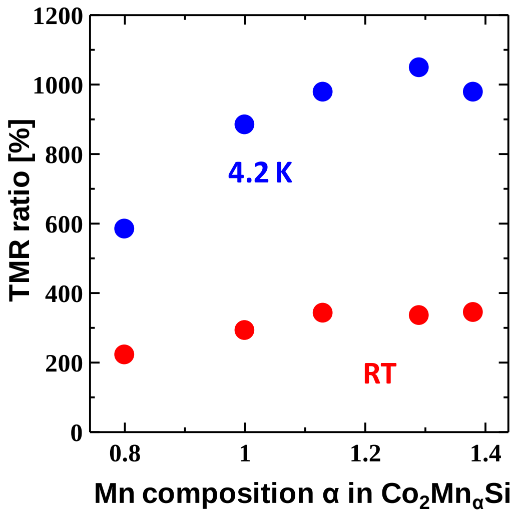

Fig. 2. TMR ratios at 4.2 K and RT for fully epitaxial $Co_{50}Fe_{50}$/MgO/CMS MTJs as a function of Mn composition α in the $Co_2Mn_\alpha Si$ upper electrodes.