Mn-composition dependence of magnetoresistance ratio of Co$_2$MnSi-based giant magneto-resistance devices

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Co-based Heusler alloy thin films have been extensively studied as a promising ferromagnetic electrode material for spintronic devices, including magnetic tunnel junctions (MTJs) and giant magnetoresistance (GMR) devices, and for spin injection into semiconductors. We have shown that harmful defects in Heusler alloy thin films of Co$_2$MnSi (CMS), Co$_x$(Mn,Fe)Si (CMFS), and Co$_2$MnGe can be suppressed by appropriately controlling the film composition, i.e., Co$_{sto}$ antisites detrimental to the half-metallicity can be suppressed by adding an excess Mn, and have demonstrated high tunneling magnetoresistance (TMR) ratios of up to 1995% (354%) at 4.2 K (290 K) in CMS/MgO/CMS MTJs having Mn-rich CMS electrodes, and up to 2611% (429%) at 4.2 K (290 K) in CMFS/MgO/CMFS MTJs having (Mn+Fe)-rich CMS electrodes. The purpose of the present study was to clarify the influence of off-stoichiometry for CMS films on the MR ratio of GMR devices. To do this, we fabricated current-perpendicular-to-plane (CPP) GMR devices having CMS electrodes with various Mn compositions, $\alpha$, and an Ag spacer, and investigated the influence of $\alpha$ on the magnetoresistance (MR) characteristics.

The fabricated GMR layer structures were as follows: (from the substrate side) MgO buffer (10 nm)/CoFe seed (10)/Ag buffer (100)/CoFe buffer (10)/CMS lower electrode (3)/CoFe (1.1)/Ag spacer (5)/CoFe (1.1)/CMS upper electrode (3)/CoFe (1.1)/IrMn (10)/Ru cap (5) with Co$_x$Mn$_{1-\alpha}$Si$_{0.82}$ electrodes, grown on MgO(001) substrates. The preparation procedure of CMS electrodes with various values of $\alpha$ was the same as for the CMS/MgO MTJs. Just after the deposition of CMS upper electrodes, the layer structure was in-situ annealed at 550 °C. We fabricated GMR devices with the nominal junction sizes ranging from 70 × 120 nm$^2$ to 400 × 640 nm$^2$ by using EB lithography and Ar ion milling. The MR characteristics were measured using a dc four-probe method at room temperature.

Figure 1 shows a typical MR curve for a GMR device having Co$_{1.45}$Mn$_{0.55}$Si$_{0.82}$ electrodes. It showed clear MR characteristics with a MR ratio of approximately 17%. The values of $R_P/A$ and $\Delta R/A$ were 52 mΩ·μm$^{-2}$ and 8.4 mΩ·μm$^{-2}$, respectively, where $\Delta R = R_{AP} - R_P$, $R_{AP}$ is the junction resistance for parallel (antiparallel) configuration, and $A$ is the nominal junction size. Figure 2 shows MR ratios as a function of Mn composition, $\alpha$. The MR ratio increased with increasing $\alpha$ from 9% for Mn-deficient $\alpha = 0.62$ to 17% for Mn-rich $\alpha = 1.45$. This result suggests a continuous increase in the spin polarization with increasing $\alpha$ from a Mn-deficient to a Mn-rich composition. Thus, it is demonstrated that enhancing the half-metallicity of CMS by appropriate control of the film composition toward a Mn-rich one is also highly effective in CMS-based GMR devices as in the MTJs.

References