Perpendicular Magnetic Tunnel Junctions with L1₀-MnGa/FeCo Bilayer Electrodes with Tunable Interfacial Exchange Coupling

Q. L. Ma¹, S. Mizukami¹, X. M. Zhang¹, Y. Ando², T. Miyazaki¹

¹ WPI Advanced Institute for Materials Research, Tohoku University, Katahira 2-1-1, 980-8577, Sendai, Japan
² Department of Applied Physics, Graduate School of Engineering, Tohoku University, Aoba 6-6-05, 980-8579, Sendai, Japan

Phone: +81-22-217-6003, E-mail: qinli-ma@wpi-aimr.tohoku.ac.jp

Abstract
Tunnel magneto-resistance (TMR) effect in perpendicular magnetic tunnel junctions (p-MTJs) based on the coupled bilayers of L1₀ MnGa/Fe₁ₓCo₀ was studied with different composition x. Change from the normal TMR curves to inverted TMR ones was observed at x of about 0.2, which was attributed to the sign change of interfacial exchange coupling between L1₀ MnGa and Fe₁ₓCo₀. The maximum TMR ratio was 60% (120%) at 300K (5K) with x = 0.6.

1. Introduction
Nowadays, the most promising spintronics application is a Gbit class magnetoresistive random access memory using perpendicular magnetic tunnel junctions (p-MTJs) and spin-transfer-torque writing (STT-MRAM) [1]. STT-MRAM is called the universal memory applicable to working as well as cash memory, such as DRAM and SRAM, respectively, because STT-MRAM is fast and high density comparable to them. Unique feature of STT-MRAM is non-volatility, which decreases power consumption of electronic devices drastically. However, there is still a lack of a key spintronics material for p-MTJ in STT-MRAM with over 10 Gbit, which must have a high perpendicular magnetic anisotropy (PMA) over 10 Merg/cm² and a low Gilbert damping constant less than 0.01 as well as a large spin polarization to obtain high tunnel magneto-resistance (TMR) ratio more than 100%.

A class of tetragonal Mn-based Heusler alloys is one of the candidates for PMA material with high PMA constant. Mn-Ga alloys with L1₀ and DO₂₂ structures are of the most interests, because they have a unique combination of large PMA more than 10 Merg/cm² and low Gilbert damping constant of 0.008 [2-4]. However, TMR of MnGa/MgO MTJs is low [5], probably because the alloys have no fully spin-polarized Δ₁ band [6]. In this work, TMR effect in p-MTJs based on the coupled bilayers of L1₀-MnGa/Fe₁ₓCo₀ was studied with different composition x to obtain high TMR ratio with maintaining perpendicular magnetization [7-9].

2. Experimental Methods
The films were fabricated using an ultrahigh-vacuum sputtering system with a base pressure less than 1 × 10⁻⁷ Pa. The MnGa (30 nm)/Fe₁ₓCo₀(1.5 nm)/MgO (2.2 nm)/Fe₁ₓCo₀(0.1 nm)/Co₂₀Fe₉₀B₂₀ (1.2 nm) multilayers were deposited on Cr-buffered MgO(001) single-crystal substrate, as schematically shown in Fig. 1. The composition of MnGa is Mn₃₋ₓGaₓ and the perpendicularly magnetized CoFeB layer [10] is used as a counter electrode. All of the layers were deposited at room temperature and annealed in situ after the deposition of Cr and MnGa at 700°C and 500°C, respectively. The Fe₁ₓCo₀ films were deposited by co-sputtering of Fe and Co elemental targets at a controlled rate to form alloys with a different composition. In situ annealing was performed after deposition of the Fe₁ₓCo₀ layer at 350°C for 30 min. The junctions were fabricated with a lateral size ranging from 10 × 10 to 100 × 100 μm² using a conventional UV lithography combined with Ar-ion etching. Then, the MTJs were annealed in vacuum at 300°C for 10 min. Spin-dependent transport properties were measured using the four-probe technique with maximum applying magnetic field of 6 T parallel to a film normal.

3. Experimental Results and Discussions
Figures 2 show TMR curves for the MTJs with different compositions x for Fe₁ₓCo₀, measured at 300 K. The MTJ with x = 0.2 shows the normal TMR curve [Fig. 2(a)], whereas the MTJ with x = 0.6 shows the inverted TMR curve [Fig. 2(b)]. This inverted curve can be explained by the magnetization process of the MnGa/FeCo bilayer with relatively large anti-ferromagnetic interfacial exchange coupling between MnGa and FeCo. In the low magnetic field regime, the magnetization of thin FeCo layer can be anti-parallel to that of MnGa layer when the anti-ferromagnetic interfacial exchange coupling is operative. Thus, the MTJs show low resistance state when the magnetization of MnGa is anti-parallel to that of CoFeB counter electrode. When the magnetic field overcomes the coercivity of MnGa, both magnetizations of MnGa and CoFe reverse with keeping anti-parallel alignment, thus the MTJ shows high resistance states. In the regime of magnetic field higher than exchange coupling field, magnetization of the thin FeCo layer gradually rotates so as to be parallel to the applied magnetic field direction as well as that of CoFeB, and then the resistance of MTJs decreases.

Figure 3 shows the composition of x dependence of TMR ratio at 300 K and 5 K. The MR shows a minimum
value when $x = 0.2$ and shows the maximum at $x = 0.6$. It has been reported that the FeCo alloy composition dependence of the TMR ratio for in-plane magnetized FeCo/MgO/FeCo and CoFeB/MgO/CoFeB MTJs shows a maximum at Co content of 25% [11,12], which is distinct from that observed in this study. The minimum TMR ratio at $x = 0.2$ is attributed to the sign change of interfacial exchange from positive (ferromagnetic) to negative (anti-ferromagnetic). The perpendicular magnetization of the FeCo layer originates from the coupling and the PMA of MnGa, smaller coupling strength causes a larger in-plane component of FeCo magnetization. Thus, a low MR ratio when $x$ is equal to 0.2 may be related to an incomplete anti-parallel configuration owing to the small coupling. On the other hand, the maximum TMR ratio was found to be 60% (120%) at 300 K at $x = 0.6$, this probably originates from the physical properties of FeCo/MgO.

3. Conclusions

TMR effect in p-MTJs using the L1$_0$-MnGa/FeCo bilayers was studied with different composition of FeCo. The MTJ with FeCo exhibits a transition from a normal TMR curve to an inverted TMR one when the Co content of about 20%, which was attributed to the sign change of interfacial exchange coupling between L1$_0$-MnGa and FeCo. The maximum TMR ratio of 60% at 300 K and 120% at 5 K were obtained with the anti-ferromagnetically coupled MnGa/FeCo bilayer. These values are the highest TMR ratios in MnGa-based MTJs.

Acknowledgements

This work was partly supported by the Strategic Japanese-German Cooperative Program ASPIMAT (JST), Grant-in-Aid for Scientific Research (No. 25600070), and the Asahi Glass Foundation. Q. M thanks to the fusion research grant of WPI-AIMR.

References


Fig. 1 Schematic illustration of stacking structure of perpendicular magnetic tunnel junctions fabricated.

Fig. 2 Tunnel magnetoresistance curves for MnGa/Fe$_{1-x}$Co$_x$/MgO/CoFeB junctions with $x$ of 0.2 (a) and 0.6 (b).

Fig. 3 Tunnel magnetoresistance (TMR) ratio for MnGa/Fe$_{1-x}$Co$_x$/MgO/CoFeB junctions measured at 300 K and 5 K as a function of Fe$_{1-x}$Co$_x$ composition $x$. 