Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp442-443

Perpendicular Magnetic Tunnel Junctions with $L1_0$-MnGa/FeCo Bilayer Electrodes with Tunable Interfacial Exchange Coupling

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Abstract

Tunnel magneto-resistance (TMR) effect in perpendicular magnetic tunnel junctions (p-MTJs) based on the coupled bilayers of $L1_0$ MnGa/$Fe_{1-x}Co_x$ 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 $L1_0$ MnGa and $Fe_{1-x}Co_x$. The maximum TMR ratio was 60% (120%) at 300K (5 K) 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 $Merg/cm^3$ 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 the candidates for PMA material with high PMA constant. Mn-Ga alloys with $L1_0$ and $D0_{22}$ structures are of the most interests, because they have a unique combination of large PMA more than 10 $Merg/cm^3$ 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 Δ_1 band [6]. In this work, TMR effect in p-MTJs based on the coupled bilayers of $L1_0$-MnGa/$Fe_{1-x}Co_x$ 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)/$Fe_{1-x}Co_x$(1.5 nm)/MgO (2.2 nm)/ $Fe_{1-x}Co_x$(0.1 nm)/$Co_{20}Fe_{60}B_{20}$ (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 $Mn_{62}Ga_{38}$, 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 $Fe_{1-x}Co_x$ 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 $Fe_{1-x}Co_x$ layer at 350°C for 30 min. The junctions were fabricated with a lateral size ranging from 10 × 10 to 100 × 100 μm^2 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 $Fe_{1-x}Co_x$ 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 (5 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 curves 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 ratiso 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 ASPIMATT (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.

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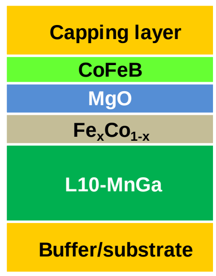

Fig. 1 Schematic illustration of stacking structure of perpendicular magnetic tunnel junctions fabricated.

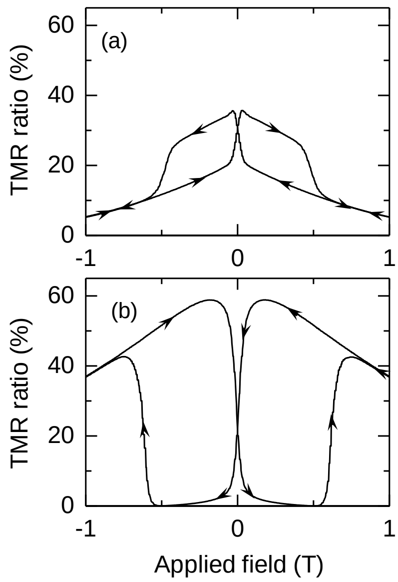

Fig. 2 Tunnel magnetoresistance curves for MnGa/Fe$_{1-x}$Co$_x$/MgO/CoFeB junctions with x of 0.2 (a) and 0.6 (b).

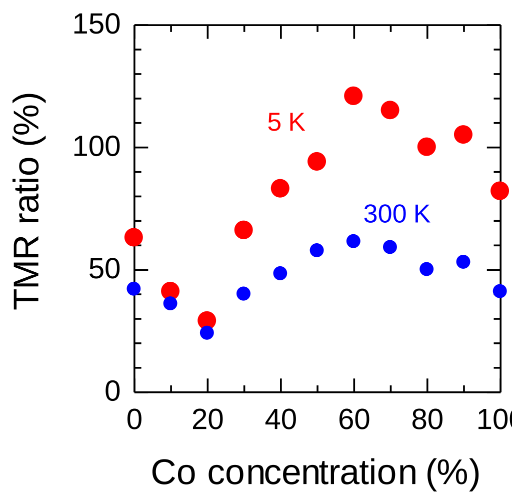

Fig. 3 Tunnel magnetoresistance (TMR) ratio for MnGa/Fe$_{1-x}$Co$_x$/MgO/CoFeB junctions measured at 300 K and 5 K as a function of Fe$_{1-x}$Co$_x$ composition x.