Development of CPP-GMR sensors with reduced layer thickness and large magnetoresistive outputs

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I. INTRODUCTION

The energy assisted magnetic recording technology realizes smaller magnetic recording bits. Accordingly, the dimension of read sensor has to be shrunk for spatial resolution of reading for the bits, therefore, reducing the resistance-area product (*RA*) of read sensor film is the critical issue. The optimal *RA* value for the read sensor for 2 $Tbit/in^2$ has been predicted to be ~0.1 Ω μm^2, [1] which is very challenging for the current tunnel magnetoresistance sensors. All-metallic current-perpendicular-to-plane giant magnetoresistance (CPP-GMR) devices using highly spin-polarized Co-based Heusler alloys is promising for the read sensors with ultralow *RA* ~0.05 Ω μm^2, [2] however the CPP-GMR readers have to solve the following items. (a) The sensor thickness has to be reduced to ≲20 nm, and (b) the sensor output has to be improved. For (a), a thin (a few nm) polycrystalline Heusler alloy films with a high spin polarization have to be fabricated under a limited annealing temperature (~300 °C in the current reader manufacturing process). For (b), a hybrid spacer structure of metal/conductive oxide (*e.g.* Ag/InZnO (IZO)) has been reported to be effective. [3]

II. EXPERIMENTAL PROCEDURES

CPP-GMR devices with polycrystalline films were deposited by magnetron sputtering on polycrystalline Cu bottom lead electrode at room temperature. Two types of device structure were fabricated; a standard spin-valve and a pseudo spin-valve (PSV). For the ferromagnetic Heusler alloy layers, $Co_2(Mn_{0.6}Fe_{0.4})Ge$ (CMFG) was used. [4] $Ag_{90}Sn_{10}$, AgSn/InZnO, AgInZnO were used for spacer layers. The CPP-GMR films were annealed at 280 °C or 300 °C and micro-fabricated to pillar devices with circular and elliptical shapes.

III. RESULTS and DISCUSSION

First, we studied the effect of the CMFG thickness on the MR ratio of the PSV devices with bottom-lead/ Ta(2)/Ru(2)/CoFe(0.5)/CoFeBTa(0.6)/CMFG(0-5)/CoFe(0.4)/AgSn(3.5)/CoFe(0.4)/CMFG(5)/CoFe(1)/Ru (thickness in nm) cap structure annealed at 300 °C. As shown in Fig. 1, the MR ratio keeps almost constant between 3 nm and 5 nm, and decreases below 2-3 nm. This indicates that the spin diffusion length of the CMFG film is very short, thus the bulk spin-dependent scattering of CMFG contributes to the CPP-GMR only within ~2 nm of the layer. This feature is practically important because the CMFG layer can be reduced down to 2-3 nm without reducing the MR ratio.

Next, we fabricated spin-valve devices as shown in Figs. 2(a) and (b). We compared the two kinds of spacer layer: AgSn(3.5 nm) as a standard metallic spacer and AgSn(0.4 nm)/IZO(1.3-1.85 nm). The spin-valve structure shown in Fig. 2(a) (Type 1 with the total sensor thickness of ~30 nm) with a AgSn spacer layer showed *RA* ~0.04 Ω μm^2 and $\Delta R/R$ ~14% as shown in Fig. 2(c). By using the AgSn/IZO spacer layers, both *RA* and $\Delta R/R$ increased. The highest $\Delta R/R$ ~30% was achieved by the AgSn(0.4)/IZO(1.7) spacer at *RA* ~0.1 Ω μm^2. [5] The maximum voltage output of the device with the AgSn/IZO spacer was 6.2 mV for a sensor utilization of 33%, whereas that with the AgSn spacer was only 1.2 mV. It should be noted that the *RA* and $\Delta R/R$ values satisfy their requirements for 2 $Tbit/in^2$ [1] (indicated by the gray zone in Fig. 2(c)). However, the sensor thickness of 30 nm is too thick for the required shield-to-shield spacing for 2 $Tbit/in^2$, which has been predicted to be 20 nm. [1] A spin-valve structure with a reduced total thickness of 22.5 nm was also fabricated (Type 2 shown in Fig. 2(b)). By reducing the CMFG thickness from the reference layer (from 3 nm to 2 nm) and the free layer (from 4 nm to 3 nm), $\Delta R/R$ decreased from ~30% to ~20%, which marginally satisfies the requirement for 2 $Tbit/in^2$.

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Further $\Delta R/R$ improvements were realized by a new AgInZnO (AIZO) spacer co-deposited from Ag and InZnO targets. The thickness of the AIZO layer was fixed to 1.2 nm and the nominal concentration of Ag was controlled between 20 at. % and 36 at. %. PSV devices with CMFG(5 nm) films for both free layers were used. As shown in Fig. 3(a), *RA* and $\Delta R/R$ of the PSV devices with the AIZO spacer increased with decreasing Ag concentration in the AIZO spacer layer. $\Delta R/R$ up to 50% at *RA* ~0.08 Ω μm^2 were obtained by the AIZO spacer with a Ag 29 at. %, which satisfies the predicted *RA*-$\Delta R/R$ requirement for 5 Tbit/in^2. [1] The detailed microstructure characterizations of the PSV film with the AIZO spacer were carried out.

We investigated the PSV devices as a *scissors sensor*, where the magnetizations of the two free layers rotate responding to external magnetic field. We tested our device with $\Delta R/R$ = 45% at *RA* = 0.08 Ω μm^2 as a scissors sensor by applying external magnetic field parallel to the minor axis of the elliptical pillars (120 nm×70 nm). Fig. 3(b) shows *H*-ΔV transfer curve at various bias current densities. A magnetization destabilization by spin transfer torque was observed in high resistance (near anti-parallel) state under a high J_{bias} ~1×10^8 A/cm^2. However, in the intermediate magnetization configuration a stable linear response regime was obtained with a large ΔV ~16 mV.

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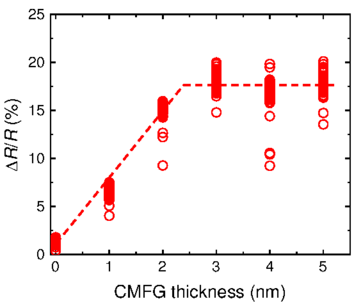

Fig. 1 The dependence of $\Delta R/R$ on the CMFG ferromagnetic layer thickness.

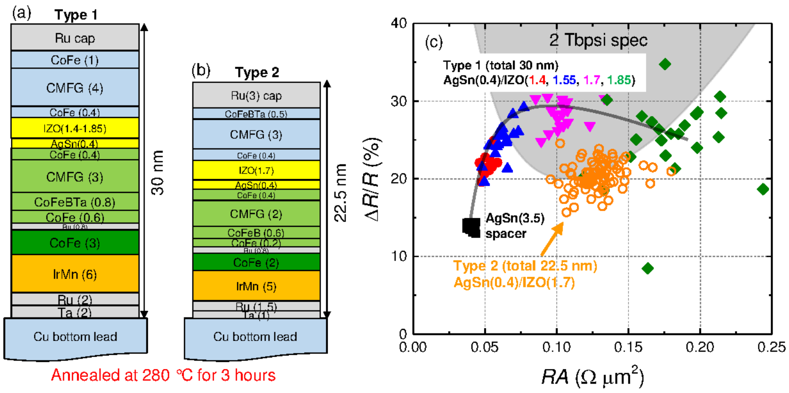

Fig. 2 (a) and (b) Spin-valve layer structures and (c) $\Delta R/R$ *vs. RA* of the spin-valve sensors with AgSn and Ag/IZO spacers. The gray zone is the required $\Delta R/R$ *vs. RA* for 2 Tbit/in^2 by Ref. [1].

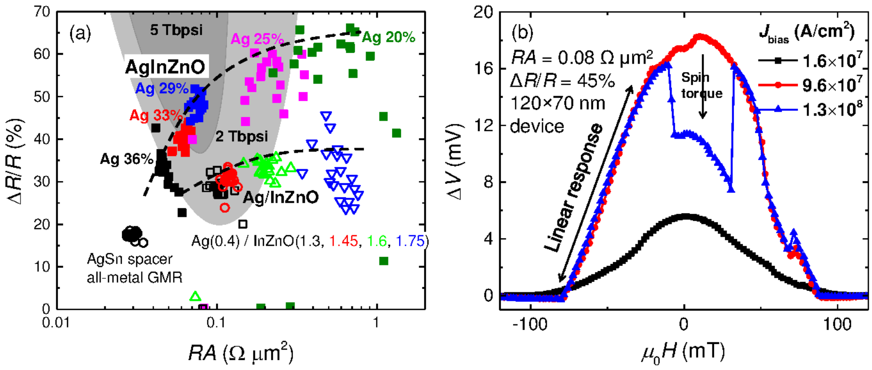

Fig. 3 (a) $\Delta R/R$ *vs. RA* of PSV devices with AIZO spacer layers. For comparison, the data for Ag/IZO bilayer and AgSn spacer layers are also plotted. (b) Voltage output transfer curve of the PSV device as a scissors sensor under various bias current density (J_{bias}) up to 1.3×10^8 A/cm^2.