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Co/Pt Multilayer Based Reference Layer in Magnetic Tunnel Junctions for Nonvolatile Spintronics VLSIs

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Abstract

We investigated perpendicular CoFeB-MgO magnetic tunnel junctions with Co/Pt multilayer based reference layer. The high thermal stability factor of 284 was obtained under zero applied field in 40 nm–diameter Co/Pt multilayer based reference layer annealed at 350°C. By employing a synthetic ferrimagnetic structure as the reference layer, the shift of the center of minor resistance-magnetic field curves can be suppressed.

1. Introduction

Magnetic tunnel junctions with perpendicular magnetic easy axis (p-MTJs) have attracted much attention as a promising building block in nonvolatile very large scale integrated circuits (VLSIs). CoFeB-MgO p-MTJs have high potential to satisfy both low intrinsic critical current (I_{C0}) for spin transfer torque (STT) switching and high thermal stability factor [$\Delta = E/k_BT$, where E is the energy barrier between parallel (P) and anti-parallel (AP) magnetization configurations, k_B the Boltzmann constant, and T the absolute temperature] [1]. It was recently reported that higher Δ can be obtained by using MgO/CoFeB/Ta/CoFeB/MgO double-interface recording structure while keeping comparable I_{C0} [2]. In connection with realization of high Δ in the recording layer, a higher Δ of reference layer is required in order to achieve stable P and AP magnetization configurations. In addition, further improvement in Δ can be expected by suppressing stray field from reference layer [3,4].

In this work, we investigate MTJ properties in CoFeB-MgO p-MTJs with Co/Pt multilayer based reference layer and report that synthetic ferrimagnetic (SyF) reference layer using Co/Pt multilayer are expected to satisfy the requirements for reference layer at a reduced dimension.

2. Experimental Procedures

All films were deposited on thermally oxidized Si substrate by dc and rf magnetron sputtering at room temperature. Two types of p-MTJs were deposited; one is a p-MTJ consisting of, from the substrate side, [Ta(5)/Pt(5)] buffer/[Co/Pt]$_6$/Co/Ta(0.4)/CoFeB(1.1)/MgO(0.9)/ CoFeB(1.5)/ [Ta(5)/Ru(5)] cap and the other is a p-MTJ consisting of [Ta(5)/Pt(5)] with a Co/Pt multilayer based reference layer buffer/[Co/Pt]$_N$/Co /Ru /[Co/Pt]$_2$/Co /Ta(0.3) /CoFeB(1.0)/ MgO(1)/ CoFeB(1.4)/ [Ta(5)/Ru(5)] cap (in nm). The former has a Co/Pt multilayer based reference layer, and the latter has a synthetic ferrimagnetic reference layer in which the magnetizations of bottom and top Co/Pt multilayers with CoFeB insertion layer are antiferromagnetically coupled through thin Ru spacer layer. The N is the number of Co/Pt bilayers. The thickness of Co, Pt, and Ru layers has been described elsewhere [5,6]. For all the stacks, CoFeB target composition of $Co_{20}Fe_{60}B_{20}$ (in at.%) was used. The stacks were processed into circular MTJs with nominal junction diameter varied from 40 to 80 nm by electron beam lithography and Ar ion milling. The MTJs were annealed at 300 °C and/or 350°C in a vacuum under a perpendicular magnetic field of 0.4 T for 1 h. To measure resistance of the MTJs, dc four-probe method was used.

3. Results and Discussion

Figure 1(a) shows major resistance-magnetic field (R-H) curves of 40 nmϕ p-MTJs with Co/Pt multilayer based reference layer annealed at a temperature T_a = 300°C and 350°C. The R-H curves have clear hysteresis with two R states, reflecting the perpendicular easy axis of recording and reference layers. The TMR ratio and resistance area product RA for the p-MTJs annealed at T_a = 300°C (350°C) are 120% (120%) and 21 Ωμm^2 (22 Ωμm^2), respectively. At T_a = 350°C, R in AP state gradually decreases with increasing H, which result from the tilt of magnetization of CoFeB layer in the reference layer. From the R change, the tilt angle is estimated to be about 30° [5], which can be reduced by optimizing the thicknesses of CoFeB layer and Ta interlayer. Figure 1(b) shows the switching probability P of reference layer as a function of pulse magnetic field H with its duration τ = 1 s for the p-MTJs annealed at 350°C. In the figure, symbols show experimental results and a solid line is a fitted curve following the equation based on Stoner-Wohlfarth model [7],

$$P = 1 - \exp\left[-\frac{\tau}{\tau_0}\exp\left\{-\Delta\left(1 \pm \frac{H - H_S^{Rec}}{H_K^{eff}}\right)^2\right\}\right] . \quad (1)$$

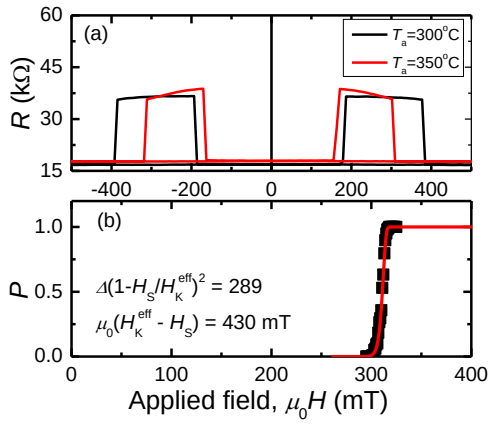

Fig.1 (a) Major *R-H* curves and (b) switching probability of reference layer as a function of applied field for the 40 nmϕ p-MTJs consisting of substrate/[Ta(5)/ Pt(5)] buffer /$[Co/Pt]_6$/ Co/Ta(0.4)/ CoFeB(1.1)/ MgO(0.9)/ CoFeB(1.5) /[Ta(5)/Ru(5)] cap annealed at 300°C and 350°C. In (b), the symbols correspond to experimental results and solid line is a fitted curve according to Eq. (1).

The fitting is done by taking $\Delta(1-H_S^{Rec}/H_K^{eff})^2$ and $(H_K^{eff} - H_S^{Rec})$ as fitting parameters, where H_K^{eff} and H_S^{Rec} are the effective anisotropy field of reference layer and the stray field from recording layer, respectively. τ_0 is the inverse of attempt frequency assumed to be 1 ns. $\Delta(1-H_S^{Rec}/H_K^{eff})^2$ means a thermal stability of reference layer under H = 0. The $\Delta(1-H_S^{Rec}/H_K^{eff})^2$ of 289 and $\mu_0(H_K^{eff} - H_S^{Rec})$ of 430 mT are extracted from the fitting. Thus, high Δ has been realized in the Co/Pt multilayer based reference layer.

To suppress stray field form the reference layer in p-MTJ, we employ Co/Pt multilayer based SyF reference layer. Figure 2 shows the minor *R-H* curves for the 40 nmϕ p-MTJs with different *N*. H_S corresponds to the shift field between the center of minor *R–H* curve and the zero magnetic field, *i.e.*, stray fields from the reference layer. The H_S changes from negative value to positive value with increasing *N*, which suggests that the H_S can be adjusted to zero by optimizing *N*. Figure 3(a) shows the TMR ratio for the CoFeB/MgO p-MTJs as a function of junction size. The TMR ratio was virtually the same within the junction size range studied here. In Fig. 3(b), the $H_S \sim 0$ is realized by adjusting $N = 6$, which results in the bi-stable state at $H = 0$ and the high thermal stability of AP magnetization configuration.

3. Conclusions

The Co/Pt multilayer based reference layer shows high thermal stability. By adjusting the number of Co/Pt bilayers in the synthetic ferrimagnetic (SyF) reference layer, the shift field can be reduced. The Co/Pt multilayer based SyF reference layer has potential to be used in application to nonvolatile spintronics VLSIs in a smaller dimension.

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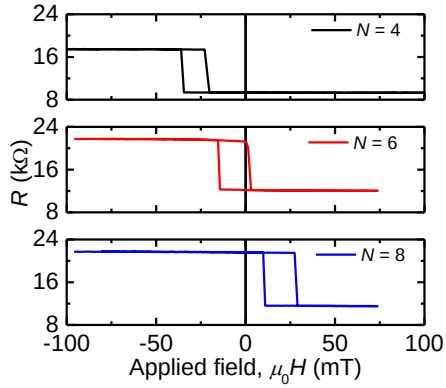

Fig.2 Minor *R-H* curves for the 40 nmϕ p-MTJs consisting of substrate/ [Ta(5) / Pt(5)] buffer / $[Co/Pt]_N$/Co/Ru/ $[Co/Pt]_2$/Co/Ta(0.3)/CoFeB(1.0)/MgO(1)/CoFeB(1.4)/[Ta(5)/Ru(5)] cap. The p-MTJs were annealed at 300°C.

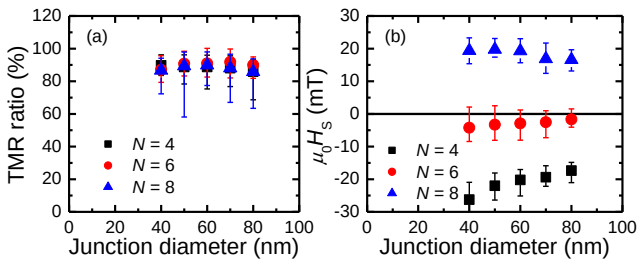

Fig.3 (a) TMR ratio and (b) H_S as a function of junction diameter for the p-MTJs consisting of substrate/ [Ta(5) / Pt(5)] buffer/ $[Co/Pt]_N$ / Co / Ru / $[Co/Pt]_2$/Co/Ta(0.3)/ CoFeB(1.0)/ MgO(1)/CoFeB(1.4)/[Ta(5)/Ru(5)] cap. The p-MTJs were annealed at 300°C.

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