$L1_0$-phase FePd fully perpendicular magnetic tunnel junctions for STT-MRAM application

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I. INTRODUCTION

Spin transfer torque devices using perpendicular magnetic anisotropy (PMA, K_u) materials have attracted much interest for the development of ultra-high-density and ultra-low energy spintronic memory and logic devices [1,2,3]. Recently, the MTJ devices with the interfacial PMA materials have made considerable progress in the application of spin-transfer-torque magnetic random access memory (STT-MRAM). When scaling spintronic devices to commercially sustainable sizes, like 10 nm nodes, the large K_u and low damping constant (α) values are required to realize longer retention time and ultra-low switching current densities. Because of their relatively low K_u (~2-5 Merg/cm^3) and relatively large α (~0.015-0.027) [4,5], they may not fully satisfy the scaling demands needed for next-generation spintronic memory and logic devices. The $L1_0$-FePd bulk PMA material possesses very attractive properties, such as a large K_u (~13-14 Merg/cm^3), a low α (~0.002) [6], which could support node sizes down to 6 nm with a reasonable thickness. In this presentation, the fabrication of the $L1_0$-FePd single layer and the $L1_0$-FePd synthetic antiferromagnetic (SAF) layer will be introduced, also the magnetic and spin-transport properties of the perpendicular MTJs (p-MTJs) with $L1_0$-FePd single layers and $L1_0$-FePd SAF structures will be shown.

II. EXPERIMENTAL DETAILS

The $L1_0$-FePd single layer and SAF structure as well as their p-MTJ stacks were prepared under ultra-high vacuum (base pressure $< 5.0\times10^{-8}$ Torr) with the standard Shamrock magnetron sputtering systems. The FePd thin films and synthetic antiferromagnetic stacks were prepared with a Cr/Pt seed layer by co-sputtering of the Fe and Pd targets. The FePd p-MTJ stacks were patterned using optical lithography and an Ar-ion milling method into micron-sized MTJ pillars with diameters ranging from 4 μm to 20 μm. Subsequently, all MTJ devices were annealed by rapid thermal annealing (RTA) process. The spin-transport properties of these p-MTJs were tested at various temperatures by a four-probe technique using a Dynacool PPMS.

III. RESULTSI AND DISCUSSION

First, we studied the tunnel magnetoresistance (TMR) of $L1_0$-FePd perpendicular magnetic tunnel junctions (p-MTJs) with a FePd free layer and inserted diffusion barrier [7]. The diffusion barriers studied here (Ta and W) were shown to enhance the TMR ratio of the p-MTJs formed using high-temperature annealing, which are necessary for the formation of high quality $L1_0$-FePd film and MgO barrier. The $L1_0$-FePd p-MTJ stack was developed with a FePd free layer with a stack of FePd/X/CoFeB, where X is the diffusion barrier, and patterned into micron-sized MTJ pillars, as shown in Fig. 1(a). The addition of the diffusion barrier was found to greatly enhance the magneto-transport behavior of the $L1_0$-FePd p-MTJ pillars such that those without a diffusion barrier exhibited a negligible TMR ratios (<1.0%), whereas those with a Ta (W) diffusion barrier exhibited TMR ratios of 8.0% (7.0%) at room temperature and 35.0% (46.0%) at 10 K after post-annealing at 350 ^{o}C, as plotted in Figs. 1(a) and 1(c). These results indicate that diffusion barriers could play a crucial role in realizing high TMR ratio in bulk p-MTJs such as those based on FePd and Mn-based PMA materials for spintronic applications.

Secondly, we demonstrated for the first time a $L1_0$-FePd perpendicular SAF structure and a $L1_0$-FePd SAF p-MTJ stack [8]. The $L1_0$-FePd p-SAF structure grown here with a (001) texture possesses a high K_u~10.2 Merg/cm^3 and low net remanent magnetization (~500 emu/cm^3). One of the most important discoveries here is the epitaxial growth of Ruthenium (Ru) spacer with a face-centered-cubic (fcc) phase on the $L1_0$-FePd thin film, which resulted in a large interlayer exchange coupling (IEC) $-J_{iec}$~2.60 erg/cm^2.

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This value is about one order of magnitude larger than that of the $[Co/Pd]_n$ or $[Co/Pt]_n$ p-SAF structures. Moreover, a tunnelling magnetoresistance (TMR) ratio of ~25.0% tested at room temperature (RT) was obtained in the $L1_0$-FePd SAF p-MTJ devices with the $L1_0$-FePd p-SAF layer after post-annealing at 350 ^{o}C. Furthermore, a TMR ratio of ~13% is retained when the post-annealing temperature is increased up to 400 ^{o}C, implying that this kind of the FePd SAF p-MTJs can be integrated into the semiconductor process, as shown in Fig. 2.

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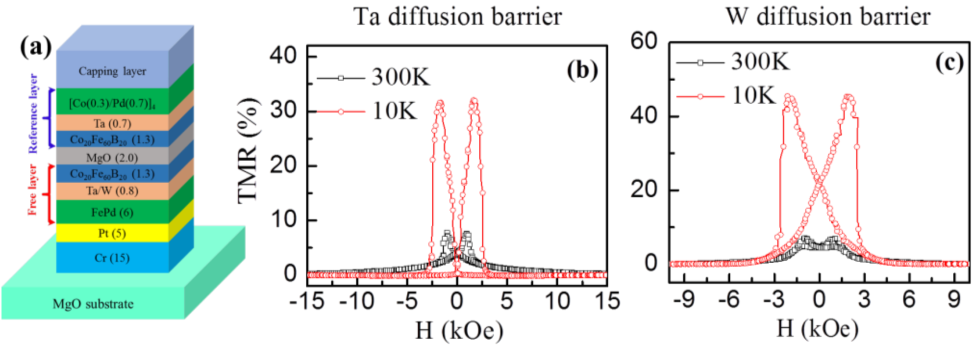

Fig. 1 A schematic illustration of the full FePd perpendicular magnetic tunnel junction stacks with Ta or W diffusion barriers. The FePd free layer with a stack of FePd/X/CoFeB (X=Ta or W) and the $[Co/Pd]_n$ reference layer with a stack of $[Co/Pd]_n$/Ta/CoFeB. (b) and (c) the tunnelling magnetoresistance versa external magnetic field (MR-H) curves measured at 10 K and 300 K of the micron-sized FePd p-MTJ devices with the Ta and W diffusion barriers, respectively. The junctions are annealed by rapid thermal anneal (RTA) at 350 ^{o}C for 30 mins.

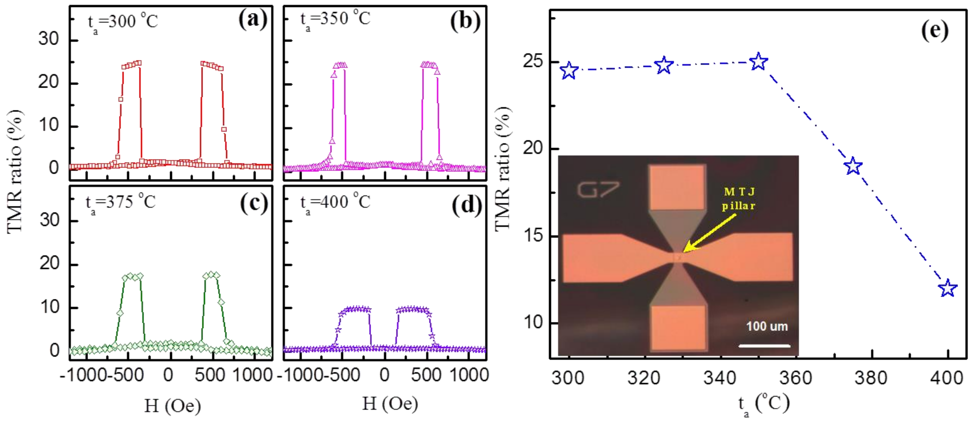

Fig. 2 The tunnelling magnetoresistance versa external magnetic field (MR-H) loops of the $L1_0$-FePd SAF p-MTJ devices post-annealed by RTA at (a) 300 ^{o}C, (b) 350 ^{o}C, (c) 375 ^{o}C and (d) 400 ^{o}C. The testing was carried out at room temperature. The external magnetic field is swapping from -1500 Oe to +1500 Oe along perpendicular plane of devices. (e) The TMR ratio as a function of the post-annealing temperatures of the $L1_0$-FePd SAF p-MTJ devices. The inset is the optical microscopy image of the real $L1_0$-FePd SAF p-MTJ device.