Fabrication of Magnetic Tunnel Junctions with Synthetic Antiferromagnetic Free Layer with Bulk Perpendicular Materials

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As promising candidates for next-generation memory and logic units, magnetic tunnel junction (MTJ)-based spin memory devices demand advanced free layer materials beyond CoFeB that exhibit high thermal stability and low Gilbert damping for sub-10 nm node, energy efficient computing devices. $[Co/Pd]_n$ multilayers is a promising replacement material, owing to its relatively large perpendicular magnetic anisotropy (PMA), moderate Gilbert damping, tunability of magnetic properties with bilayer thickness, and existing industry-compatibility. Among several other candidate materials, $L1_0$ FePd exhibits a very large PMA as well as an ultralow damping constant (~0.007), thus is also attractive [1, 2]. MTJ devices with a synthetic antiferromagnetic (SAF) free layer provide many advantages for spin memory applications, such as low stray field, high thermal stability, and ultrafast switching speed [1]. So far there has been no reporting on the nano-sized MTJs with p-SAF and bulk PMA free layer. One of challenges is the patterning process for those materials, as MTJs can be particularly sensitive to redeposition/shorting during patterning. Here, we report the first experimental results of nano-sized MTJs fabricated with photo/electron beam lithography and Ar^+ ion milling based on SAF free layer materials. The patterning process using a negative electron beam resist is reported here. The free layer of the MTJs are SAF structures consisting of either STT-RAM industry compatible $[Co/Pd]_n$ multilayers or $L1_0$ FePd.

The schematic illustration of the MTJ stacks and the fabrication process is shown in Figure 1. In one embodiment, the free layer is $[Co/Pd]_n$/Ru/Ta/CoFeB. The $[Co/Pd]_n$ multilayer is antiferromagnetically coupled with CoFeB, forming a SAF structure. In another embodiment, the free layer is FePd/Ru/FePd/Ta/CoFeB. The two FePd layers are coupled antiferromagnetically through a Ru spacer. The CoFeB is ferromagnetically coupled with its adjacent FePd layer through a thin Ta spacer. Figure 2(a) shows the STEM element mapping of the Co/Pd-based SAF. The electrode footprint and the SEM image of a resist pillar of this layer stacking structure are additionally shown in Figure 2(b) and its inset, respectively. The pillar size is smaller than 100 nm. Figure 2(c) shows the magnetoresistance versus applied field testing result of this structure. A tunnel magnetoresistance (TMR) ratio of more than 60% at 20 K is achieved. The SEM image of a resist pillar of the FePd-based SAF and the corresponding resistance-field hysteresis loop are shown in Figure 3(a) and 3(b), respectively. A pillar size of about 115 nm was estimated and a TMR ratio of about 6.5% at room temperature was obtained.

References

[1] D. Zhang, C. Sun, Y. Lv, et al., *Phys. Rev. Appl.* **9**, 044028 (2018).

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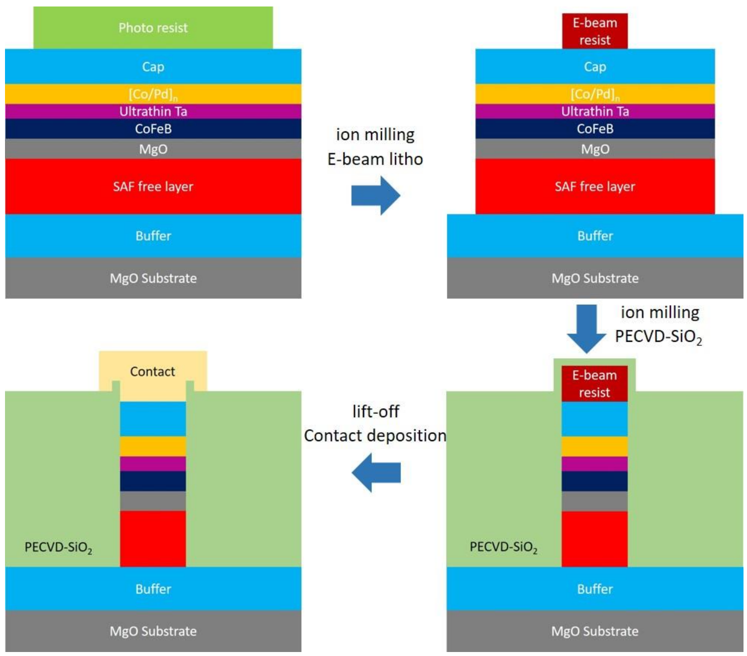

Figure 1: The MTJ stacks and fabrication flow. The free layer is a SAF structure consisting of either $[Co/Pd]_n$ multilayers or $L1_0$ FePd.

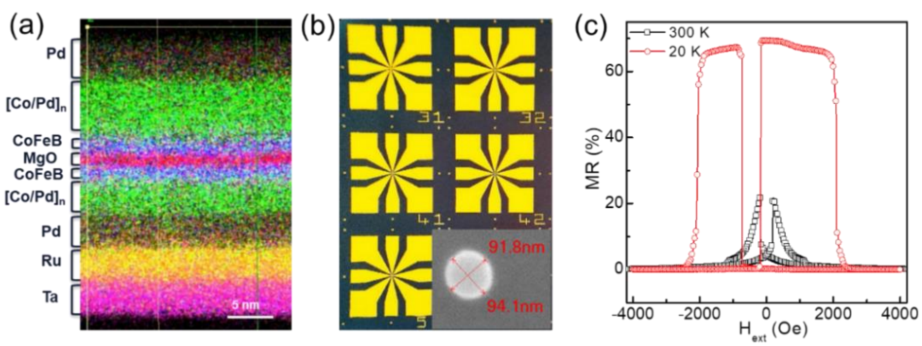

Figure 2: The STEM characterization (a), footprint (b), and (c) testing result of the Co/Pd-based SAF. The inset of (b) is the SEM image of a resist pillar of this stacking structure.

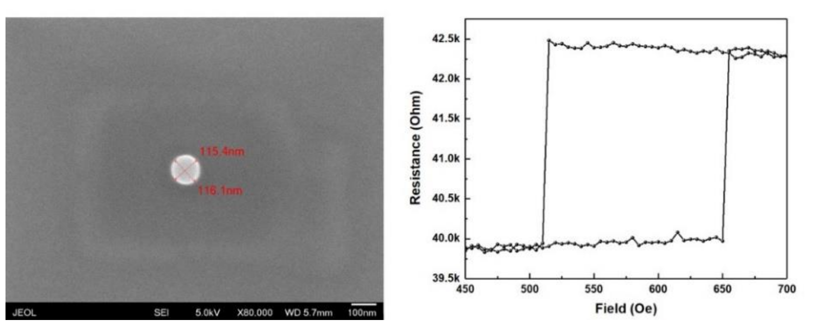

Figure 3: (a) The SEM image of a resist pillar and (b) room temperature resistance-field hysteresis loop of the FePd-based SAF.