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FURTHER TECHNOLOGIES FOR STT-MRAM

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I. 3D Integration Technology for STT-MRAM

Three-dimensional (3D) integration technology based on direct wafer bonding and backside silicon removal processes is a key technology not only for 3D stacking of MTJ cells for ultrahigh-density MRAM but also for integrating epitaxial MTJs with a single-crystal tunnel barrier and a novel magnetic material in MRAM chips during the back end of line (BEOL) process. In this study, for the first time, we aimed to develop a 3D integration technology for perpendicularly-magnetized MTJs (p-MTJs) [1].

A p-MTJ film (poly-crystal in this study) was fabricated on a 6” bare Si wafer by sputtering. On an 8” counter wafer, a lead electrode layer (based on low-resistance Cu-N layers) was stacked. Note that the counter wafer corresponds to a CMOS wafer with copper lines on top in an MRAM application. Tantalum was used for the cap layer both in the p-MTJ and counter wafers. The 6”-p-MTJ and 8”-electrode wafers were bonded by a room-temperature bonding apparatus as shown in Fig. 1. In the HRTEM image of the bonded wafers, the two Ta cap layers are bonded almost perfectly. Next step was the removal of the backside Si in the 6”-p-MTJ wafer by a high-speed (yet damage-less) process. Photograph of the grinded and etched wafer is shown in Fig. 2. Because the backside Si was completely removed, the surface of the wafer is a Ta layer, which was originally the seed layer of the MTJ film. After the 3D process, Spin-transfer-torque (STT) switching properties were studied for p-MTJ nano-pillars (φ = 35 nm). Higher MR ratio (143%) was obtained when 3D process was applied, while STT switching properties changed only slightly. The p-MTJ showed average switching current of 62 μA and average Δ of 98 (i.e., switching efficiency of 1.6).

It can be concluded that the p-MTJ nano-pillars exhibited favorable STT switching properties and no serious degradations after the wafer bonding and silicon removal. STT-MRAM technology incorporating direct wafer bonding and removal of backside silicon will make it possible to integrate epitaxial MTJs with a single-crystal tunnel barrier and novel materials.

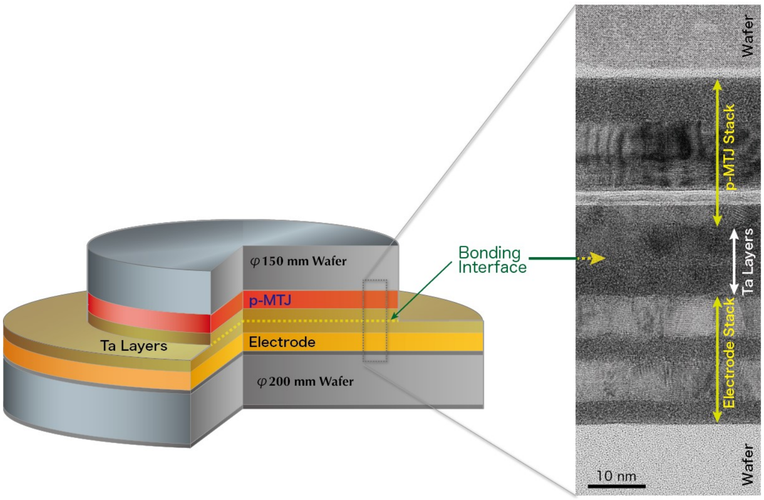

Fig. 1 Schematic illustration of a bonded sample and the HRTEM image of the cross-section around the bonding interface.

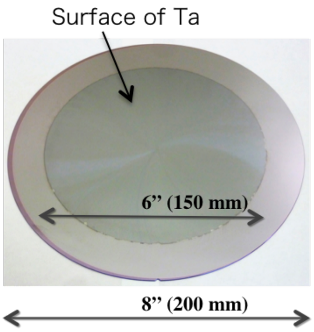

Fig. 2 Photograph of a sample after the Si removal process.

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II. Materials Research on Reference Structure

One of the important properties for STT-MRAM is the stability of the reference layer for stable read/write operations. Recent studies demonstrated perpendicularly magnetized synthetic antiferromagnetic (p-SAF) structures with an even stronger antiferromagnetic (AF) interlayer exchange coupling (IEC) effect: the plot of the IEC coupling energy density (J_{ex}) versus Ru spacer thickness displays oscillations the largest being the first one, which appears at 0.45-0.50 nm [2]. Other candidate materials for the SAF spacer include Rh and Ir, but they have not been extensively investigated. In this study, we investigated an IEC property for Co/Pt-based p-SAF structures with an Ir or a Rh spacer layer [3].

For Ir spacer, J_{ex} peak is broader and higher than the case of Ru spacer, and the peak is at a slightly thicker spacer layer as shown in Fig. 3. This broad peak enables us to obtain a high J_{ex} exceeding 2 erg/cm^2 over a wide spacer layer thickness range between 0.40 to 0.54 nm. The range is twice that of the Ru case. This feature will be a great advantage for the manufacturability of STT-MRAMs because it tolerates the thickness variations of the spacer layer. We also fabricated p-MTJ nano-pillars and evaluated their magnetoresistance and STT switching properties. Figure 4 shows typical R-H minor loops of a p-MTJ pillar with φ = 25 nm for t_{Ir} = 0.48 nm and T_{a} = 350ºC. It retains a large AF-coupled field exceeding ±8 kOe. Figure 5 shows the STT switching properties for the same pillar. The average I_{c0} and Δ were 43 μA and 85, resulting in a switching efficiency of about 2.

We can conclude that the Ir spacer is superior to the conventional Ru spacer in various aspects and has no disadvantages, and it enables us to make a very stable reference layer for p-MTJs in STT-MRAM.

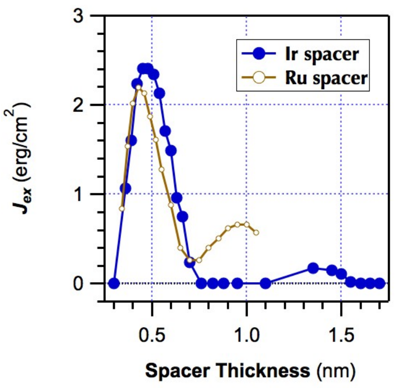

Fig. 3 J_{ex} vs. spacer thicknesses for p-SAFs.

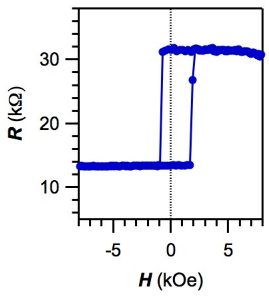

Fig. 4 *RH* minor loop for a p-MTJ with an Ir spacer.

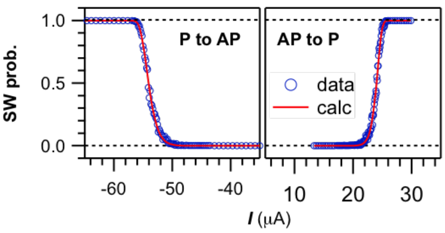

Fig. 5 STT switching properties for a p-MTJ with an Ir spacer (φ = 25 nm).

ACKNOWLEDGEMENT

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