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Spin orbit torque magnetization switching of a tungsten based three terminal perpendicular magnetic tunnel junction for low power Spin Orbit Torque MRAM application

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Abstract

We show the spin orbit torque magnetization switching of a three terminal perpendicular magnetic tunnel junction (MTJ) for Spin Orbit Torque Magnetic Random Acess Memory (SOT – MRAM) application. Using Tungsten (W) as the heavy metal seed layer, a large decrease of the critical current density is observed as compared to standard Tantalum (Ta) based perpendicular MTJ.

1. Introduction

STT-MRAM has been identified by the ITRS as a promising candidate for the non-volatile replacement of L1 and L2 SRAM cache memory technology. However, cache memory applications typically require very fast operations (~ns for L1 cache) combined with large endurance due to their large access rate. For fast operations, STT-MRAM suffers from serious reliability and endurance issues due to the rapid aging of the tunnel barrier induced by the high write current density at large speed as well as erroneous writing by read current.

Recently, SPINTEC has proposed a novel memory concept, named Spin Orbit Torque-MRAM (SOT-MRAM), that combines the advantages of STT and naturally solves these issues [1,2]. The memory is based on the discovery, that a current flowing in the plane of a magnetic multilayer composed of a heavy metal (HM)/ferromagnet (FM)/oxyde layer with structural inversion asymmetry, such as Pt/Co(0.6nm)/AlOx, exerts a torque on the magnetization [2,3]. This "spin orbit torque" (SOT) can lead to magnetization reversal in perpendicularly magnetized nanodot in the presence of a small in-plane field and this reversal can be induced by very short current pulses (< 300 ps) [4].The key advantage of the SOT-MRAM is that write and read are decoupled due to independent current paths. Thus, the SOT-MRAM naturally solves the reliability issues in current STT-MRAM related to read disturbance and barrier aging with a potentially infinite endurance. We have recently demonstrated the spin orbit torque magnetization switching of a three terminal perpendicular magnetic tunnel junction (MTJ) [1]. The MTJ was based on a Ta/CoFeB/MgO/CoFeB structure and magnetization switching induced by 500 ps pulses were demonstrated. However, the current density for switching was still too high for cache memory application.

Here we used MTJ with a W/Hf/CoFeB/MgO/CoFeB structure where a very large SOT is expected due to the large spin Hall angle of W [5,6]. We observe a large reduction, by a factor 7, of the critical current density as compared to MTJ with a Ta based seed layer and for short (5 ns) current pulses. These results are promising for the non volatile cache memory application of SOT-MRAM where fast and low power operations are needed.

2. Results

Nanofabrication

Magnetic tunnel junction (MTJ) was deposited by magnetron sputtering using a Singulus Timaris deposition machine. The MTJ had the following structure: 3.9 W / 0.12 Hf/ 1 $Fe_{60}Co_{20}B_{20}$ / MgO / 1.5 $Fe_{60}Co_{20}B_{20}$ / 0.4 Ta / FM1/Ru0.85/FM2 (thickness in nm), where FM1 and FM2 are composed of (Co/Pt) multilayers. Functional three-terminal single cells down to 100 nm diameter on top of a W track were fabricated as follow: the memory dot is defined in two steps. First, a Ta pillar, which acts as a hard mask, was defined by Electron Beam Lithography (EBL) followed by Reactive Ion Etching (RIE), then the Magnetic Tunnel Junction (MTJ) was defined by Ion Beam Etching (IBE).

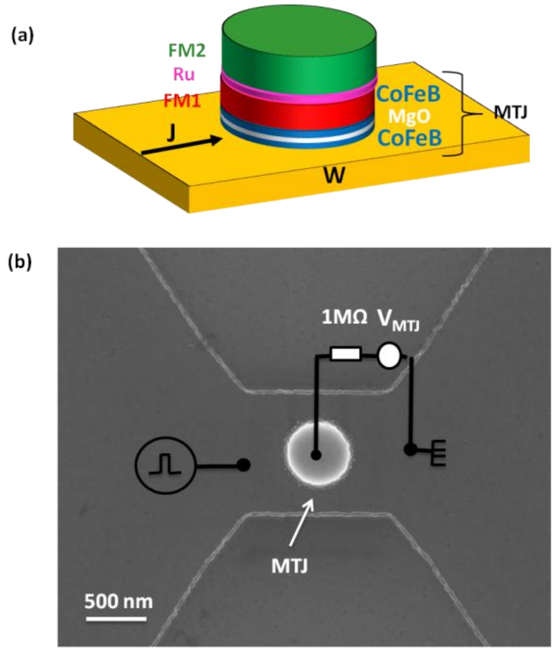

Fig. 1(a) 3D schematic of the SOT MRAM and (b) top view SEM image of memory dot over a heavy metal W track.

The W track was then defined by EBL over the memory dot and structured by IBE tool. An organic resist was then spin coated and planarized to insulate the top contact of the device from W track. Finally a lift off process of Cr-Al was performed for the realization of electrical contact electrodes. The Fig. 1(a) and 1(b) show respectively a 3D schematic of the device and a top view SEM image of memory dot over a heavy metal W track.

Magneto-electric characterization

The Figure 2 shows the Tunnel Magnetic Resistance (TMR) measurement of an MTJ dot cell of 1.2 µm diameter over a 1.5 µm wide W track as a function of a magnetic field applied perpendicularly to the layer plane. The abrupt change of the TMR shows that the magnetic layers are perpendicularly magnetized and the value of the TMR is about 100 % with a product area of 746 $\Omega.\mu m^2$.

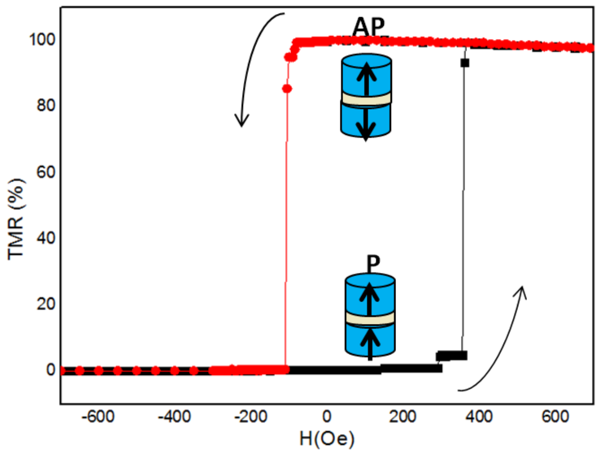

Fig. 2 Tunnel Magnetic Resistance (TMR) measurement as a function of out of plane magnetic field.

For the current induced magnetization switching experiments, a current pulse was injected in the W track and the TMR was measured after the current pulse injection using a DC voltage source connected to the MTJ to detect the magnetization switching of the 1nm CoFeB free layer. To allow for the magnetization switching [2], an in-plane magnetic field of 75 mT was applied along the track. The figure 3 demonstrates the magnetization switching by an in-plane current pulses and its detection by the TMR for short (5-20 ns) pulse widths. The average switching current density is about 10^{11} A/m² for 5 ns current pulses, which is about 7 times lower compared to Ta heavy metal.

Herein we confirm that using W instead of Ta track the power consumption can be strongly reduced making the SOT MRAM a serious candidate for non-volatile cache memory applications.

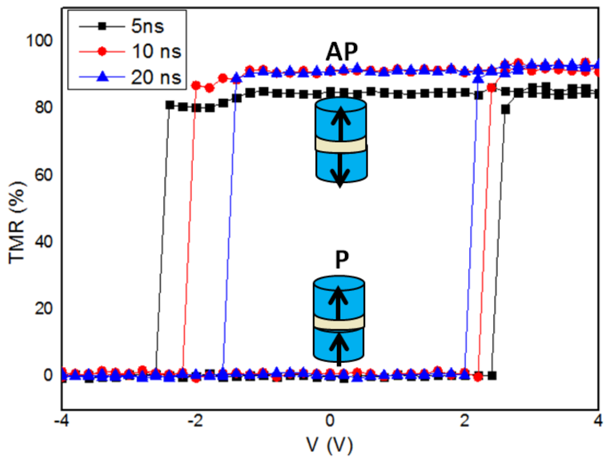

Fig. 3 TMR as a function of the voltage pulse amplitude injected in the W tracks for different current pulse widths. An external in plane field of 75 mT is applied along the track direction.

3. Conclusions

The spin-orbit torque magnetization switching of a three terminal perpendicular SOT-MRAM memory cell with W heavy metal layer was demonstrated using short (5 ns) current pulses. We demonstrate a large reduction of the critical current density, (a factor 7), as compared to Ta heavy metal MTJ, while achieving large TMR (100%).

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