Switching field variation in MgO magnetic tunnel junction nanopillars: experimental results and micromagnetic simulations

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Intense research regarding the development of magnetic tunnel junctions (MTJ) has been driven by the magnetic data storage industry [1]. Particularly, MgO-based MTJs showing large tunnel magnetoresistance (TMR) are expected to originate novel spintronic devices [2]. The capability to fabricate MTJs with low resistance-area (RxA) and TMR>100% must be combined with the aptitude to define structures below 100nm and to effective integrate the pillar into a device architecture.

The MTJ stack was deposited on a Timaris sputtering tool, consisting of Si/SiO2/Ta(5)/CuN(50)/Ta(30)/CuN(50)/Ta(3)/PtMn(15)/CoFe30(2.3)/Ru(0.85)/CoFe40B20(2.5)/MgO<1/CoFe40B20(2.5)/Ta(10)/CuN(30)/Ru(7)/TiWN2(5) (nm), then annealed in vacuum for 1h at 330ºC under 1T, showing TMR~200% and RxA~5Ωµm2. The films were patterned into circular (200 to 500nm) and elliptical pillars (150x300 to 200x650nm2), combining electron beam lithography, ion-milling and lift-off. Simulations of both magnetic and magnetotransport behaviors were performed with SpinFlow3D [3].

The measured devices show an average RxA~6Ω.µm2 with TMR up to 145% [Fig.1a], demonstrating the quality and robustness of the nanofabrication process. In fact a yield of ~70% was obtained, with ~55% of the devices showing a TMR>90%. Overall, squared TMR curves are observed in these samples, although with smaller switching field (Hsw) than expected from simulations [Fig.2]. Fig.2b compares the experimental (Hsw=90Oe) and simulated (Hsw=320Oe) transfer curve of a 150x300nm2 pillar. In fact, the obtained Hsw is significantly smaller than the expected from simulations, which together with the Barkhausen jumps visible in particular curves, suggests complex magnetization reversal processes within the free-layer (FL). Furthermore, TEM images revealed dimensions larger than nominal and a FL tapered profile, signature of an ion beam milling process used for nanopillar definition [Fig.1b]. Simulations including a tapered FL indicate a decrease in the Hsw [Fig.2b], which allied to larger sizes and edge roughness can justify the obtained Hsw values. Therefore, such high TMR and low RxA devices with controlled Hsw can be successfully used in spin transfer based devices.

References

[1] P.P. Freitas et al J. Phys.-Cond. Mat. 19 (2007), pp. 165221

[2] Shen, E. Et al (2005) Appl. Phys. Lett. 86, pp. 253901

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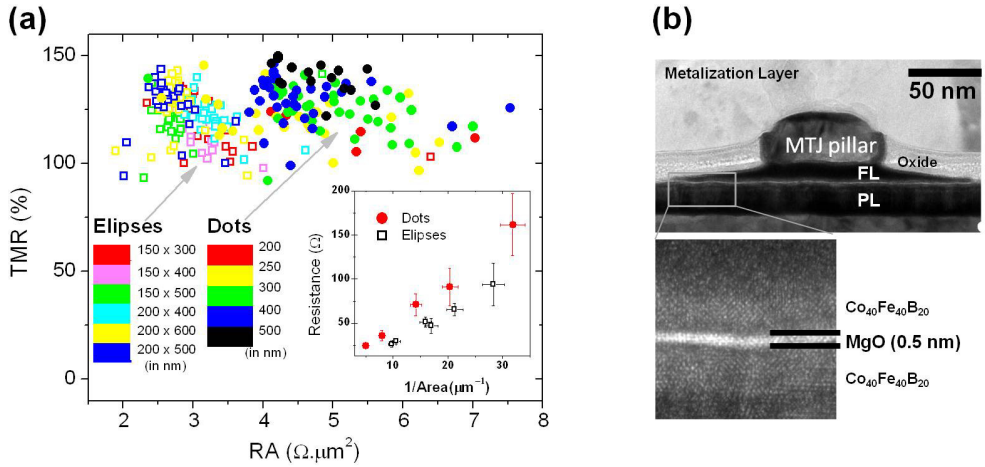
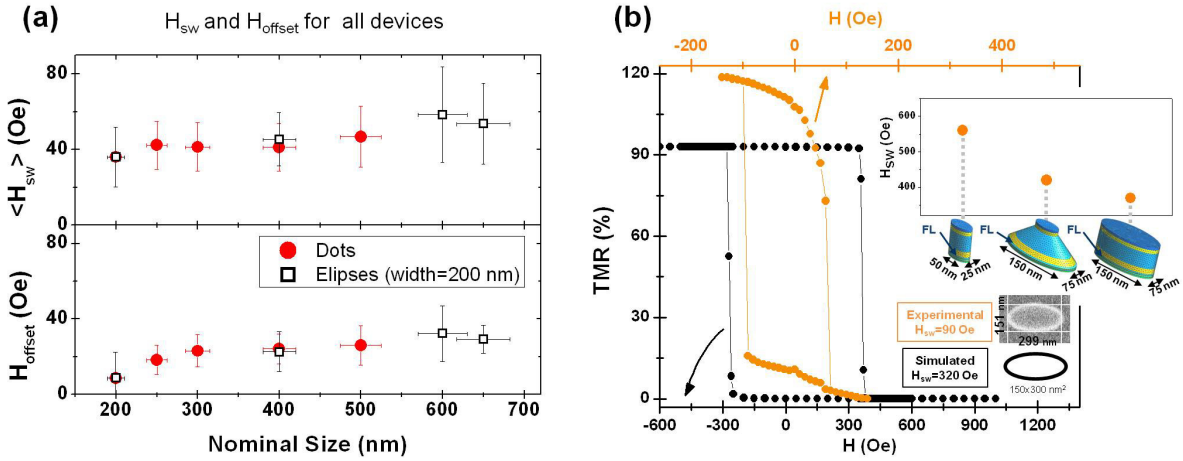
Figures


(a)
TMR (%)
RA (Ω.μm²)
Elipses
150 x 300
150 x 400
150 x 500
200 x 400
200 x 600
200 x 500
(in nm)
Dots
200
250
300
400
500
(in nm)
Dots
Elipses
Resistance (Ω)
1/Area(μm⁻¹)
(b)
Metalization Layer
50 nm
MTJ pillar
Oxide
FL
PL
Co40Fe40B20
MgO (0.5 nm)
Co40Fe40B20


(a)
Hsw and Hoffset for all devices
<Hsw> (Oe)
Hoffset (Oe)
Dots
Elipses (width=200 nm)
Nominal Size (nm)
(b)
H (Oe)
TMR (%)
Hsw (Oe)
FL
50 nm
25 nm
150 nm
75 nm
Experimental
Hsw=90 Oe
151 nm
299 nm
Simulated
Hsw=320 Oe
150x300 nm²
H (Oe)