Influence of interlayer exchange coupling on switching of CoFeB/MgO/CoFeB Pseudo Spin-Valves with perpendicular anisotropy

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In an attempt to design of Magnetic Tunnel Junction (MTJs) with a low critical switching current, Two kind of ultrathin $Co_{40}Fe_{40}B_{20}$/MgO/$Co_{40}Fe_{40}B_{20}$, Pseudo Spin-Valve (PSV) bilayers were deposited using Singulus sputtering cluster tool system. To determine optimal perpendicular anisotropy range of pinned and free layer, sample with crossed double wedge (bottom $Co_{40}Fe_{40}B_{20}$ thickness: 0.66-1.08, top: 0.99-1.62 nm) was prepared and nanostructurised. In order to check the influence of interlayer coupling on PSV switching fields, the second sample, with MgO wedge (barrier thickness 0.8 - 1.3 nm), was deposited and characterised.

The optimal thickness of the MgO barrier is also crucial for obtaining high TMR ratio and low resistance area product (2.2 $\Omega\mu m^2$), which is important for a down-size scalability. Fabricated MTJs revealed good clearance between operating voltage and breakdown voltage, although shift of (100 Oe) of minor hysteresis loop was measured due to the ferromagnetic interlayer exchange coupling (IEC=0.007 mJ/m^2). Field-voltage phase diagram reveal that anti-parallel state can be established in zero-field state using 80 mV of negative bias voltage (which correspond to 4 MA/cm^2 current density).

In addition, the dynamic FMR measurements performed for as-deposited bilayers shows two resonance peaks, one indicating in-plane anisotropy and one typical for perpendicular to plane anisotropy, although quasi-static hysteresis loop suggest easy axis perpendicular to plane. After annealing in 330 ºC, only one resonance peak with mixed behavior is observed due to increased coupling between both CoFeB layers. Such phenomena was confirmed by micromagnetic simulations and VSM and MOKE measurements of samples with varying MgO barrier thickness. Hysteresis loop of CoFeB (0.93 nm) / 1.3MgO (1.3 nm)/ CoFeB (1.31 nm) PSV shows two easy-axes, in-plane and perpendicular to the plane, whereas same sample with thin (0.8 nm) MgO exhibit pure perpendicular to plane anisotropy.

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Background

Magnetic tunnel junctions (MTJs) with perpendicular magnetic anisotropy (PMA) are of great interest in realizing next-generation high-density non-volatile memory and logic chips, due to the potentially low switching current and downscalable junction size.

Goal

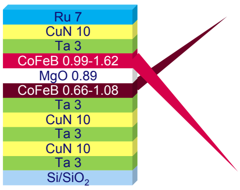
Reduction of the switching current and voltage in MTJs with PMA for future use in MRAM devices by optimizing magnetic and barrier layers thicknesses.

Approach

Deposition of magnetic tunnel junction stack layers with CoFeB and MgO wedge, using a Singulus Technologies Timaris PVD cluster tool system. Wafer level characterization to select optimal region for nanopatterning and perform transport measurements on patterned samples.

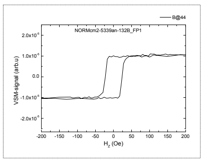
Step 1: dual crosswedge wafer

Stack structure, annealed 330ºC

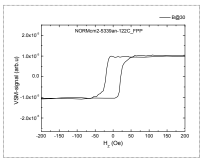


$Co_{40}Fe_{40}B_{20}$/MgO/$Co_{40}Fe_{40}B_{20}$ Wafer characterisation by MOKE and VSM for optimization of CoFeB thickness suitable for PSV with PMA

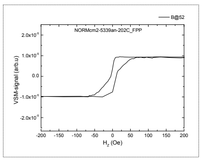
VSM measurements perpendicular to plane



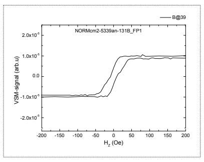
1.31 nm top, 0.90 nm bottom



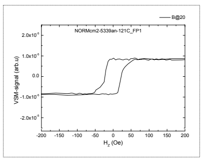
1.22 nm top, 0.90 nm bottom



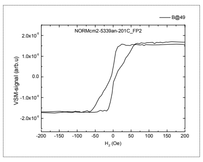
1.17 nm top, 0.90 nm bottom



1.31 nm top, 0.83 nm bottom

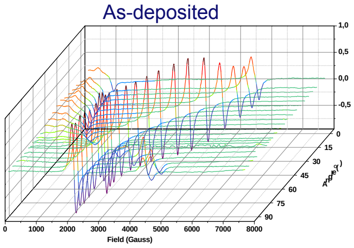


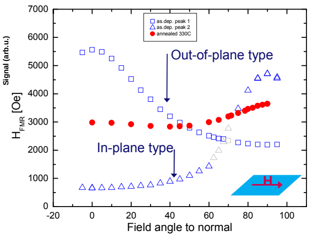
1.22 nm top, 0.83 nm bottom



1.17 nm top, 0.83 nm bottom

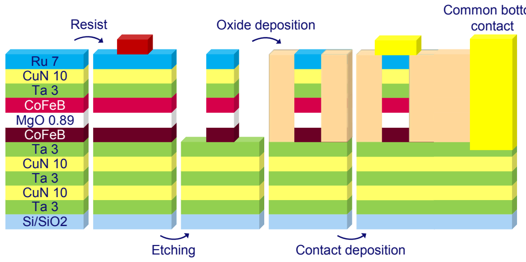
FMR measurements





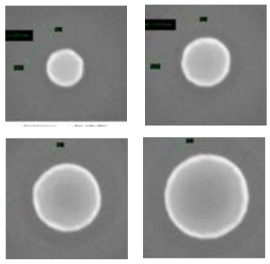
Step 2: Nano-patterning for TMR/CIMS

Procedure



Fabricated junctions

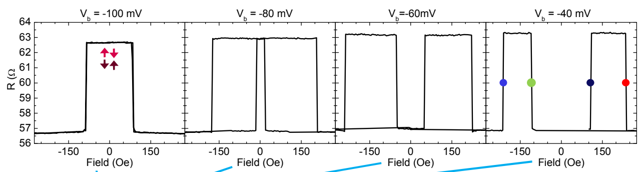
150 ... 370 nm size



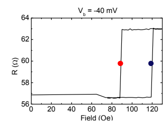
Magnetization Switching

t_{top} = 1.31 nm, t_{bottom} = 0.93 nm

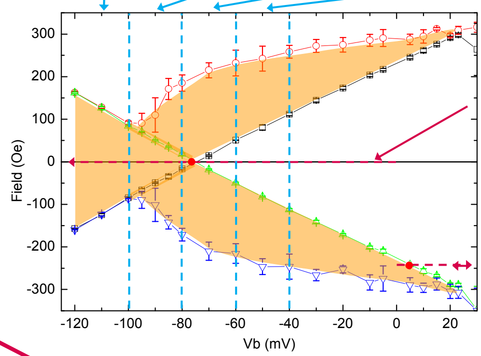
Field Induced, major loop



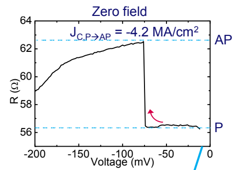
minor loop

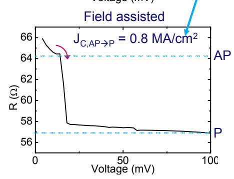


IEC = -0.012 mJ/m²



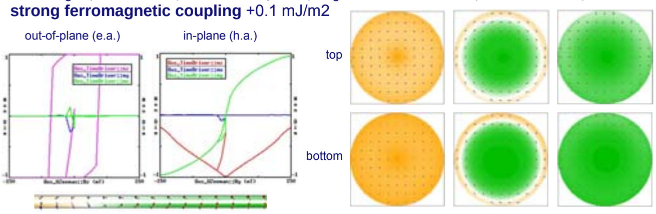
Current Induced



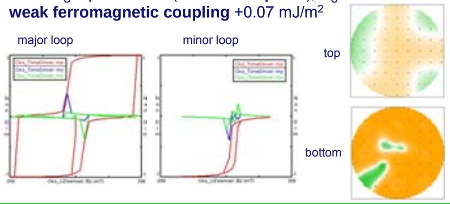


Micromagnetic simulations

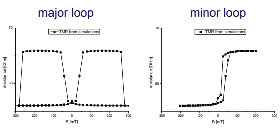
300nm diameter, 1nm CoFeB/1nm MgO/1nm CoFeB (2x2x1nm cell size)
PMA: K_U top 350kJ/m³ (effective: **in plane**), K_U bottom 500 kJ/m³ (effective: **PMA**)
strong ferromagnetic coupling +0.1 mJ/m2



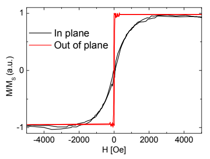
PMA: K_U top 380kJ/m³ (effective: **in plane**), K_U bottom 600 kJ/m³ (effective: **PMA**)
weak ferromagnetic coupling +0.07 mJ/m²



TMR calculated from magnetisation (paralell channels model)



Questions:

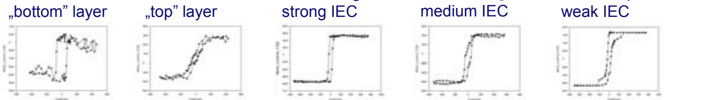


1. Origin of mixed in-plane/out-of-plane behaviour of layers magnetisation? Whole bilayer system switch like PMA.
2. How MgO thickness (and interface exchange coupling) is affecting PSV with perpendicular magnetic anisotropy?

Step 3: additional wedge samples

1. $Co_{40}Fe_{40}B_{20}$ wedge 0.82...1.46nm /MgO „bottom"
2. MgO/$Co_{40}Fe_{40}B_{20}$ wedge 0.82...1.46nm „top"
3. $Co_{40}Fe_{40}B_{20}$ /MgO wedge 0.8...1.3nm /$Co_{40}Fe_{40}B_{20}$

as deposited & annealed (330ºC)



Conclusions

Top CoFeB layer reveal no perpendicular magnetic anisotropy, altough in complete PSV stack it is expressed only as different dynamic behaviour, whereas effective easy axis is perpendicular to plane. Thin MgO allow current induced switching much below breakdown voltage, altough must to be taylored due to strong interface exchange coupling. IEC increases during annealing process.

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