Spin-transfer-torque dependence on MgO tunnel barrier thickness in MTJs

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Motivation

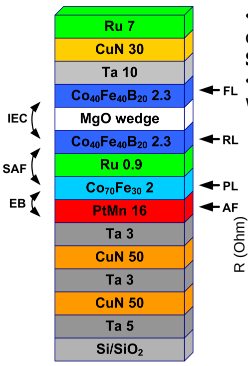
High density and fast **MRAM** can be implemented using current induced magnetization switching (**CIMS**) effect [1], caused by the interaction between spin-polarized current and local magnetization of the FL in the **MTJ** cell, called STT [2]. STT is also utilized in MTJ nanooscillators, that generate signals in the **GHz frequency** range when supplied with DC current [3].

Aim

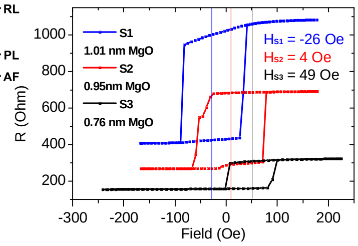
To understand the STT effect in order to:
- reduce the critical current density in the **CIMS** effect
- optimize the MTJ parameters for **memory technologies**
- apply MTJ in **microwave electronics**

Sample description

A1. Deposition

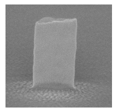


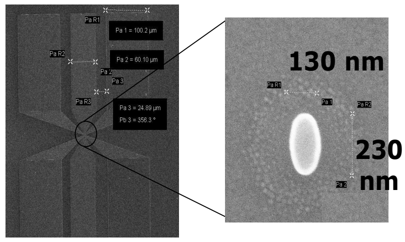
- deposited using a Timaris PVD cluster tool system from **Singulus Technologies**
- linear dynamic deposition (LDD) wedge technology [4]



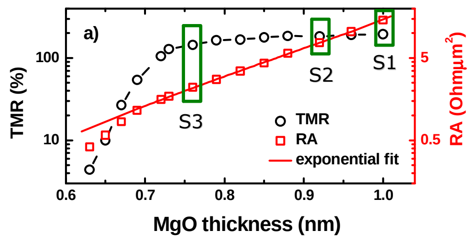
A2. E-beam lithography

- 3 step lithography process using e-beam lithography, ion milling, lift-off





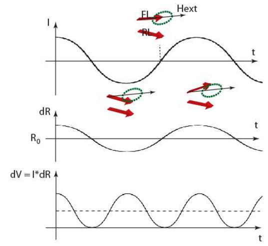
A3. Wafer level characterization



- High **TMR** values (**170%** down to **110%**)
- for thin MgO barriers (down to 0.75 nm)
- **RA** product changes exponentially with the tunnel barrier thickness down to **2 Ωµm²**.

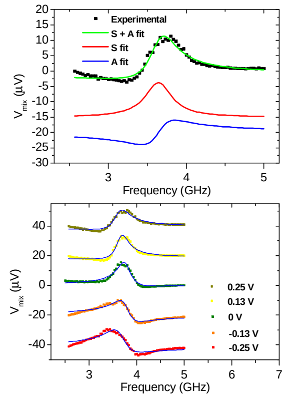
Experiment

B1. Spin torque diode effect [5]

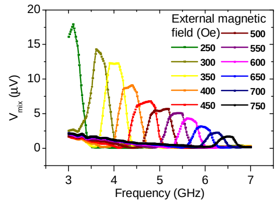


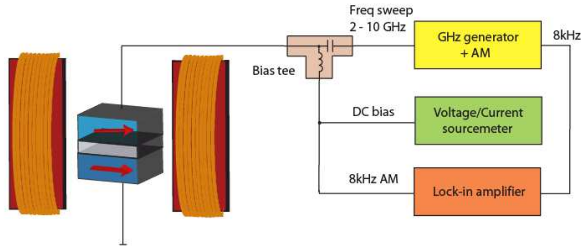
$$V_{mix} = \frac{1}{4}\frac{\partial^2 V}{\partial I^2} I_{RF}^{\ 2} + \frac{1}{2}\frac{\partial^2 V}{\partial I \partial \theta}\frac{\hbar \gamma \sin\theta}{4eM_s Vol \sigma} I_{RF}^{\ 2}\left[\xi_{\parallel} S(\omega) - \xi_{\perp}\Omega_{\perp} A(\omega)\right] \quad [6]$$

$$\xi_{\parallel} = \frac{2e}{\hbar}\sin\theta \frac{dV}{dI}\frac{d\tau_{\parallel}}{dV} \qquad \xi_{\perp} = \frac{2e}{\hbar}\sin\theta \frac{dV}{dI}\frac{d\tau_{\perp}}{dV}$$



B2. Setup

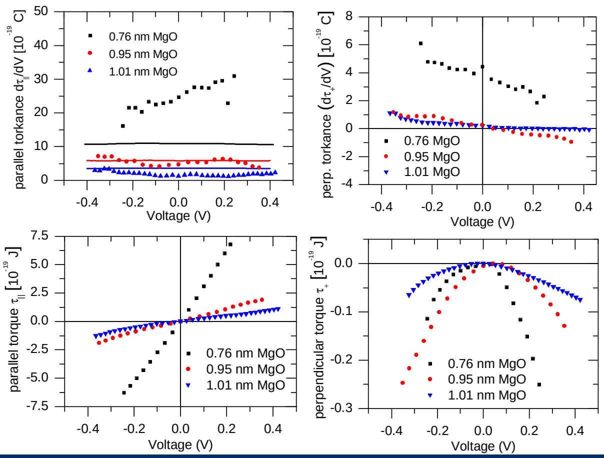




Spin-transfer ferromagnetic resonance (**ST-FMR**) measurement technique takes advantage of a DC voltage generated by a MTJ when supplied with a RF current [7, 8]:
- generation of the DC voltage ***Vmix***, when the current frequency is in **resonance** with resistance oscillations, arising from the **STT**
- the RF current was typically swept in the range of 2 - 12 GHz
- MTJ placed in a external magnetic field and at the certain angle, so that the angle (**θ**) between FL and RL during spin-torque diode measurement is **fixed to 90°**

Results and discussion

C1. Torques and torkances



- Parallel and perpendicular torkances derived from the **ST-FMR** signals
- Separate fitting procedure for each measurement with different DC voltage applied
- **Torque** numerically integrated from **torkance**

$$\frac{d\tau_{\parallel}}{dV} = \frac{\hbar}{2e}\frac{2p}{1+p^2}\left(\frac{dI}{dV}\right)_{\parallel} \qquad [9]$$

C2. Summary

- **Parallel torque** weakly depends on an applied DC bias voltage
- **Absolute torque** values increases with decreasing tunnel barrier thickness – consistent with a theory [9]
- **Perpendicular torque** amplitude measured in applied DC bias voltage range is max. 20% of the parallel one
- Strong **coupling** causes deviation from the theory

Name	MgO [nm]	RA [Ωµm²]	TMR [%]	$d\tau_{\parallel}/dV$ (V=0) [C]	$\tau_{\parallel}$ (V=0.2) [J]
Sankey [7]	1.25	15	160	4.3E-20	8.3e-21
S1	1.01	9.5	170	1.3E-19	5.2e-20
S2	0.95	6.5	165	4.75E-19	1.2e-19
S3	0.76	3.5	110	2.47E-18	6.7e-19
Wang [6]	1	1.5	92	3.3E-19	
Kubota [9]	1	2	154		1e-19

Summary of measured MTJ parameters.

References and acknowledgments

[1] – W. Skowroński et al. *JAP* ***107****, 093917 (2010)*, **[2]** – J. Slonczewski *JMMM* ***159****, L1 (1996)* **[3]** – A. Deac et al. *NatPhys* ***4****, 803 (2008)*, **[4]** – J. Wrona et al. *JP:CS* ***200****, 032052 (2010)*, **[5]** – A.A. Tulapurkar et al. *Nat* ***438****, 339 (2005)*, **[6]** – C. Wang et al. *PRB* ***79****, 22 (2009)*, **[7]** – J. Sankey et al. *NatPhys* ***4****, 67 (2007)*, **[8]** – H. Kubota et al. *NatPhys* ***4****, 37 (2007)*, **[9]** – J. Slonczewsk and J.Z. Sun *JMMM* ***310****, 169 (2007)*

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