Electric-field-induced ferromagnetic resonance in magnetic tunnel junctions

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Motivation

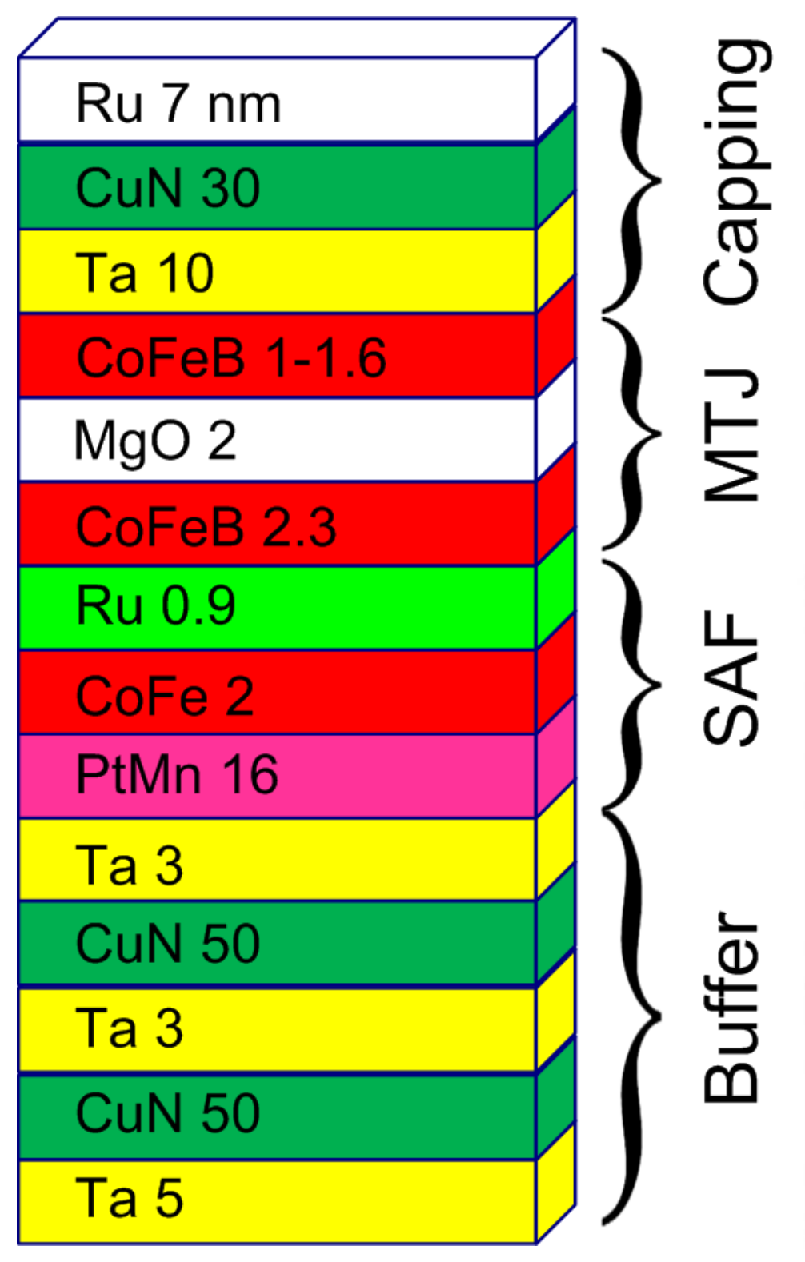
Steady-state magnetization precessions in magnetic tunnel junctions (**MTJ**) that are induced by microwaves result in a DC response when the precessing and stimulating signals are in resonance **[1]**. Depending on the MTJ multilayer structure, the magnetization precession can originate either from the spin-transfer-torque (**STT**) effect **[2]** or from electric-field-induced (**E-field**) changes to the magnetic anisotropy of MTJ free layer **[3]**.

Aims

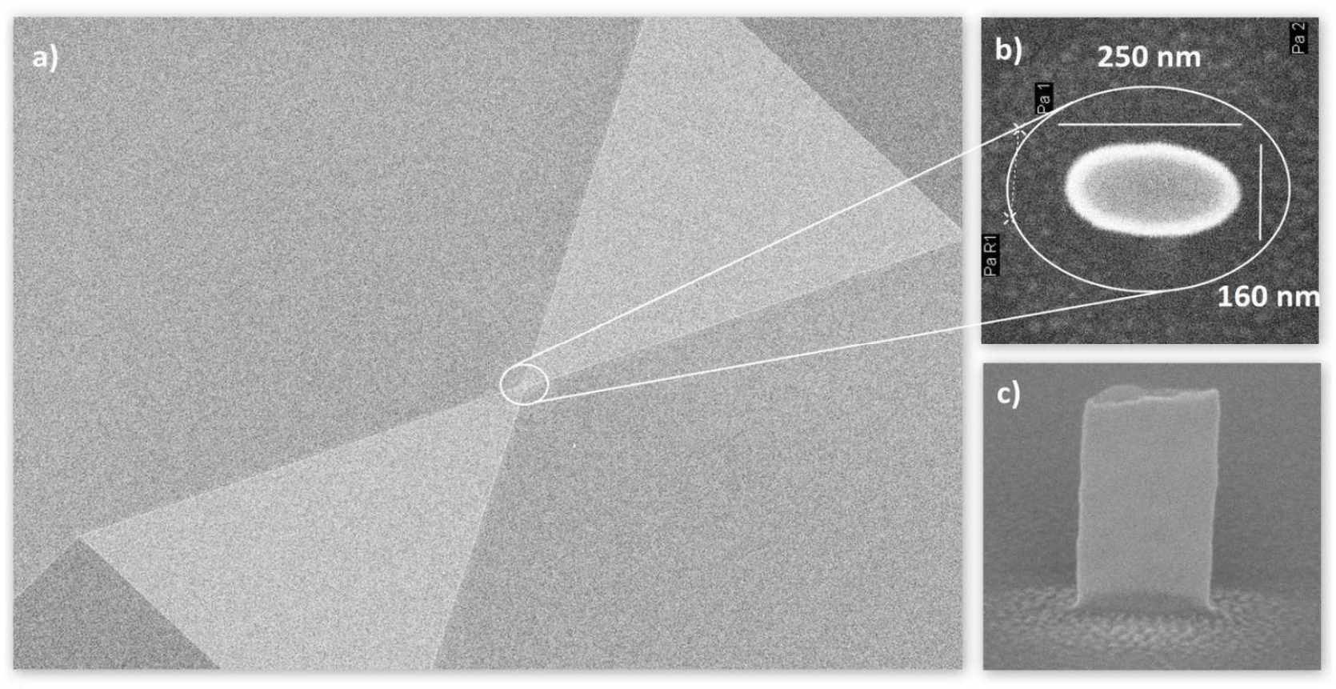
To investigate ferromagnetic resonance (**FMR**) in MTJ that can be used in microwave oscillators, detectors, magnetic field sensors. Distinguish between: **E-field-FMR** and **STT-FMR.**

Sample description

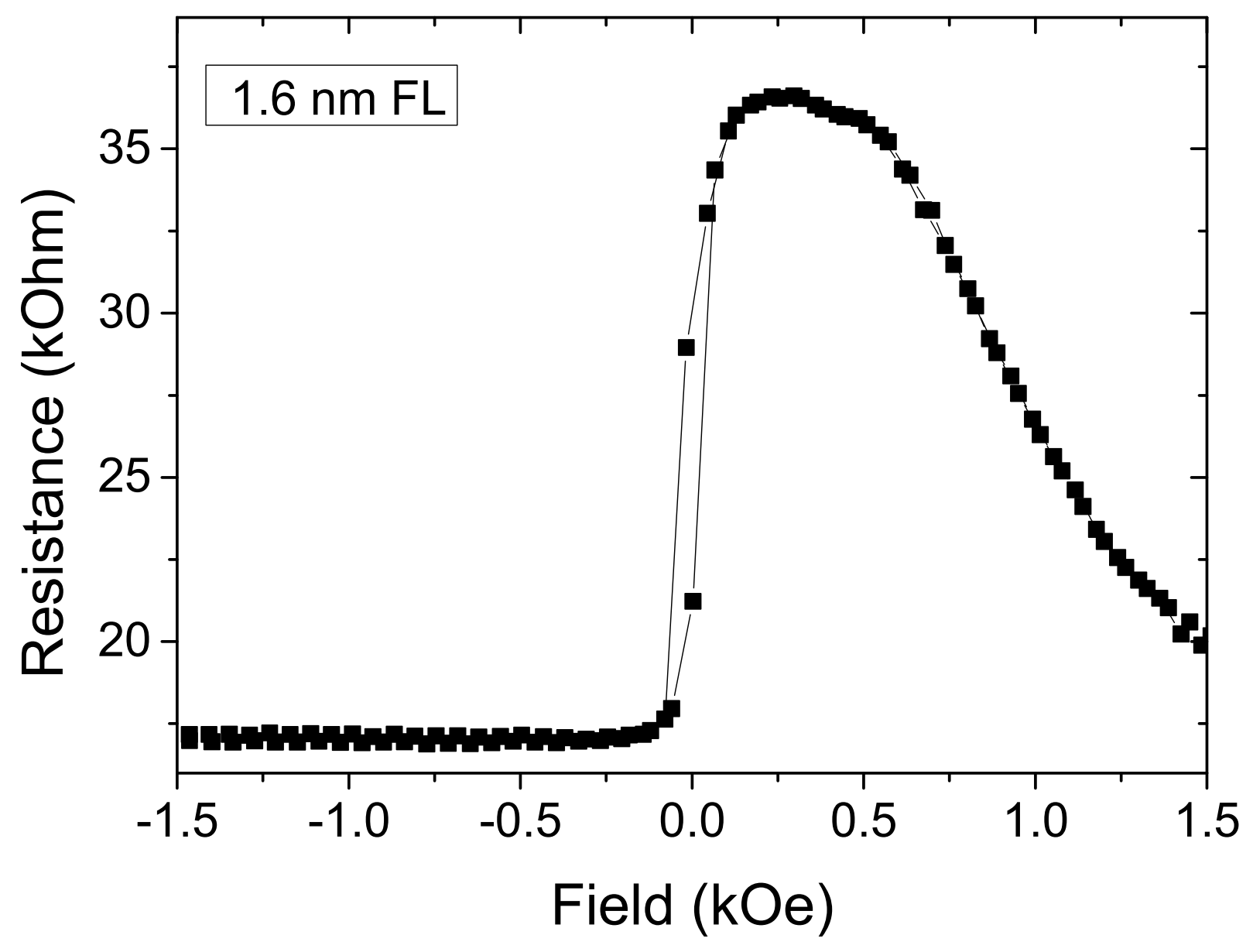
A1. MTJ nanopillar

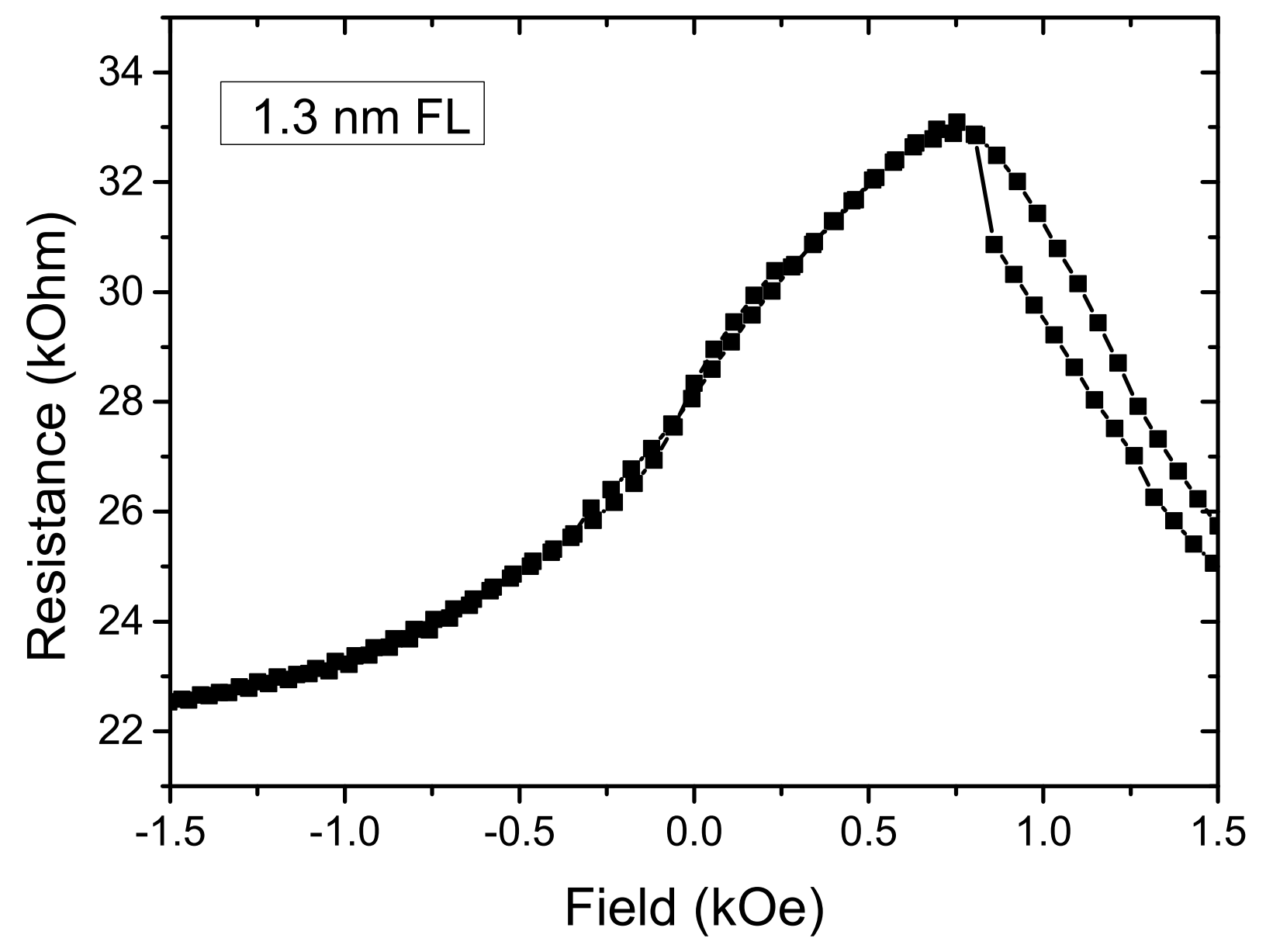


Deposited using a Timaris PVD cluster tool system from **Singulus Technologies** .
3 step lithography process:
- e-beam lithography
- ion milling,
- lift-off



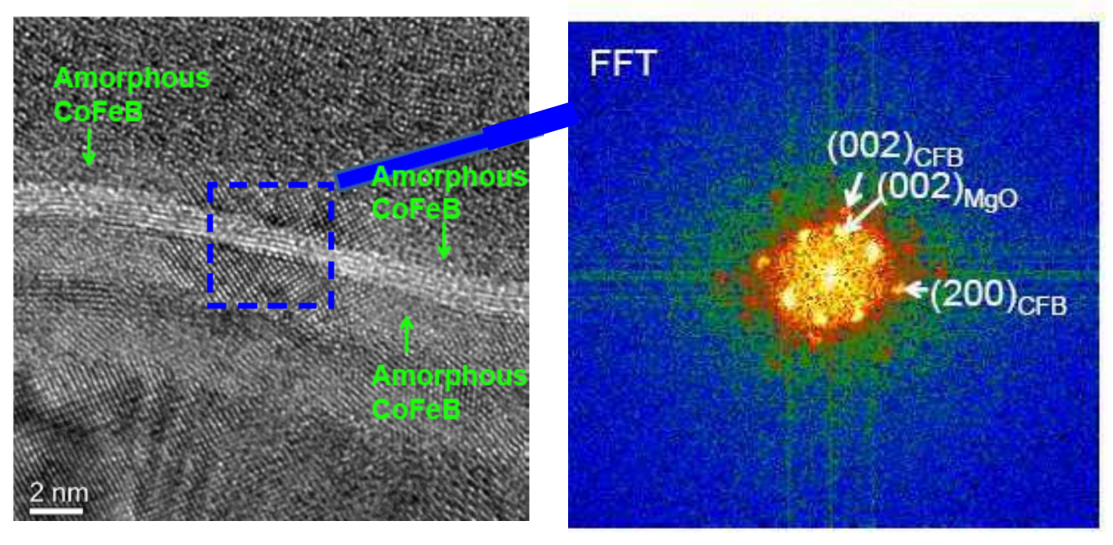
A2. MTJ optimization





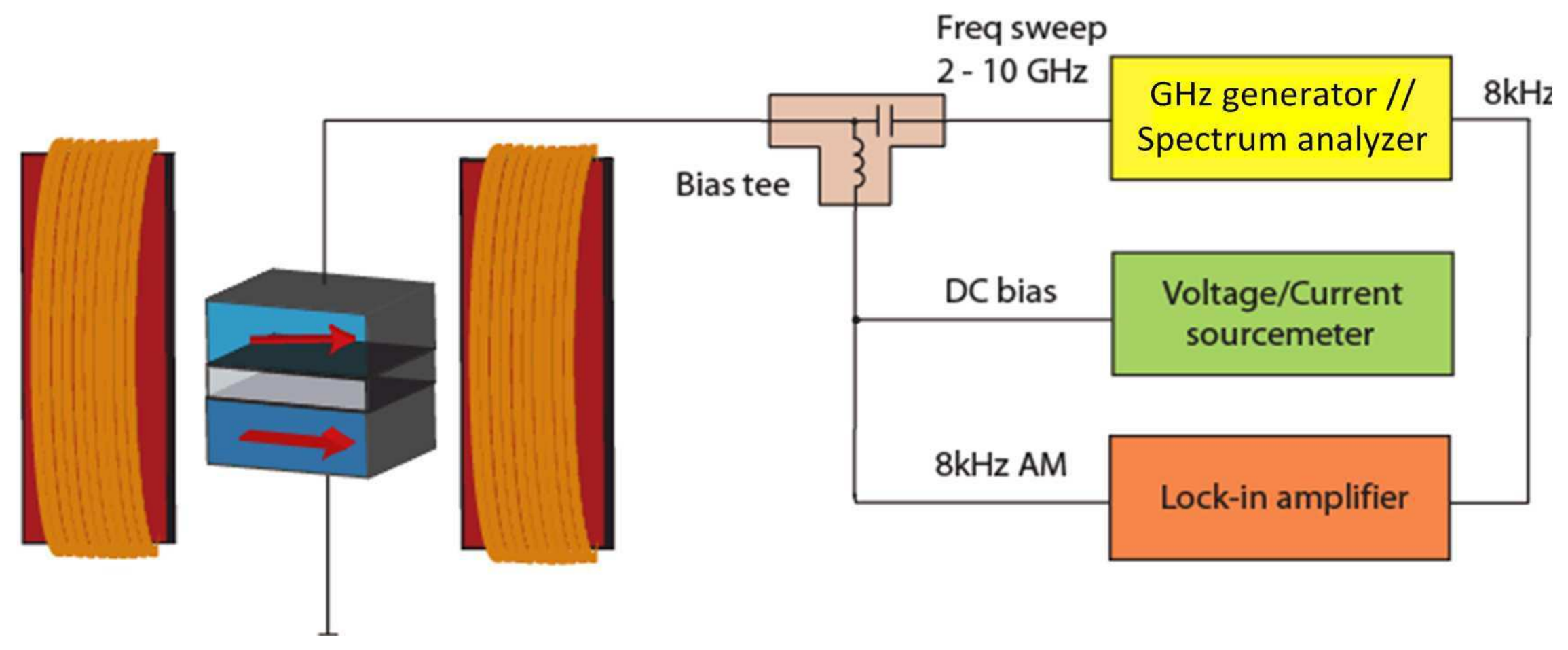
In-plane anisotropy for 1.6 nm thick free layer (FL) and **perpendicular** anisotropy for 1.3 nm thick FL. The measured **TMR** ratio is between 70 and 100 %.

2 nm MgO tunnel barrier results in an **RA** product of **2 kΩμm²**, two MTJ size of 120 x 230 nm and 280 x 530 nm. Annealed at 250°C with in-plane magnetic field (4 kOe) in order to set the exchange bias direction.



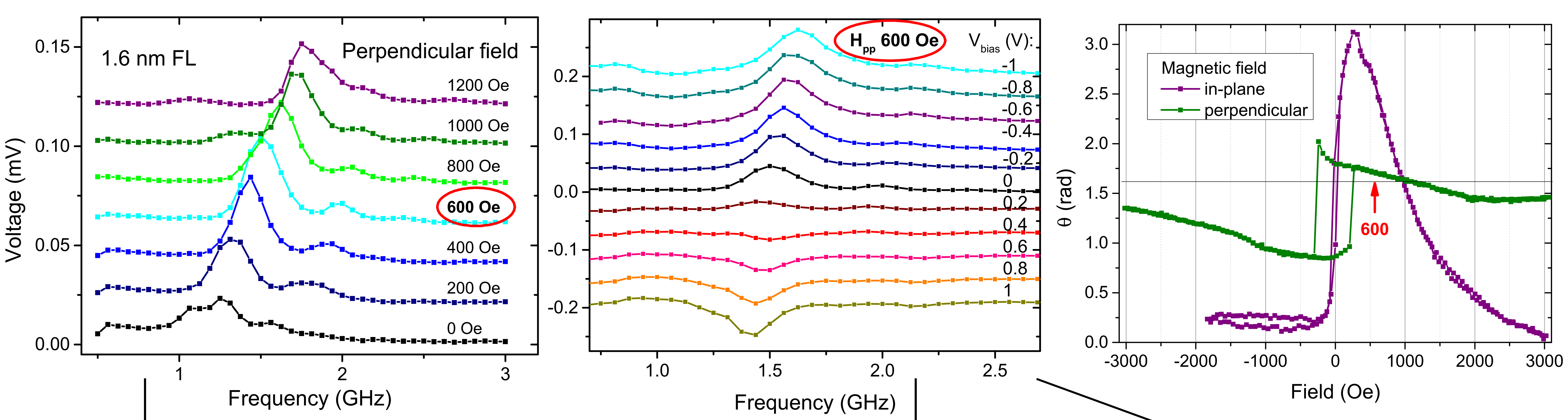
Experiment and results

B1. Measurement setup

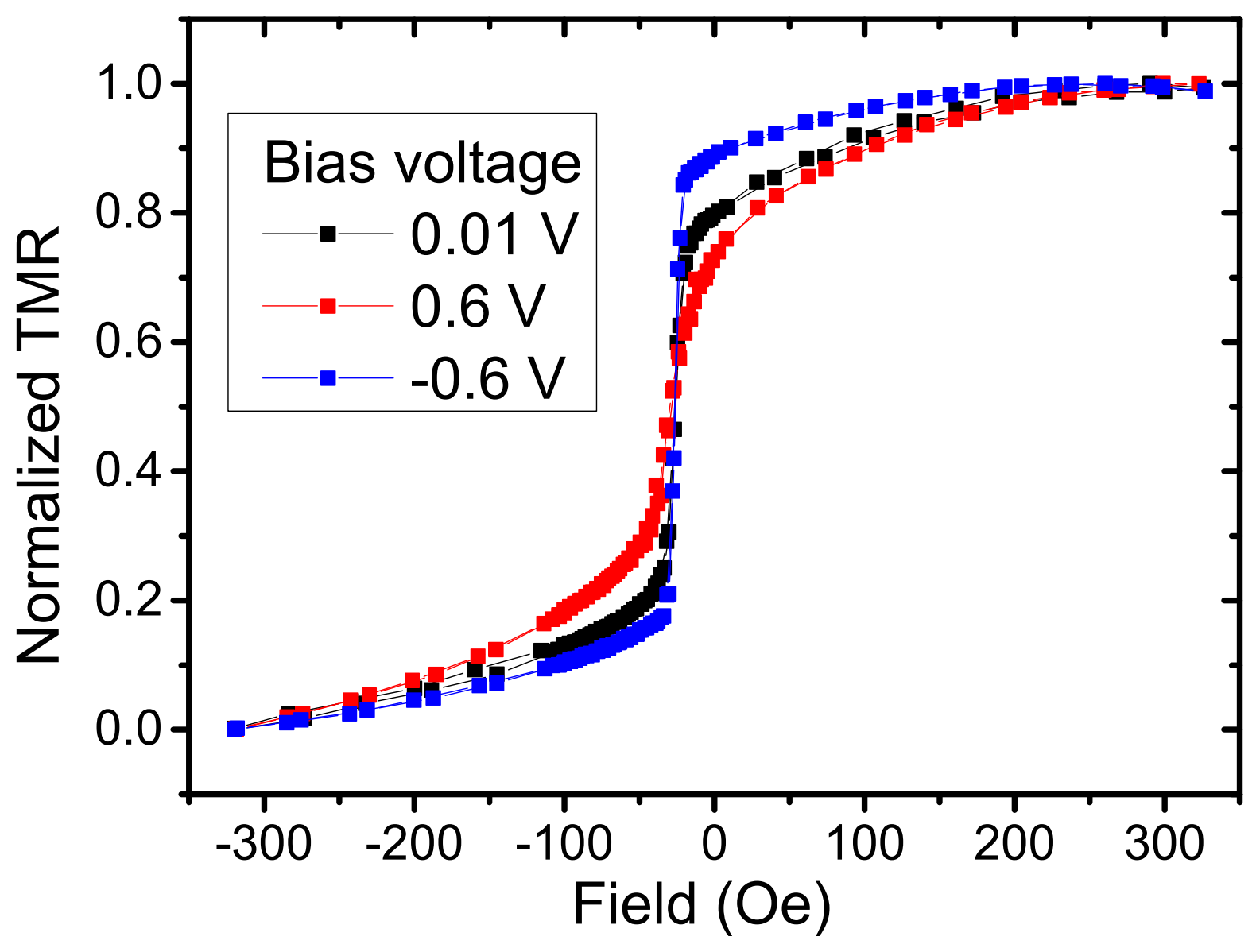


$\mathbf{P_{in}}$ = -10 dBm (100 μW), G = (Z-50)/(Z+50) = 0.995
$\mathbf{P_{MTJ}}$ = Pin*(1-G^2) = -30 dBm (1 μW), **A** = 0.12 um2
I = $(P_{MTJ}/R)^{0.5}$ = 6 μA, **J** = 5.1e7 A/m^2

B3. FMR measurements and calculations



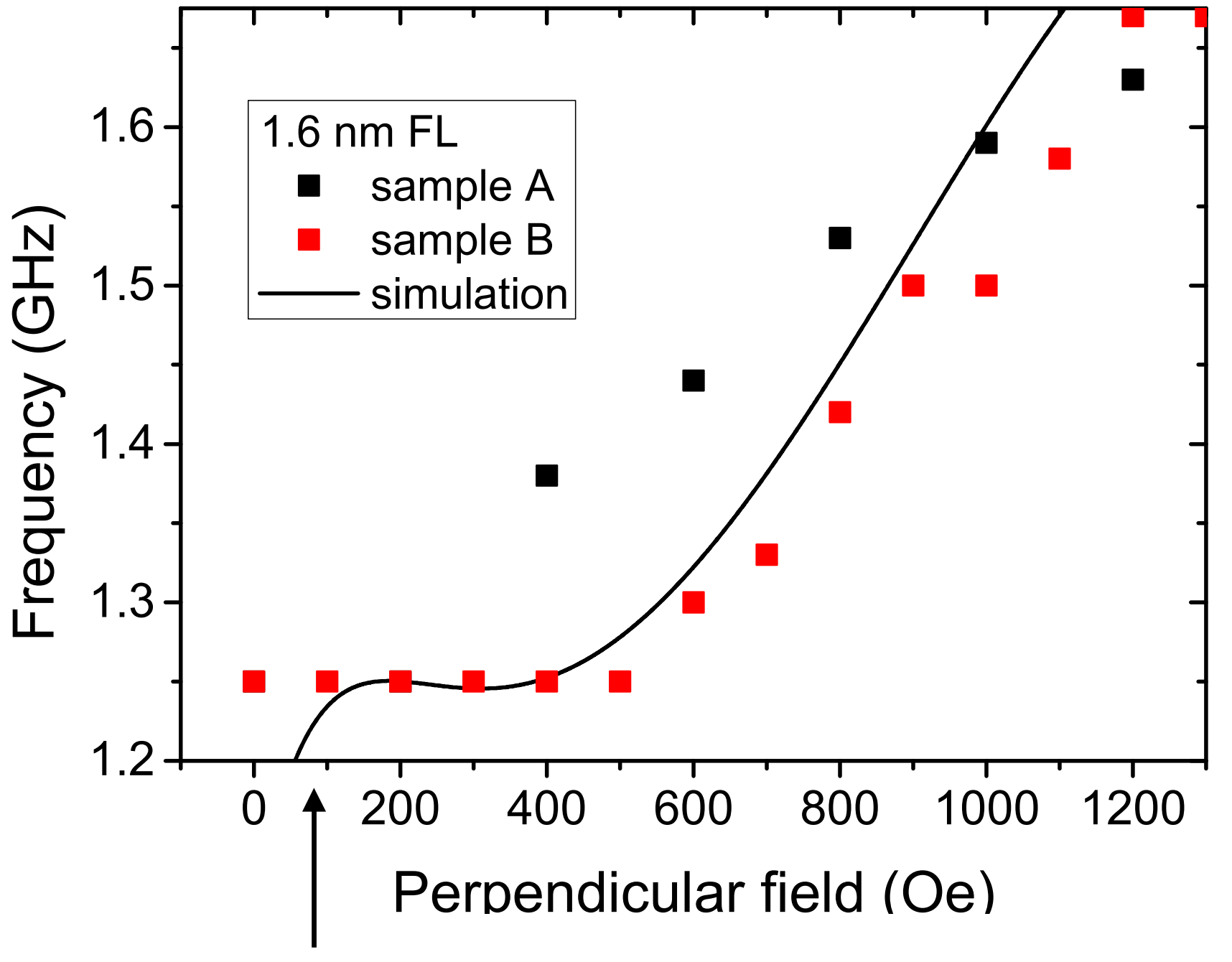
B2. TMR for diff. voltage

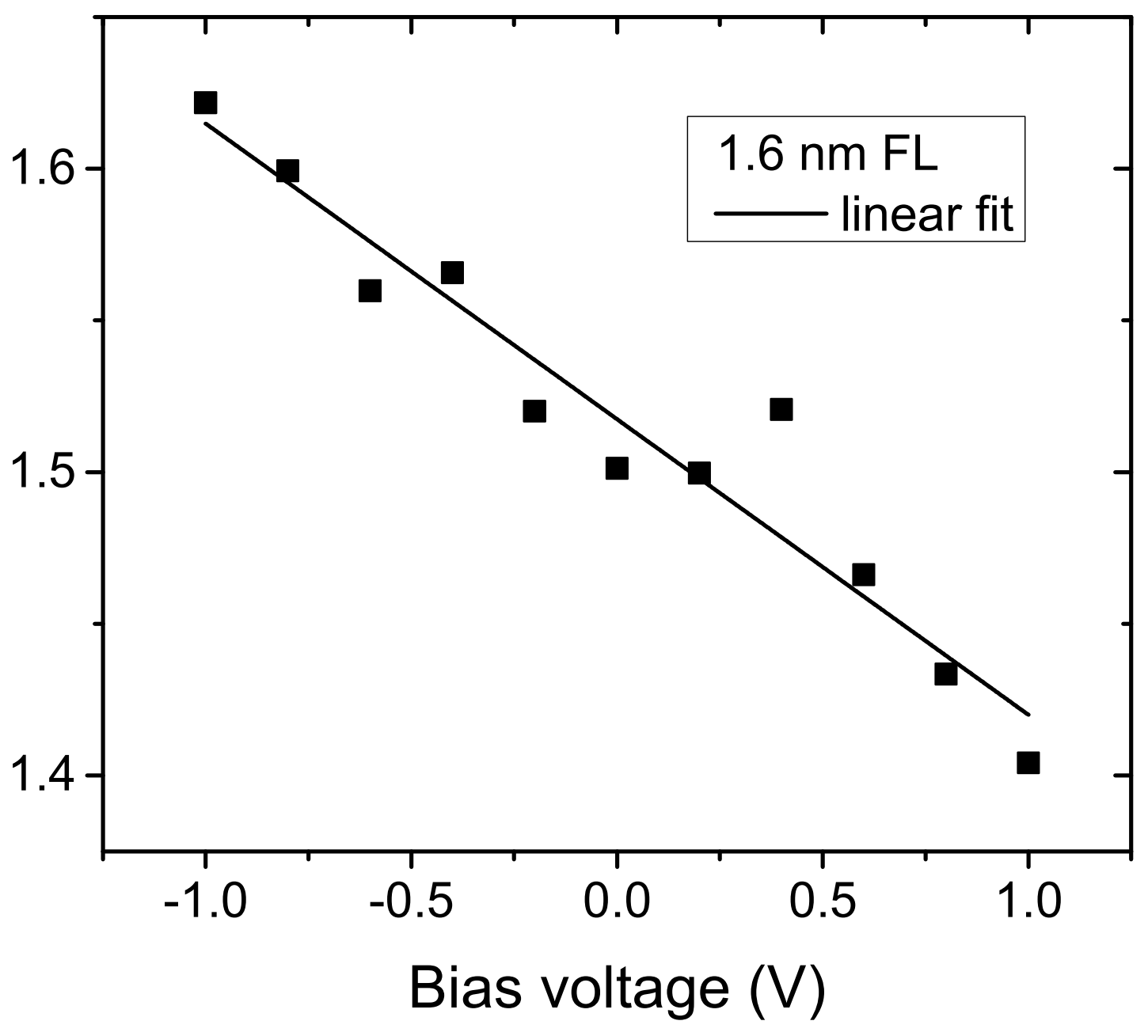


- Positive voltage enhances perpendicular anisotropy (hard axis for in-plane field)
- Negative voltage reduces peprendicular anisotropy **[4]**

B4. FMR frequency vs. magnetic field and bias voltage, in-plane STT derivation

- For MTJs with 1.6 nm FL strong FMR signal detected for perpendicular field
- FMR frequency shifts with bias voltage
- FMR frequency vs. field curve modeled using equation **[5]**:





$$f=\frac{\gamma_e}{2\pi}\left[\frac{1}{\Gamma\sin\theta_s}\left[2H_S\cos 2\theta_s-H\cos\left(\theta_H-\theta_s\right)+M_S\cos 2\theta_s\left(N_{dx}-N_{dy}\right)\right]\times\right.$$
$$\left.\left[-H\sin\theta_H\sin\theta_s+M_S\sin^2\theta_S\left(N_{dy}-N_{dx}\right)\right]\right]^{0.5}$$

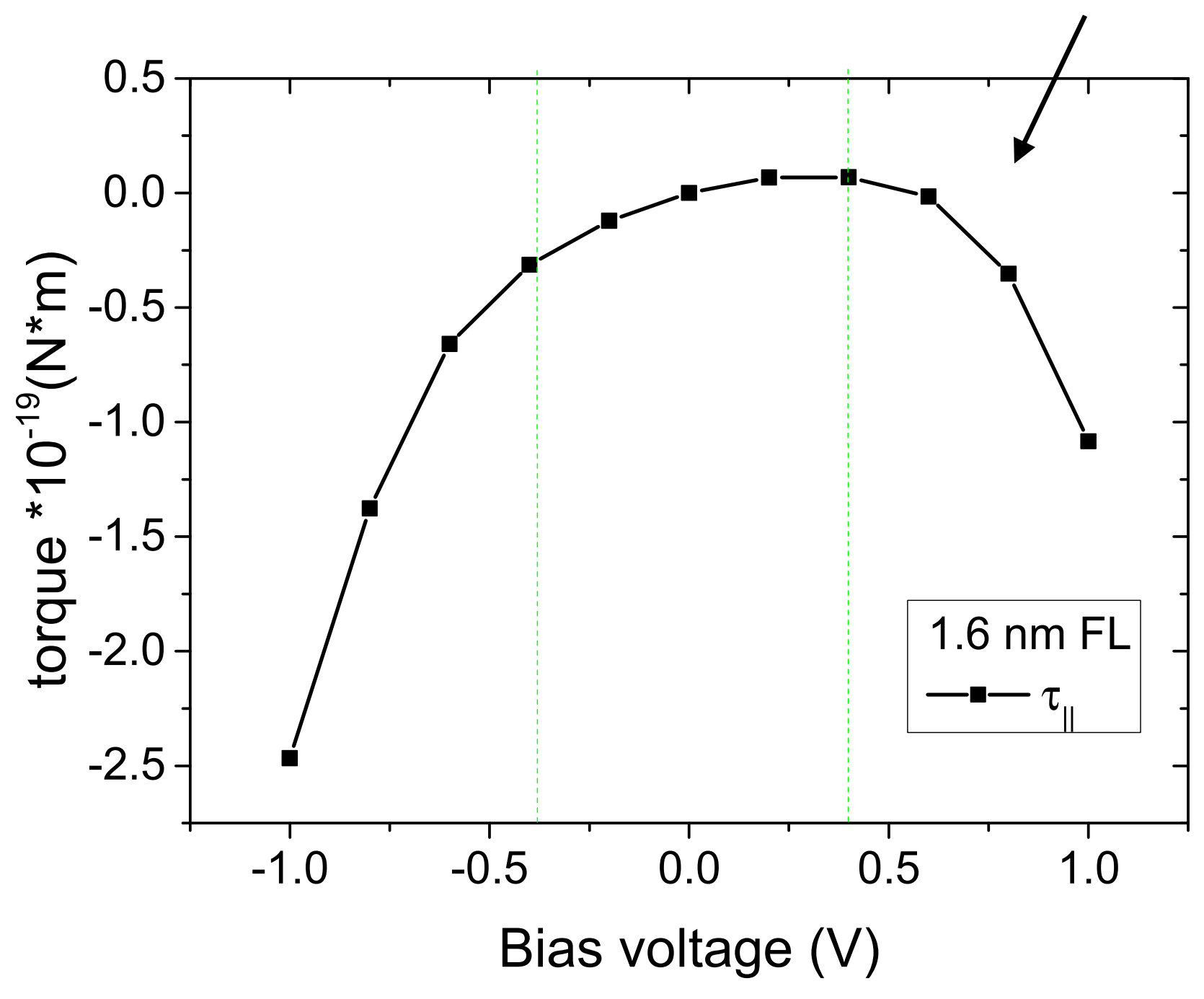
Comparision between E-field FMR and STT-FMR:
- Different V_{mix} shape (symmetric vs. asymmetric Lorentzian curve)
- Different angle behaviour (maximum vs. minimum at θ = 90 degree)
- Different current denisity supplied (high vs. small)

In-plane STT derived from V_{mix} signal:

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

Integrated in-plane torque:

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



In-plane torque was measured in a **high** bias voltage range (+/- 1V) revealed parpabolic shape **[6]**.

Summary

- MTJ with thick MgO barrier and different FL fabricated and patterned to nm-scale devices
- Magnetic anisotropy shifts from **in-plane** to **perpendicular** at 1.4 nm thick CoFeB layer
- Perpendicualr magnetic anisotropy is increased by positive voltage and decreased by negative bias voltage
- FMR signal induced by **STT** is modulated by static bias voltage, in-plane torque is measured in a high bias voltage range

References and acknowledgments

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[4] – W. Skowronski et al. APL 101, 192401 (2012) **[5]** – J. Zhu et al. PRL 108, 197203 (2012) **[6]** – M. Wilczyński et al. PRB 77, 054434 (2008)

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