Spin transfer torque in magnetic tunnel junctions with a wedge MgO barrier

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Outline

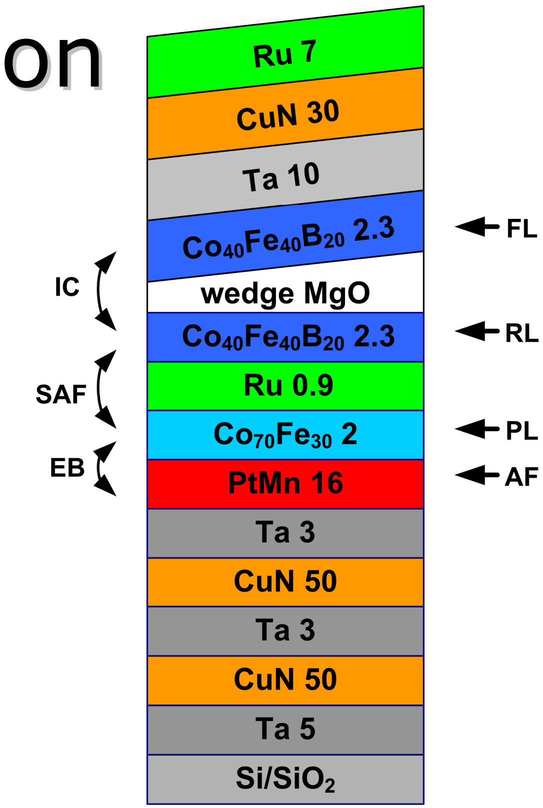
- Introduction
- Sample preparation
- Wafer level characterization
- Interlayer coupling
- Transport measurements – CIMS
- Conclusions

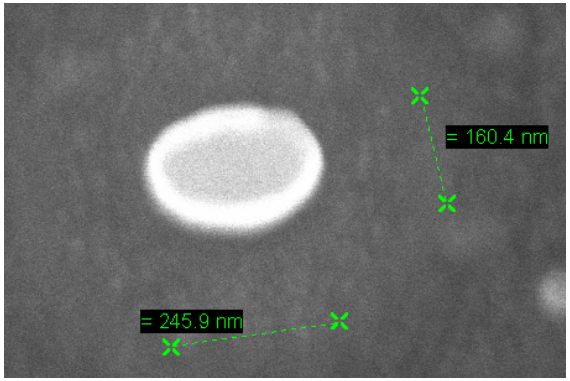
Introduction

- Aim:
  - To study the influence of a **MgO barrier thickness** (below 1 nm) in MTJs on the critical current density in CIMS

Sample preparation

- MTJ stack deposited in Singulus Timaris PVD cluster tool system
- MgO wedge thickness: 0.62 nm up to 0.96 nm (slope 0.017 nm/cm)
- 2 step e-beam lithography, ion etching, lift-off
- 3 sizes of MTJs:
  - 0.03 um² (160 x 250 nm)
  - 0.08 um² (280 x 430 nm)
  - 0.13 um² (280 x 620 nm)

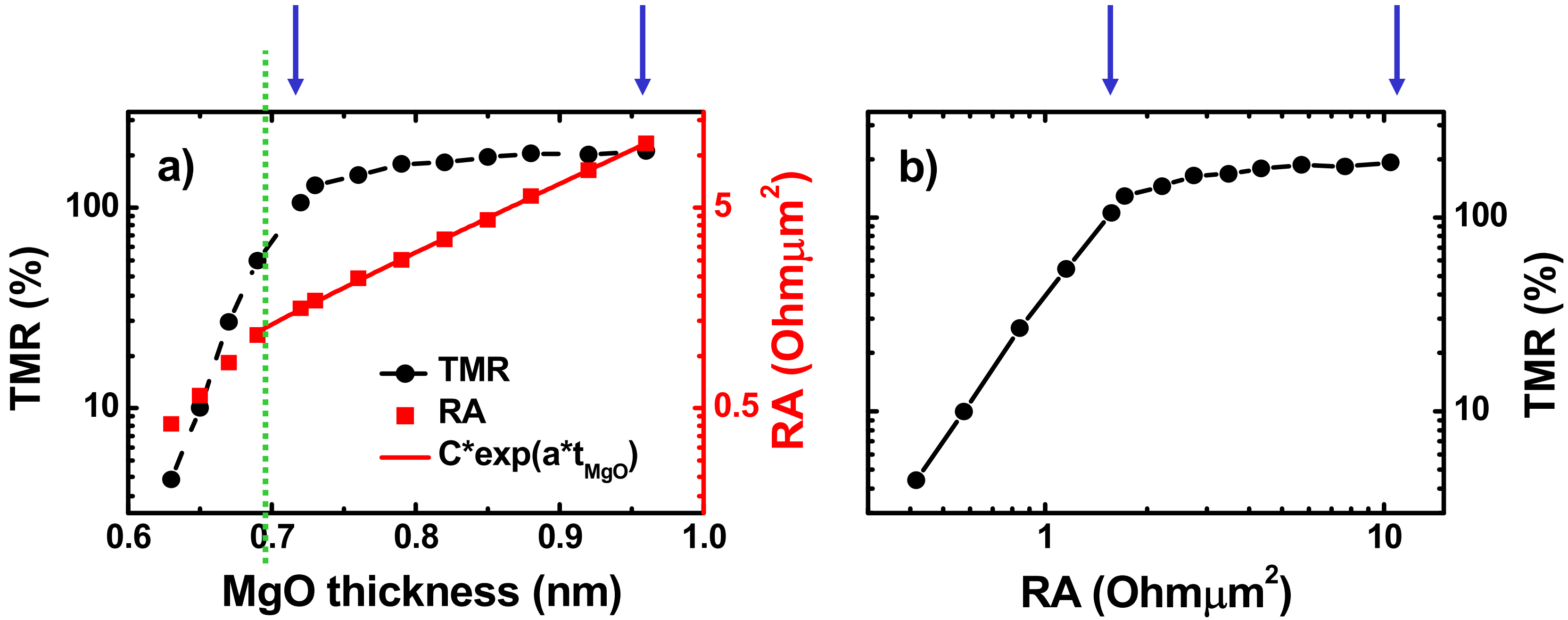




Wafer level characterization

*Worledge et al. APL **83,** 84, 2003*

- Measured using CIPT technique
- Small TMR change down to 0.75 nm MgO thickness
- When RA < 1.5 Ohm·um^2 (0.7 nm MgO) TMR drops rapidly – barrier imperfection



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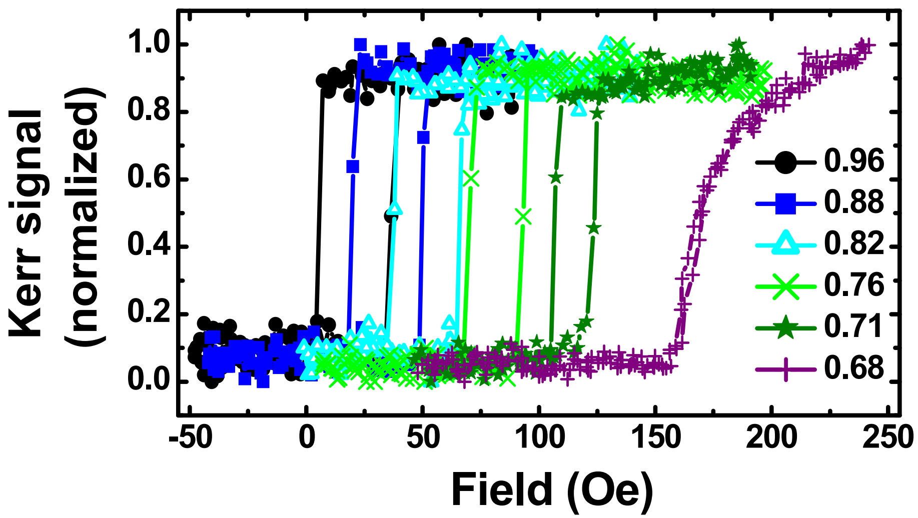
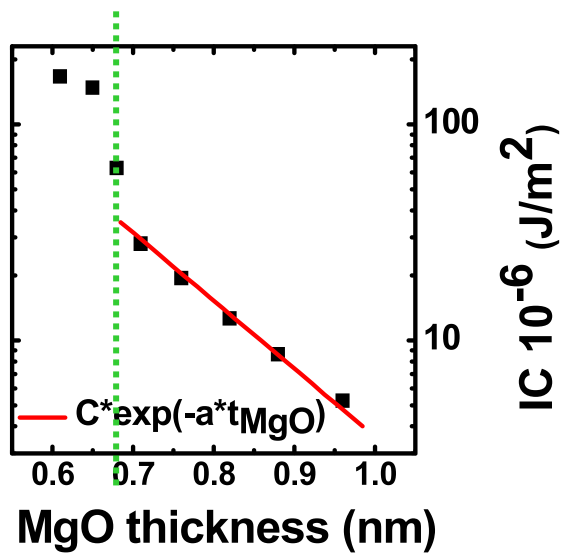
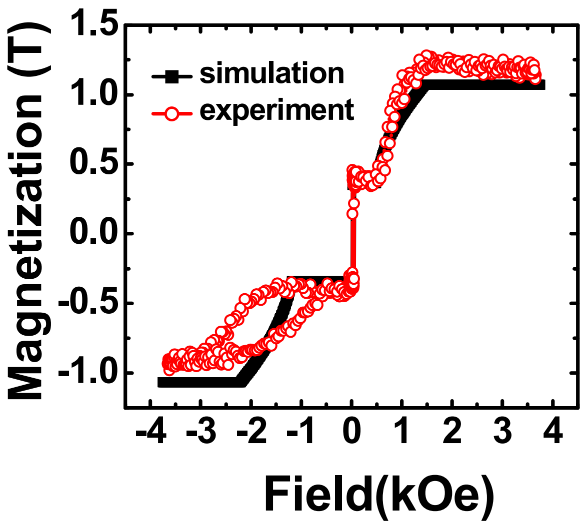
Interlayer coupling

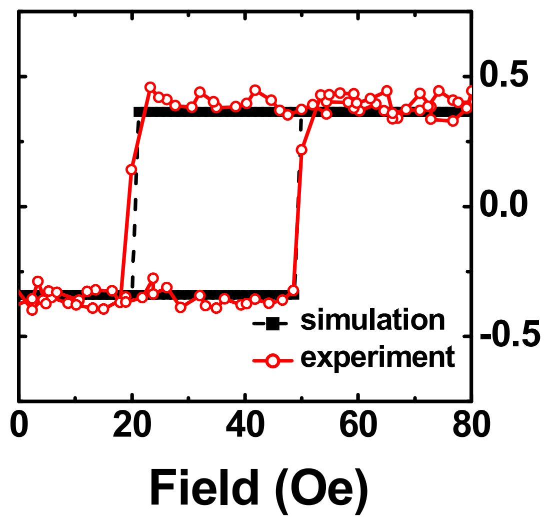




*J.Faure-Vincent et al. PRL **89**, 2002 and*

*Katayama et al. APL **89**, 2006*

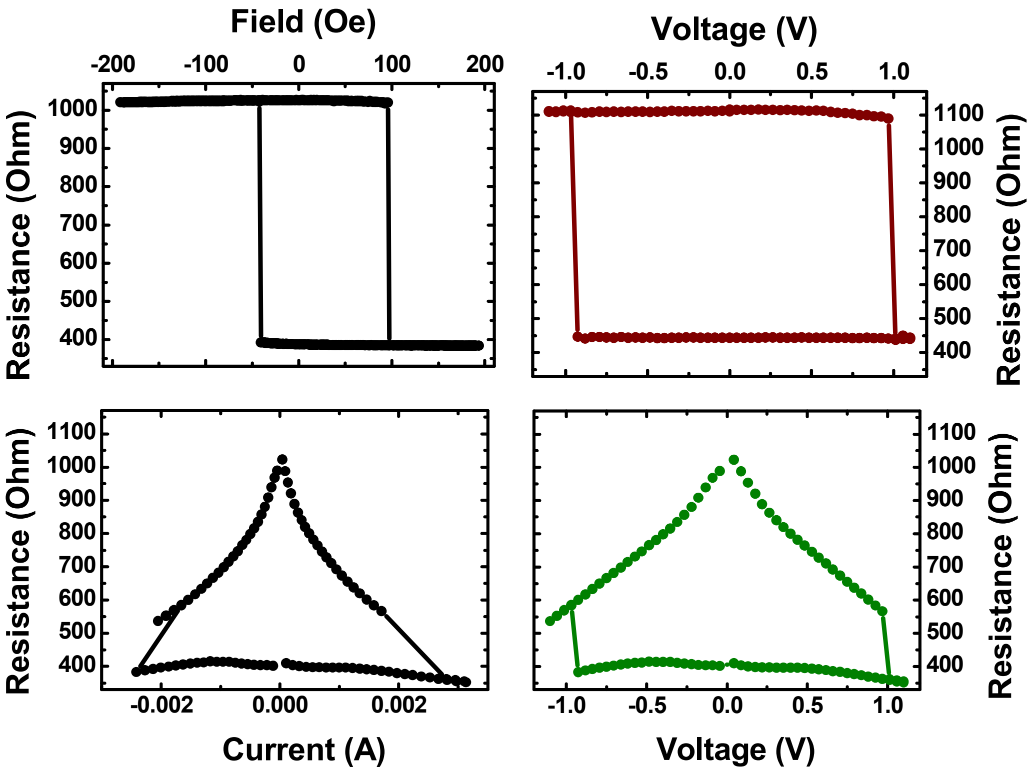


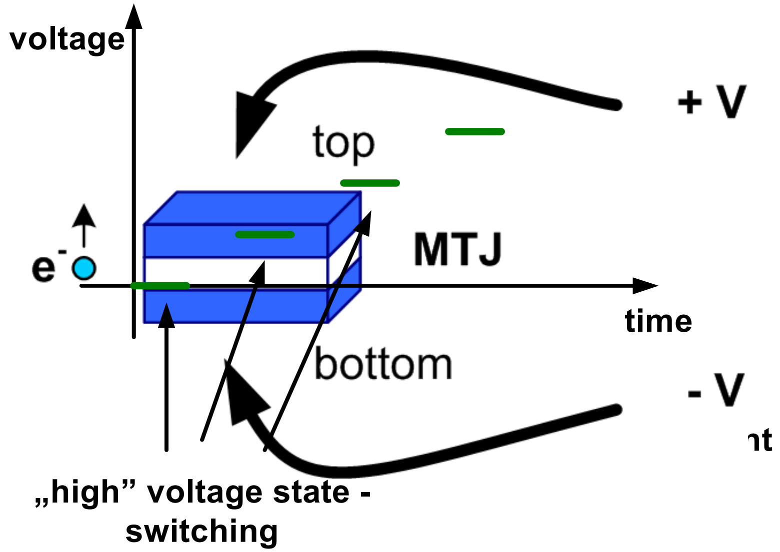


- $\mu_0 M_{CoFeB} = \mu_0 M_{FL} = \mu_0 M_{RL}$ = **1.35** T,
- $\mu_0 M_{CoFe} = \mu_0 M_{PL}$ = **1.6** T,
- $K_{FL} = K_{RL}$ = **940** J/m^3
- K_{PL} = **100** J/m^3
- K_{AF} = **60** kJ/m^3
- J_{SAF} = **−0.221** mJ/m^2
- J_{EB} = **0.188** mJ/m^2

Transport measurements - methods

- 2 point contact method (lead and contact resistance neglectably small < 2 Ohm)
- Voltage source, current measurement
- Pulse length of 400ms





Current induced switching - results

- For 0.71 nm MgO

AP->P

J_c = **7.3 MA/cm²**

P->AP

J_c = **-12.5 MA/cm²**

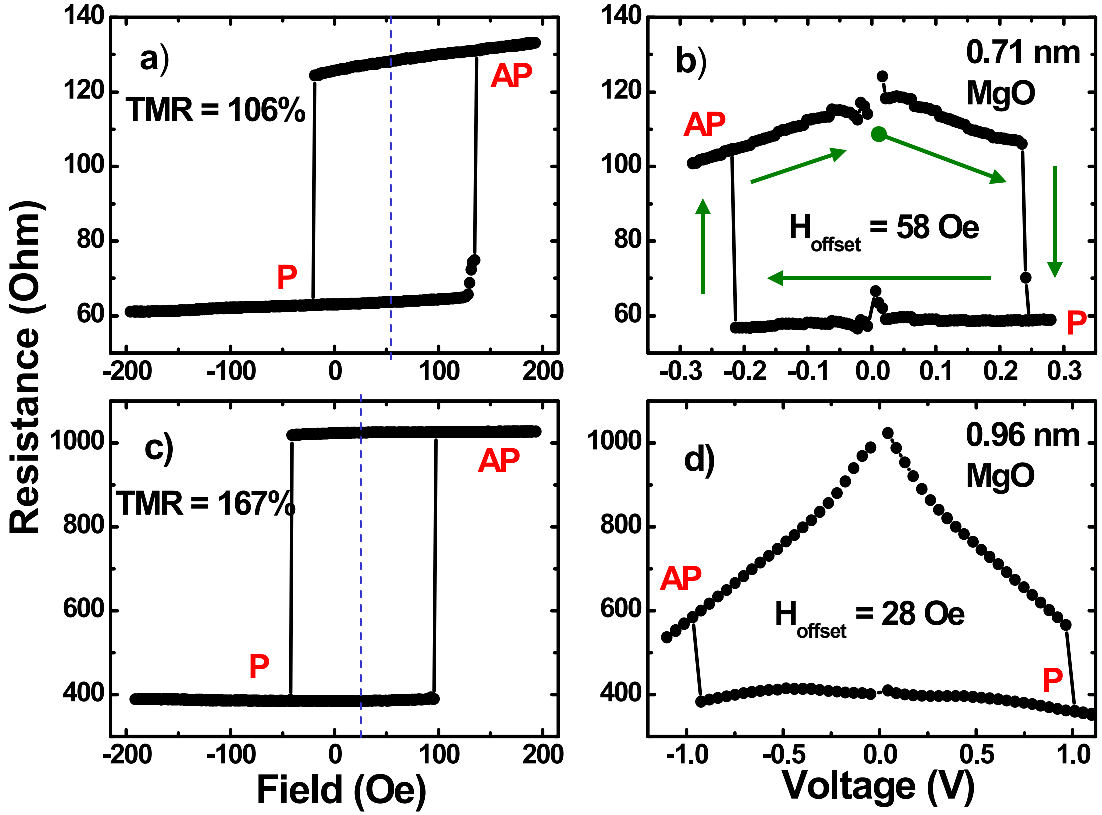
- For 0.96 nm MgO

AP->P

J_c = **5.6 MA/cm²**

P->AP

J_c = **-8 MA/cm²**



*Itoh JPD **40** 1228, 2007*

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Current induced switching - model

- Slonczewski's model:

$$J_{c0} = \frac{2e\alpha\mu_0 M_S{}^2 t_F}{\hbar\eta}$$

$$\eta = \frac{p}{2(1+p^2\cos\theta)}$$

$$J_c = J_{c0}\left[1 - \frac{2k_B T}{M_S V}\cdot\frac{\ln\left(\frac{\tau_P}{\tau_0}\right)}{H_C}\right]$$

M_S = 1.35 T

t_F = 2.3 nm

area = 0.03 um²

α = 0.015

τ_P = 400 ms

H_C = 4 kA/m

		Exp. (MA/cm²)	**Calc.** (MA/cm²)
MgO 0.71 nm	AP->P	**7.3**	**10.1**
	P->AP	**-12.5**	**-20.4**
MgO 0.96 nm	AP->P	**5.6**	**7.7**
	P->AP	**-8**	**-19.2**

– Incorrect assymetry calculation

– Correlates TMR with STT (not really true)

- Better model needed

*Huai et al. JMMM **304** 88, 2006*

*Sankey et al. Nature Phys. **4** 783, 2008*

Summary

- Successful fabrication of MTJ nanopillars with a ultrathin MgO barrier
- IC increases with a decreasing MgO thickness
- The switching current asymmetry increases with a decreasing barrier thickness
- The critical current density is lower for a sample with a thicker MgO barrier (but the switching voltage is higher)

Colaborations

- Bielefeld University, prof. Reiss group
- Helsinki University of Technology, prof. Van Dijken group
- PTB Braunschweig, prof. Schumacher group

Acknowledgement

I would like to thank the Foundation for Polish Science MPD Programme co-financed by the EU European Regional Development Fund.

Thank you for your attention.