



AGH UNIVERSITY OF SCIENCE
AND TECHNOLOGY



Micromagnetic Simulations of Magnetization Dynamics in Magnetic Tunnel Junctions

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Outline

- Introduction to spintronics and its applications
- Real devices: Magnetic Tunnel Junctions
- Investigated phenomenon: Spin Transfer Torque
- Micromagnetic Simulations
- Results and comparison with experiment
- Summary

CHARGE

SPIN

Semiconductor
Integrated Ci

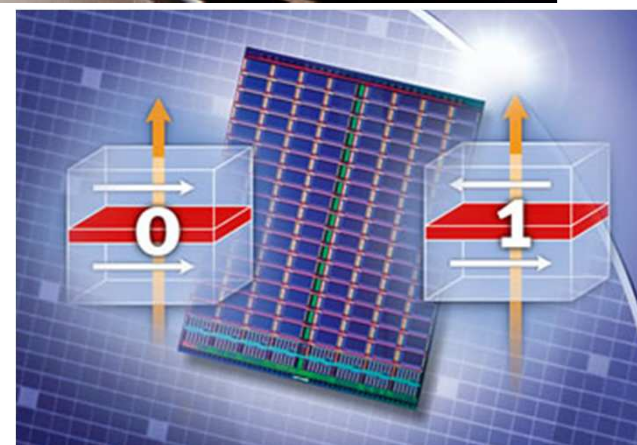
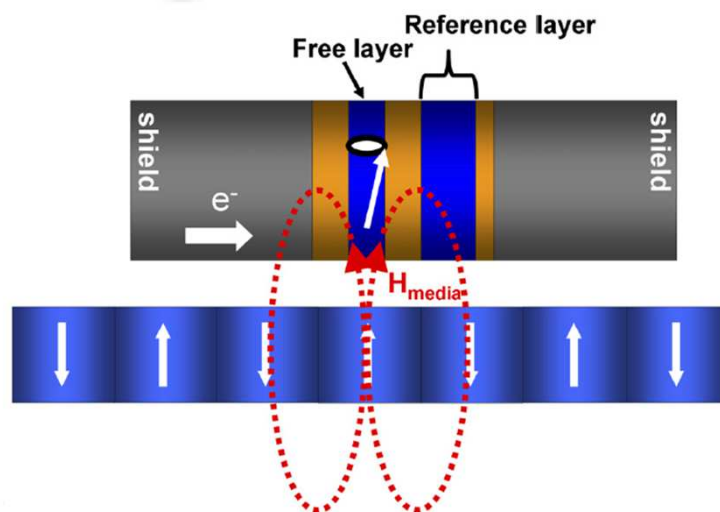
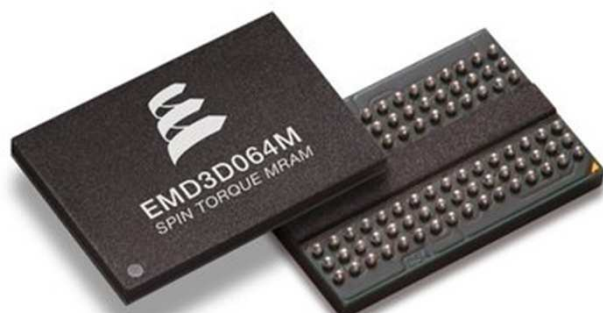
SPINTRONICS

Magnetic Recording
Magnetic Field Sensors

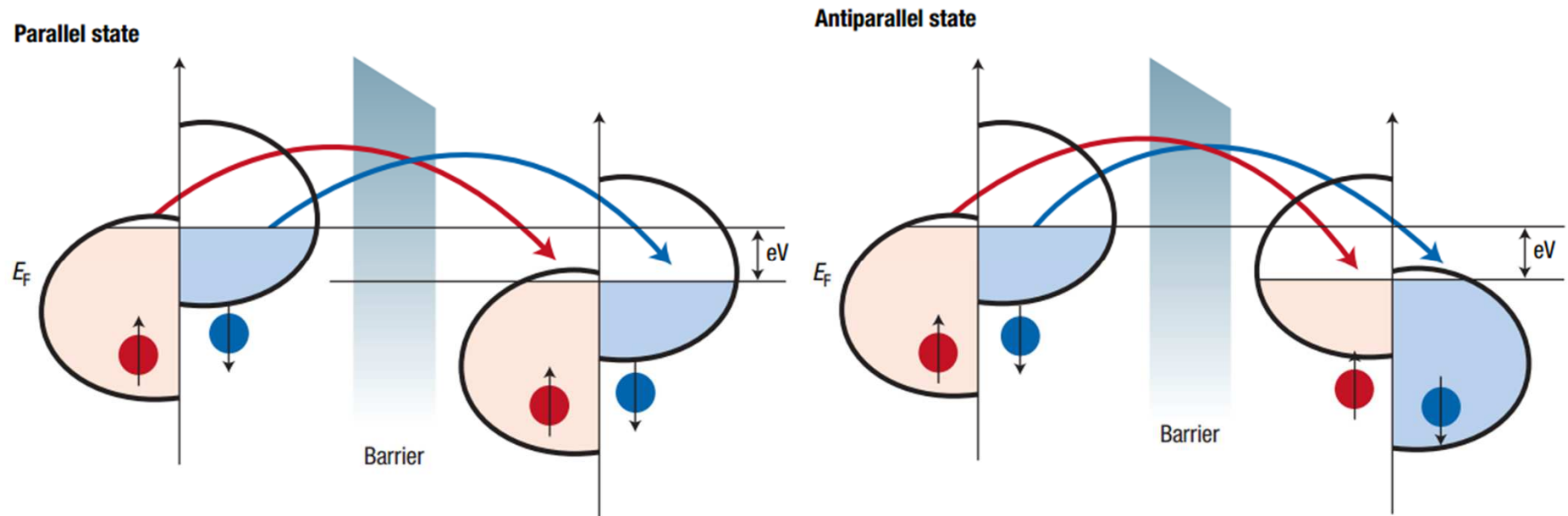
NANOTECHNOLOGY

Applications

- magnetic RAM, nano-oscillators, HDD read heads: data storage density beyond Tb/in²



Magnetic Tunnel Junctions



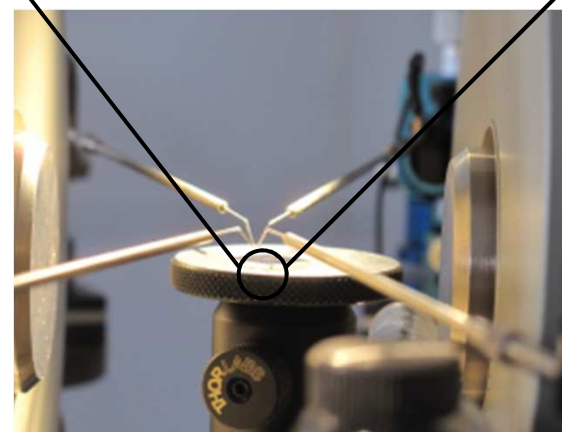
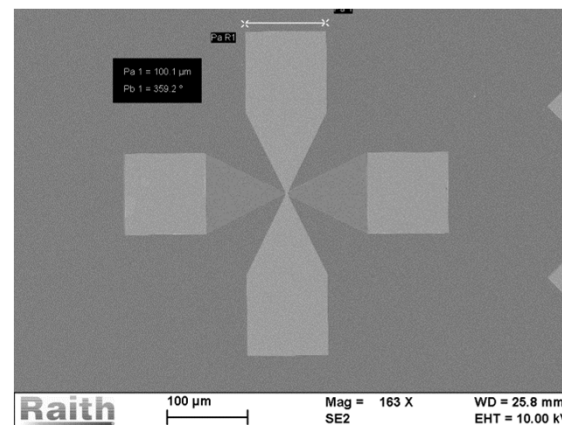
Resistance change due to TMR



theoretically up to 1500% ($T=0K$)
 experimental record 1000% ($T=0K$)
 600% ($T=300K$)



Nanoprocessing and experiments

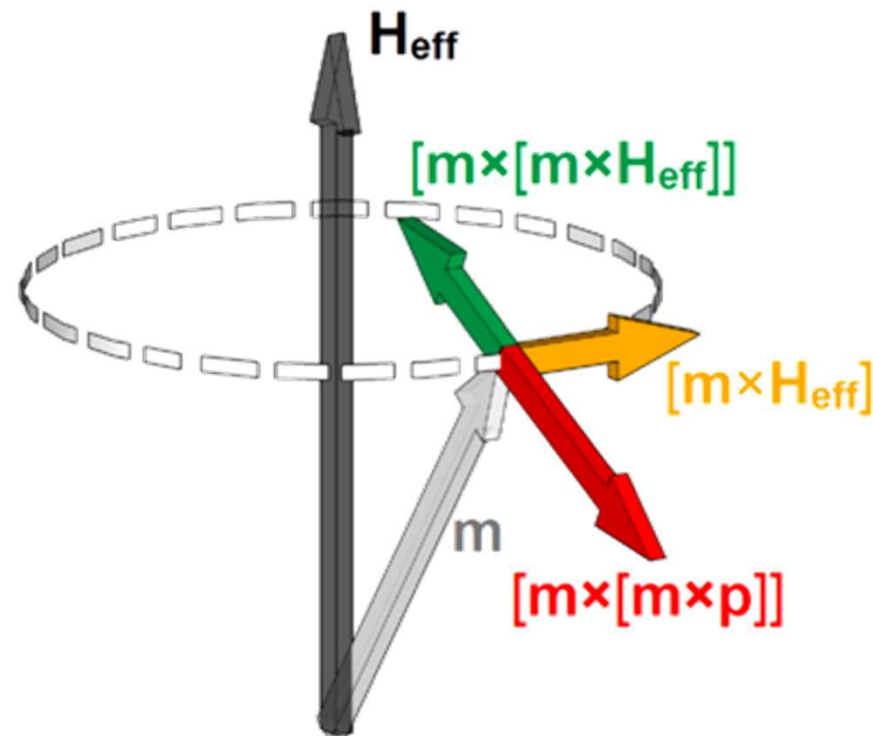


ACMiN
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Spin-Transfer-Torque

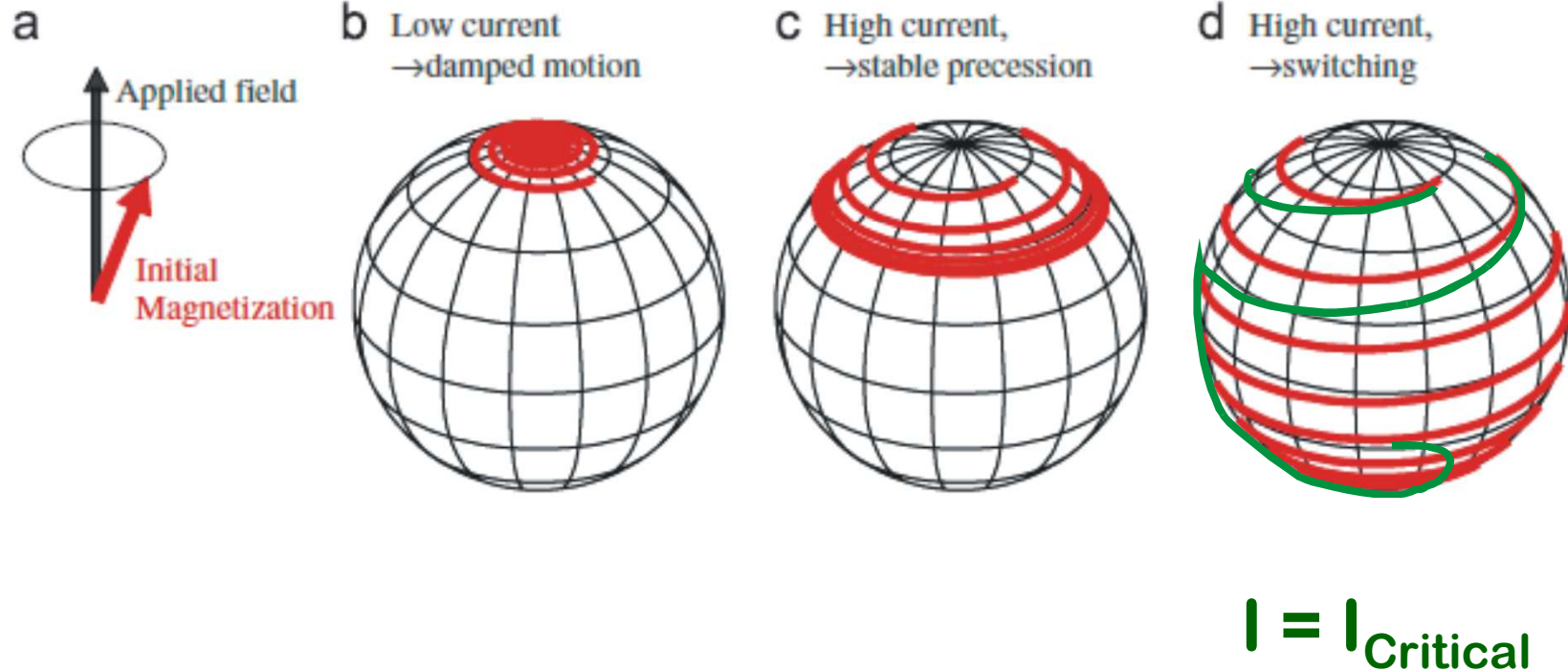
Landau-Lifszyc-Gilbert-Slonczewski (LLGS) equation:

$$\frac{dm}{dt} = -\frac{\gamma}{1+\alpha^2} \left([m \times H_{eff}] + \alpha [m \times [m \times H_{eff}]] - \frac{\hbar j}{eM_{sd}} g(\theta) (\beta [m \times p] - [m \times [m \times p]]) \right)$$



Precession vs. current

Moment in an applied field along z with no anisotropy



Ralph, Stiles JMMM 320, 1190 (2008)

Models of magnetization dynamics based on LLG equation

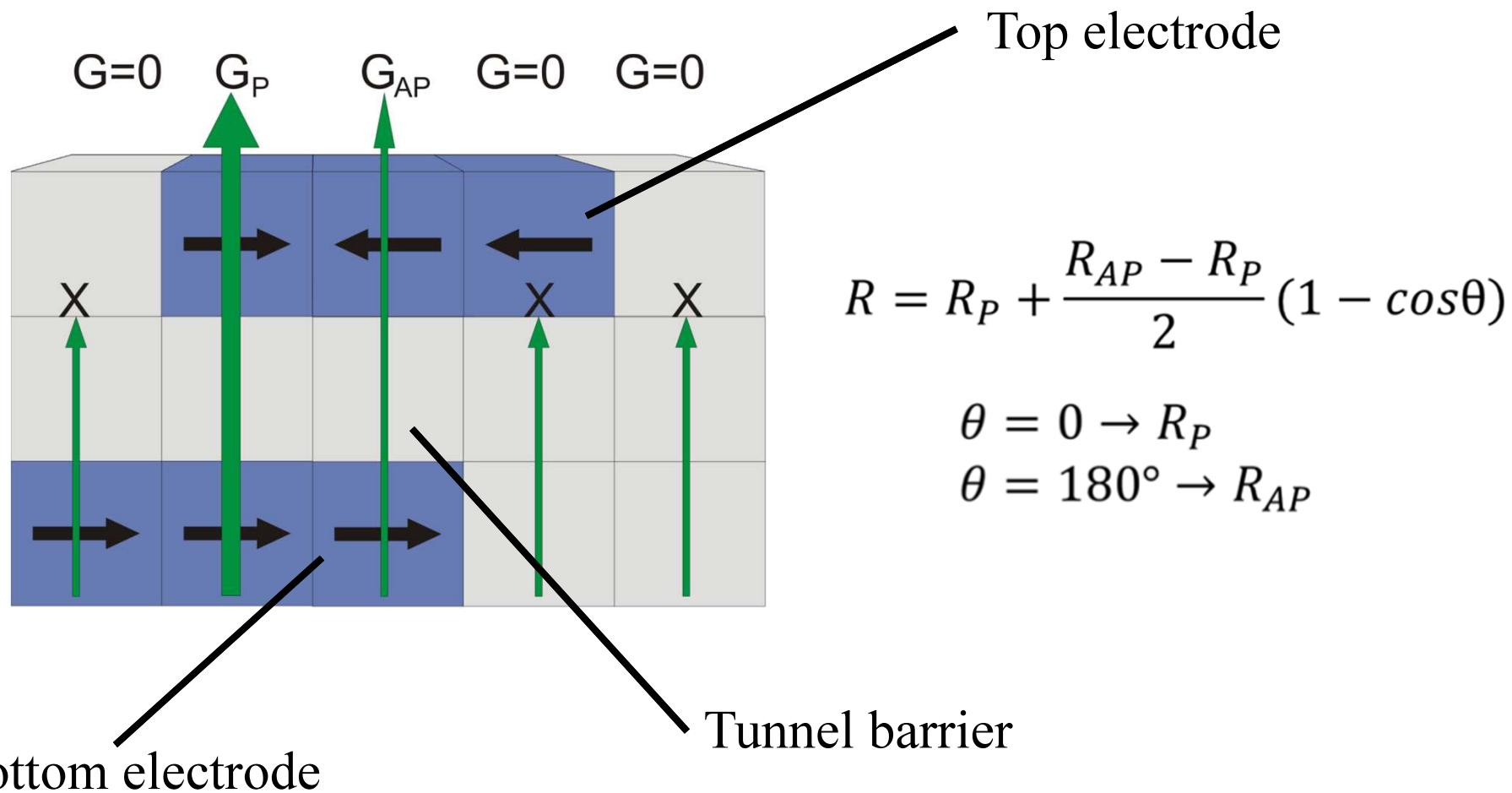
Macrospin:

- Homogenous magnetization
- Analytical calculations possible

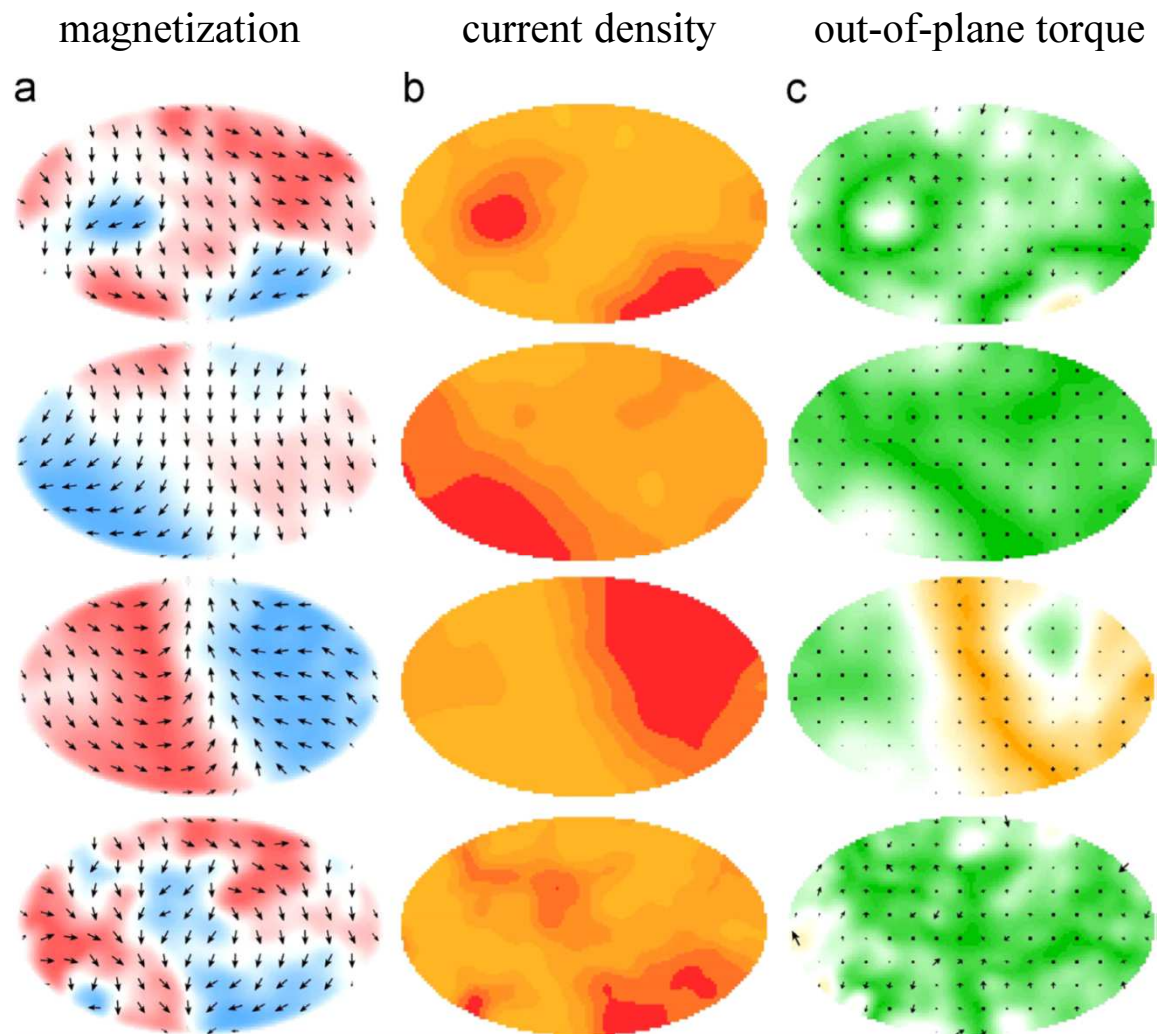
Microspin:

- Spatial distribution of magnetization (continuous medium model)
- Numerical calculations

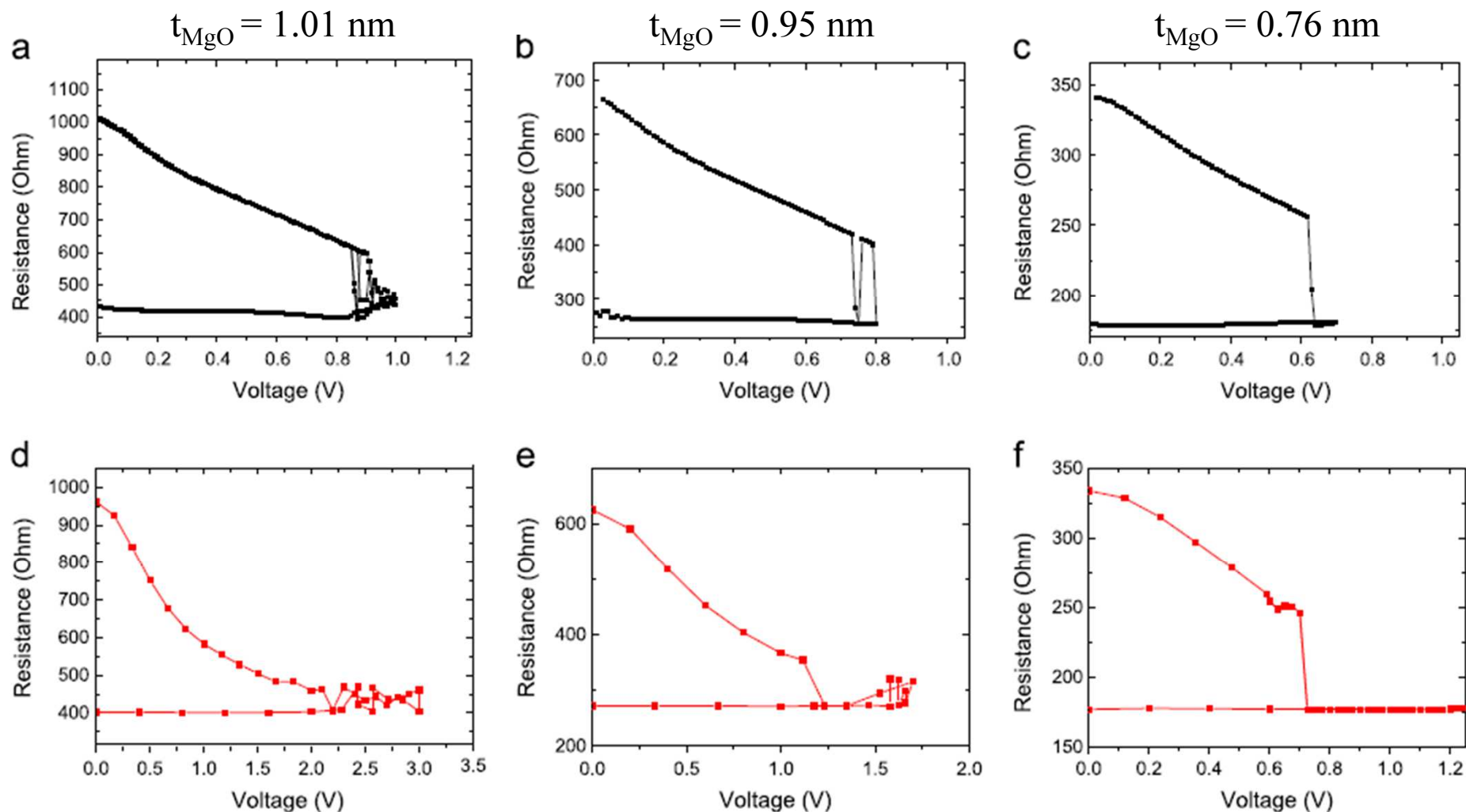
Current flow model



Local values of simulation variables

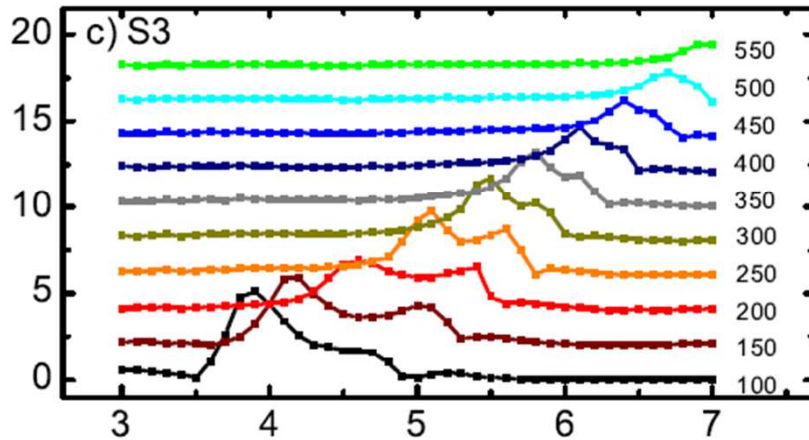
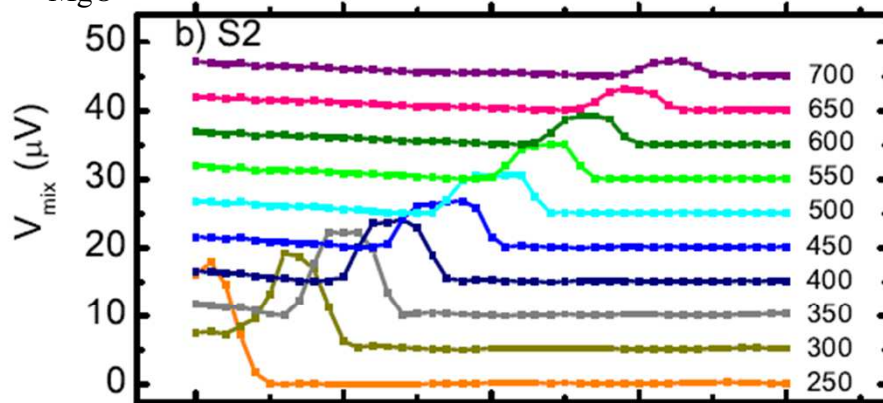


Backhopping effect

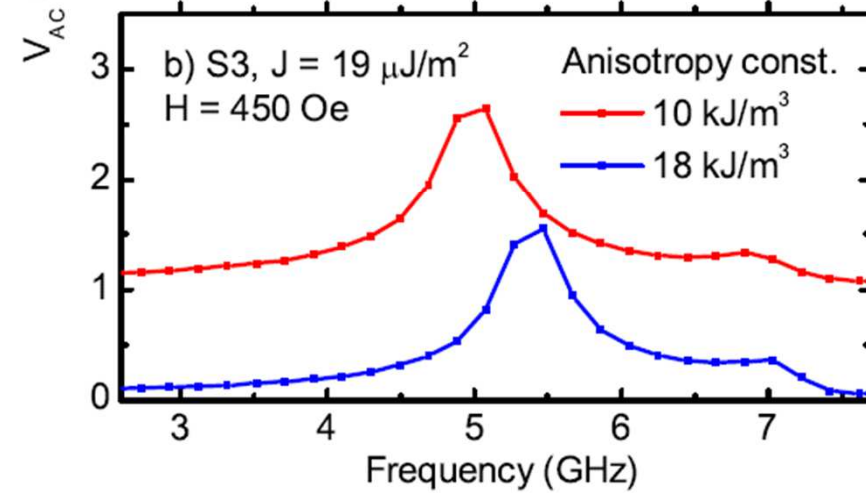
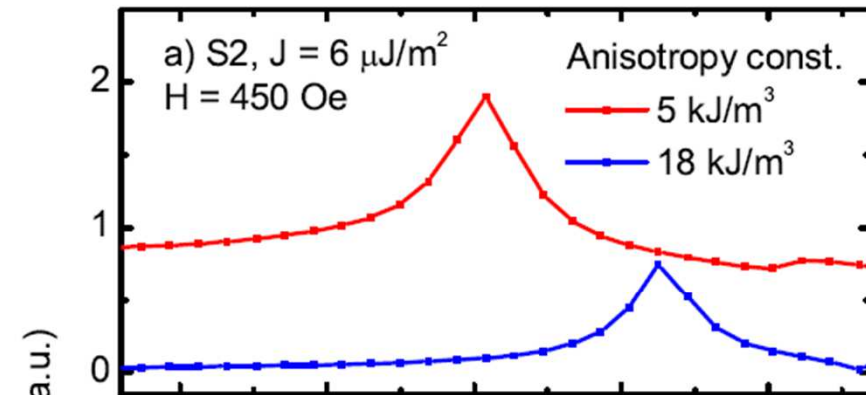


Spin Torque - FMR

$t_{\text{MgO}} = 0.95 \text{ nm}$



$t_{\text{MgO}} = 0.76 \text{ nm}$





Summary

- Spintronics – interdisciplinary branch of science providing electronics nano-elements
- Micromagnetic simulations – efficient modelling method of spintronics devices
- Agreement with experimental data obtained also on AGH
- Usege of PL-GRID infrastructure allows for extensive simulations



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References citing PL-GRID

- [1] W. Skowroński, M. Czapkiewicz, **M. Frankowski**, J. Wrona, T. Stobiecki, G. Reiss, K. Chalapat, G. S. Paraoanu, S. van Dijken, *Influence of MgO tunnel barrier thickness on spin-transfer ferromagnetic resonance and torque in magnetic tunnel junctions*, **Physical Review B**, 2013, vol. 87 iss. 9 s. 094419-1–094419-5.
- [2] **M. Frankowski**, M. Czapkiewicz, W. Skowroński, T. Stobiecki, *Micromagnetic model for studies on magnetic tunnel junction switching dynamics, including local current density*, **Physica B: Condensed Matter**, 2014, 435, 105–108.
- [3] W. Skowroński, **M. Frankowski**, J. Wrona, T. Stobiecki, P. Ogrodnik, J. Barnaś, *Spin-torque diode radio-frequency detector with voltage tuned resonance*, **Applied Physics Letters**, 2014, 105, 072409.
- [4] **M. Frankowski**, W. Skowroński, M. Czapkiewicz, T. Stobiecki, *Backhopping in magnetic tunnel junctions: Micromagnetic approach and experiment*, **Journal of Magnetism and Magnetic Materials**, 2015, 374, 451–454.
- [5] **M. Frankowski**, J. Chęciński, M. Czapkiewicz, *Spatial Spectrum Analyzer (SSA): a tool for calculations of spatial distribution of fast Fourier transform spectrum from Object Oriented Micromagnetic Framework output data*, **Computer Physics Communications** 189 (2015), 207–212.
- [6] S. Ziętek, P. Ogrodnik, **M. Frankowski**, J. Chęciński, P. Wiśniowski, W. Skowroński, J. Wrona, T. Stobiecki, A. Żywczak, J. Barnaś, *Rectification of radio-frequency current in a giant-magnetoresistance spin valve*, **Physical Review B**, 2015 91, 014430.



Thank you for your attention.