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CONTRIBUTION

# Backhopping in magnetic tunnel junctions – micromagnetic approach and experiment

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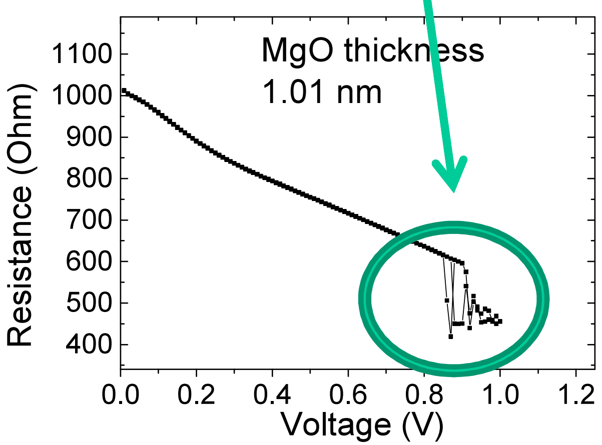
# Outline

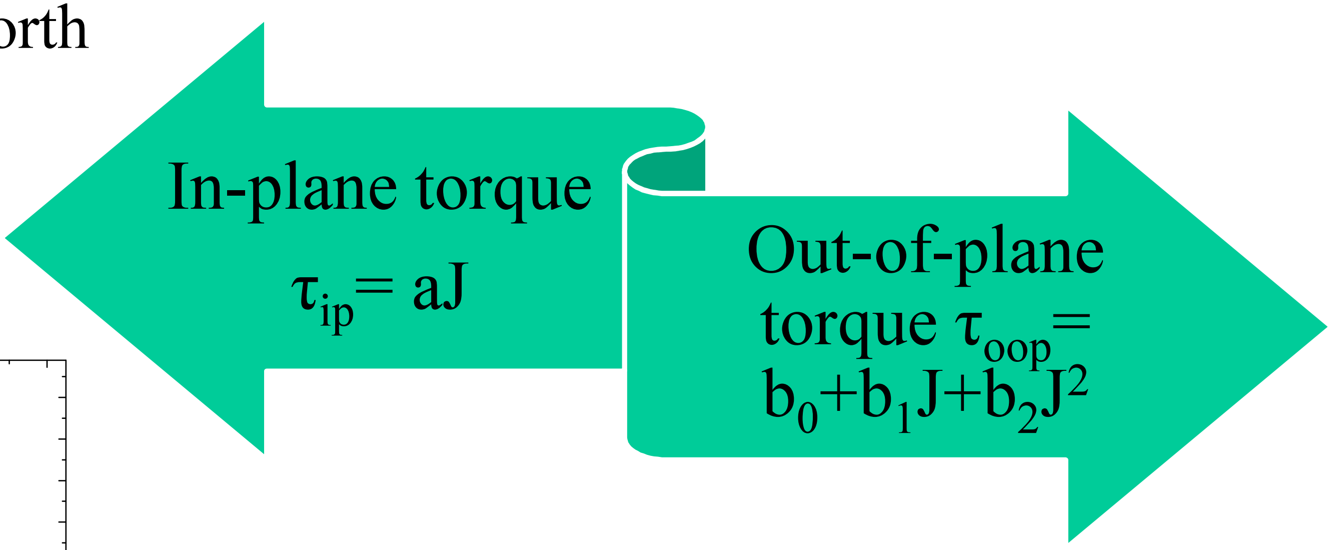
- Backhopping phenomena origin
- Investigated system
- Micromagnetic model
- Results and comparison with experiment
- Summary

# Backhopping phenomena

Random back-and-forth switching



Competition between STT components



In-plane torque

$\tau_{ip} = aJ$

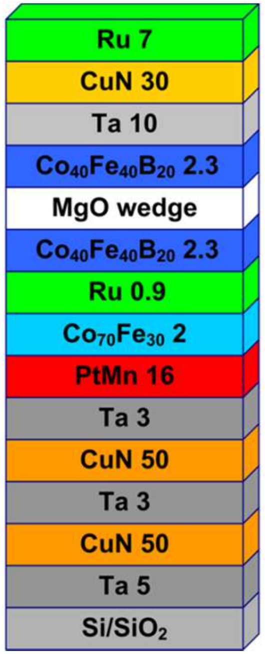
Out-of-plane torque $\tau_{oop} = b_0 + b_1 J + b_2 J^2$

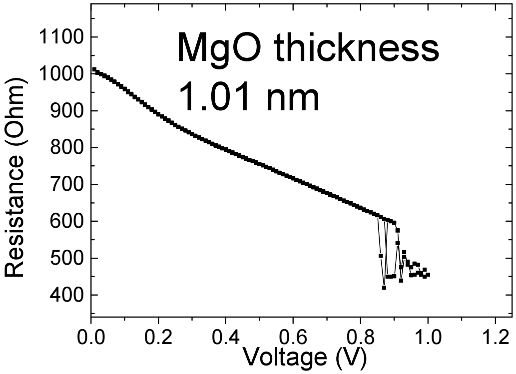
For certain voltage range torques have similar magnitudes and opposite signs

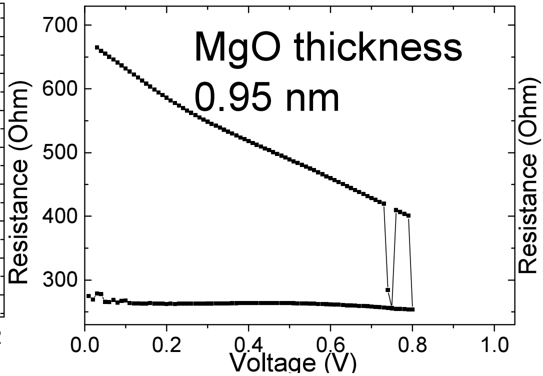
W. Skowroński et. al. J. Appl. Phys. **114**, 233905 (2013).

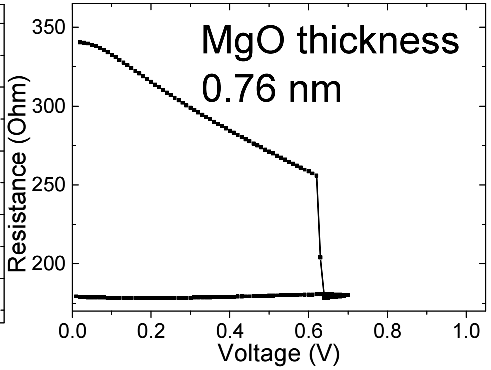
# Investigated system

## System specification and CIMS expreiment









Interlayer exchange coupling

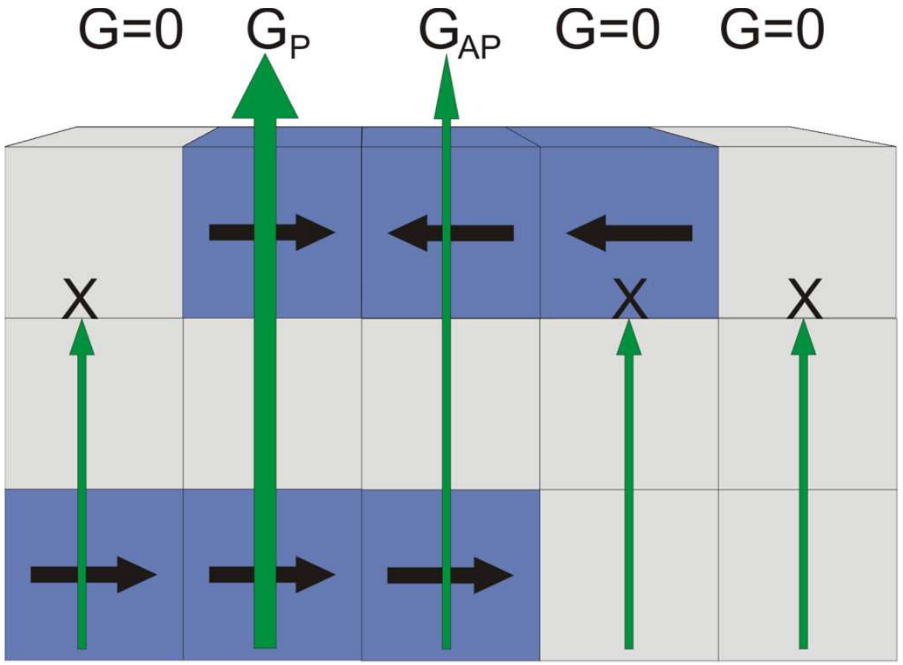
Anti-ferromagnetic

Ferromagnetic

W. Skowroński et. al. J. Appl. Phys. **114**, 233905 (2013).

# Micromagnetic model

## Channels connected in parallel



resistance given by formula:

$$R = R_P + \frac{R_{AP} - R_P}{2}(1 - cos\theta)$$

$$\theta = 0 \rightarrow R_P$$
$$\theta = 180° \rightarrow R_{AP}$$

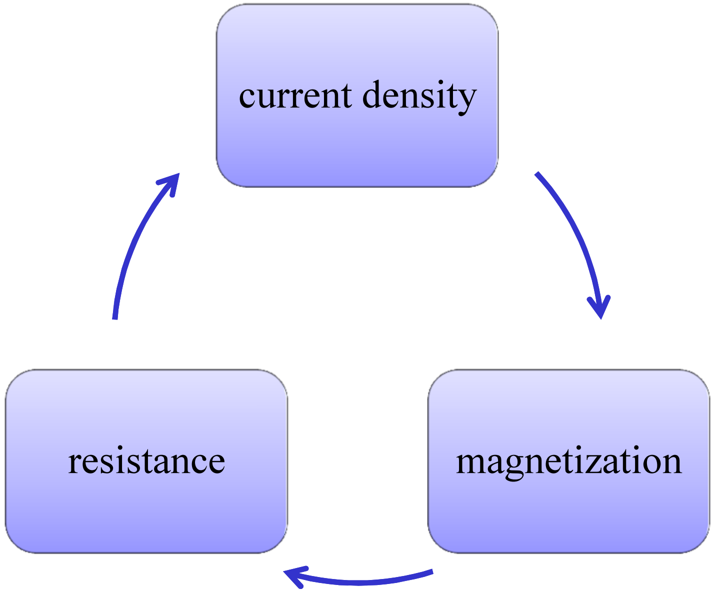
where $R_{AP}$ can be constant or fitted from the experiment

M. Frankowski et. al. Phys. B 435, 105–108 (2014).
D. Aurelioa et. al. J. M. M. 321, 39133920 (2009).

# Spin-Transfer-Torque

## LLG equation with Slonczewski's component

$$\frac{d\vec{m}}{dt} = \underset{\substack{\uparrow \\ \text{precession}}}{-\gamma_0 \vec{m} \times \vec{H}_{eff}} + \underset{\substack{\uparrow \\ \text{damping}}}{\alpha \vec{m} \times \frac{\partial \vec{m}}{\partial t}} + \underset{\substack{\uparrow \\ \text{in-plane torque}}}{\gamma_0 a_J \vec{m} \times (\vec{m} \times \vec{p})} + \underset{\substack{\uparrow \\ \text{prependicular torque}}}{\gamma_0 b_J \vec{m} \times \vec{p}}$$


current density

magnetization

resistance

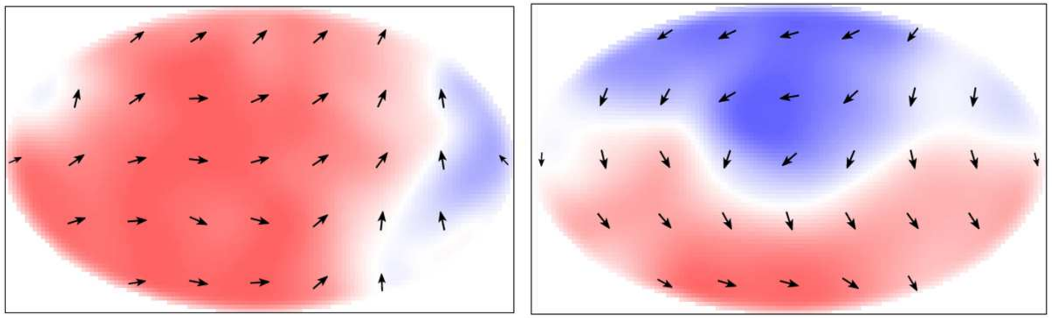
current-resistance feedback
due to STT and magnetoresitance

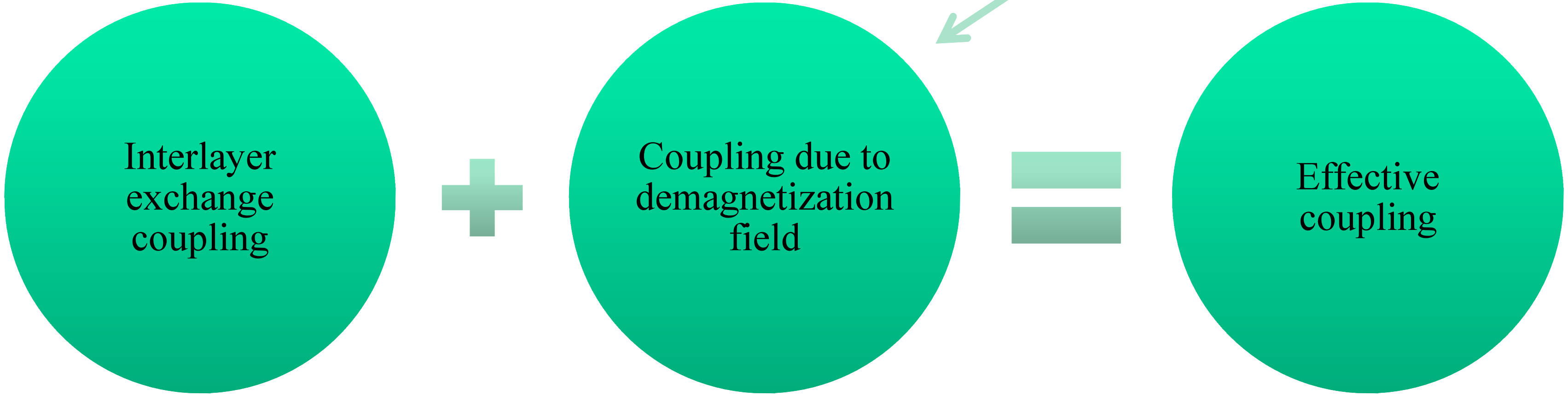
# Model parameterization

Obtainable in experiment

$$\tau_{oop} = b_0 + b_1 J + b_2 J^2$$

Not obtainable in experiment





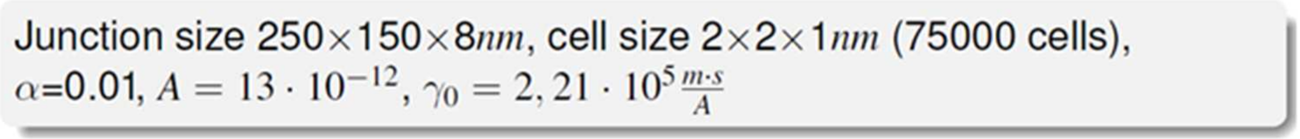
Interlayer exchange coupling

Coupling due to demagnetization field

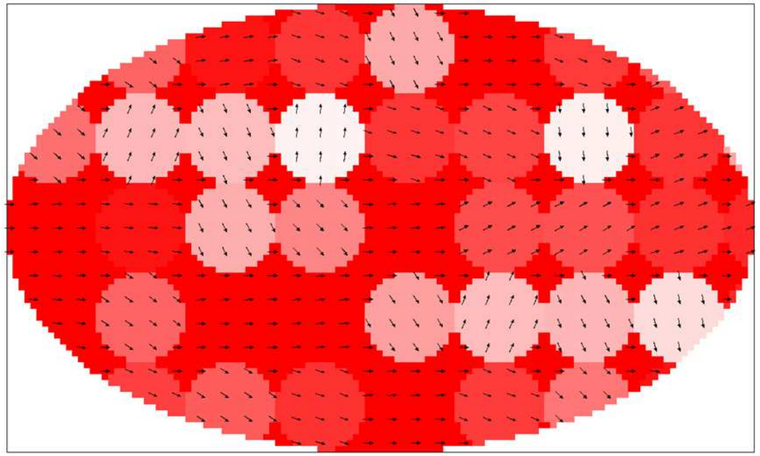
Effective coupling

W. Skowroński et. al. Phys. Rev. B **87**, 094419 (2013).

# Model parameterization


Junction size 250×150×8$nm$, cell size 2×2×1$nm$ (75000 cells),
$\alpha$=0.01, $A = 13 \cdot 10^{-12}$, $\gamma_0 = 2,21 \cdot 10^5 \frac{m \cdot s}{A}$

Non-ideal synthetic antiferromagnet due to Tsunoda model



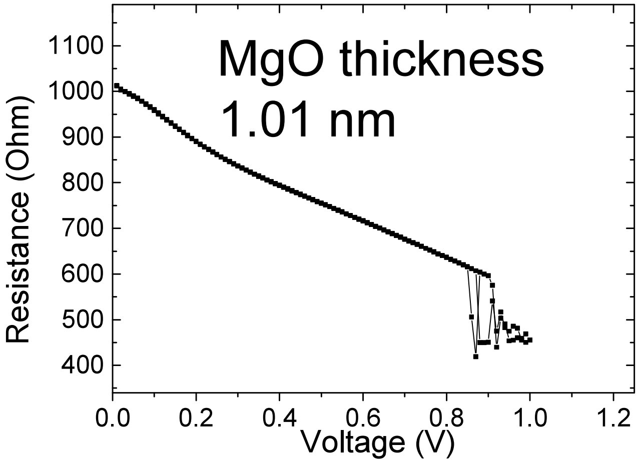
M. Tsunoda et. al. J. M. M. 239, 149153 (2002).

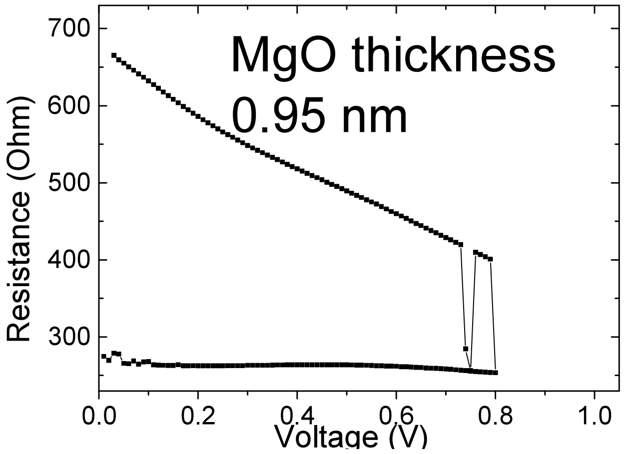
$J_{MgO}(0.76nm) = 6.7\mu J/m^2$ → Effective ferromagnetic coupling

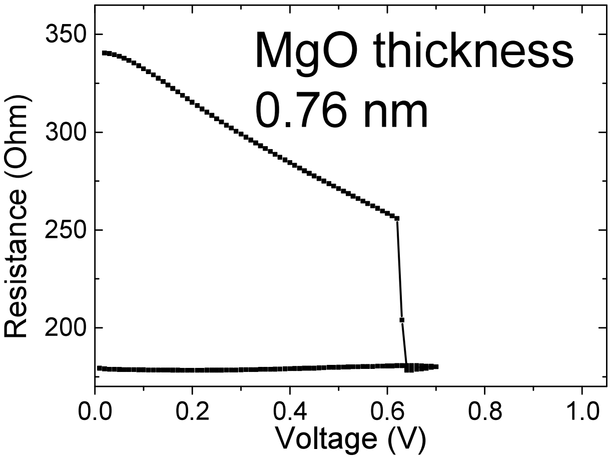
$J_{MgO}(0.95nm) = 1.8\mu J/m^2$ → Effective weak anti-ferromagnetic coupling

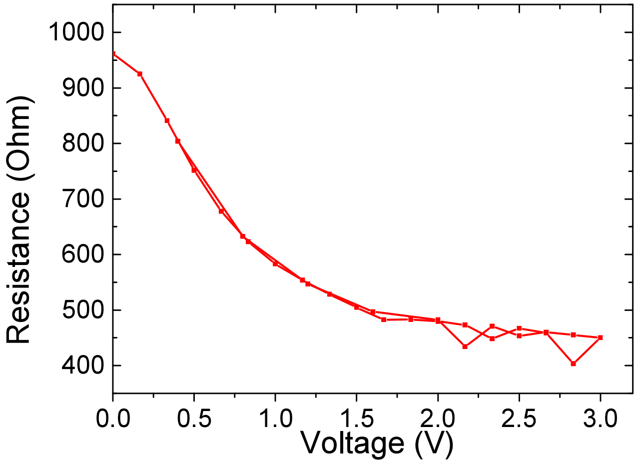
$J_{MgO}(1.01nm) = 0.1\mu J/m^2$ → Effective strong anti-ferromagnetic coupling

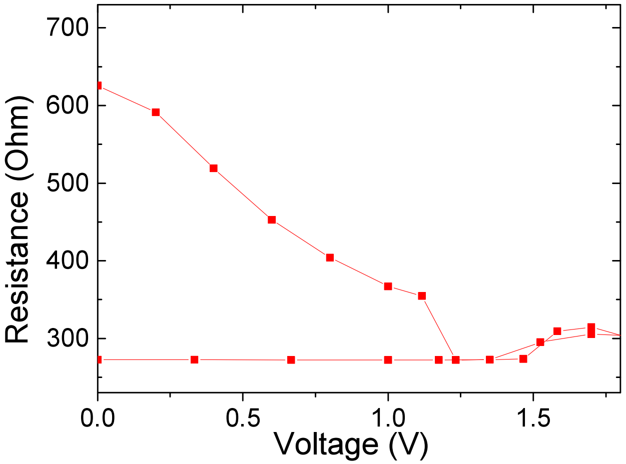
# Results

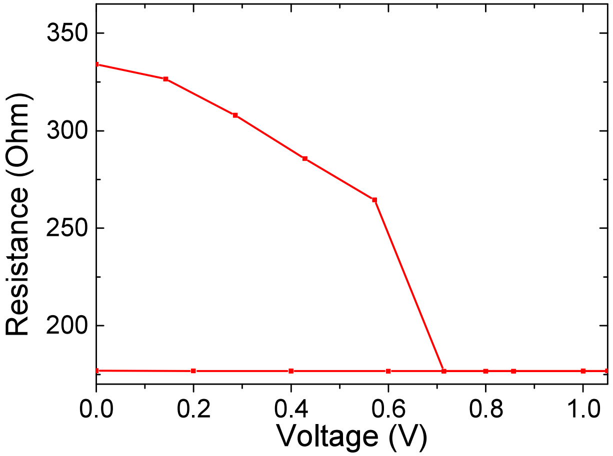

MgO thickness
1.01 nm
Resistance (Ohm)
1100
1000
900
800
700
600
500
400
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Voltage (V)


MgO thickness
0.95 nm
Resistance (Ohm)
700
600
500
400
300
0.0
0.2
0.4
0.6
0.8
1.0
Voltage (V)


MgO thickness
0.76 nm
Resistance (Ohm)
350
300
250
200
0.0
0.2
0.4
0.6
0.8
1.0
Voltage (V)


Resistance (Ohm)
1000
900
800
700
600
500
400
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Voltage (V)


Resistance (Ohm)
700
600
500
400
300
0.0
0.5
1.0
1.5
Voltage (V)


Resistance (Ohm)
350
300
250
200
0.0
0.2
0.4
0.6
0.8
1.0
Voltage (V)

# Summary

- We have developed an open source extension of OOMMF, that allows for simulation of STT due to current flow in function of applied time-changing voltage.
- We have implemented current-resistance feedback and AP state resistance changes which affects dynamics of switching process.
- We have investigated backhopping occurrence in function of effective interlayer exchange coupling trough MgO barrier confirming previous macrospin calculations which shown that for ferromagnetic coupling there can be no backhopping near switching voltage.

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