AGH University of Science and Technology

Electric-field controlled spintronic devices (E-CONTROL)

Micromagnetic analysis of voltage-driven dynamics in thin ferromagnetic layer systems

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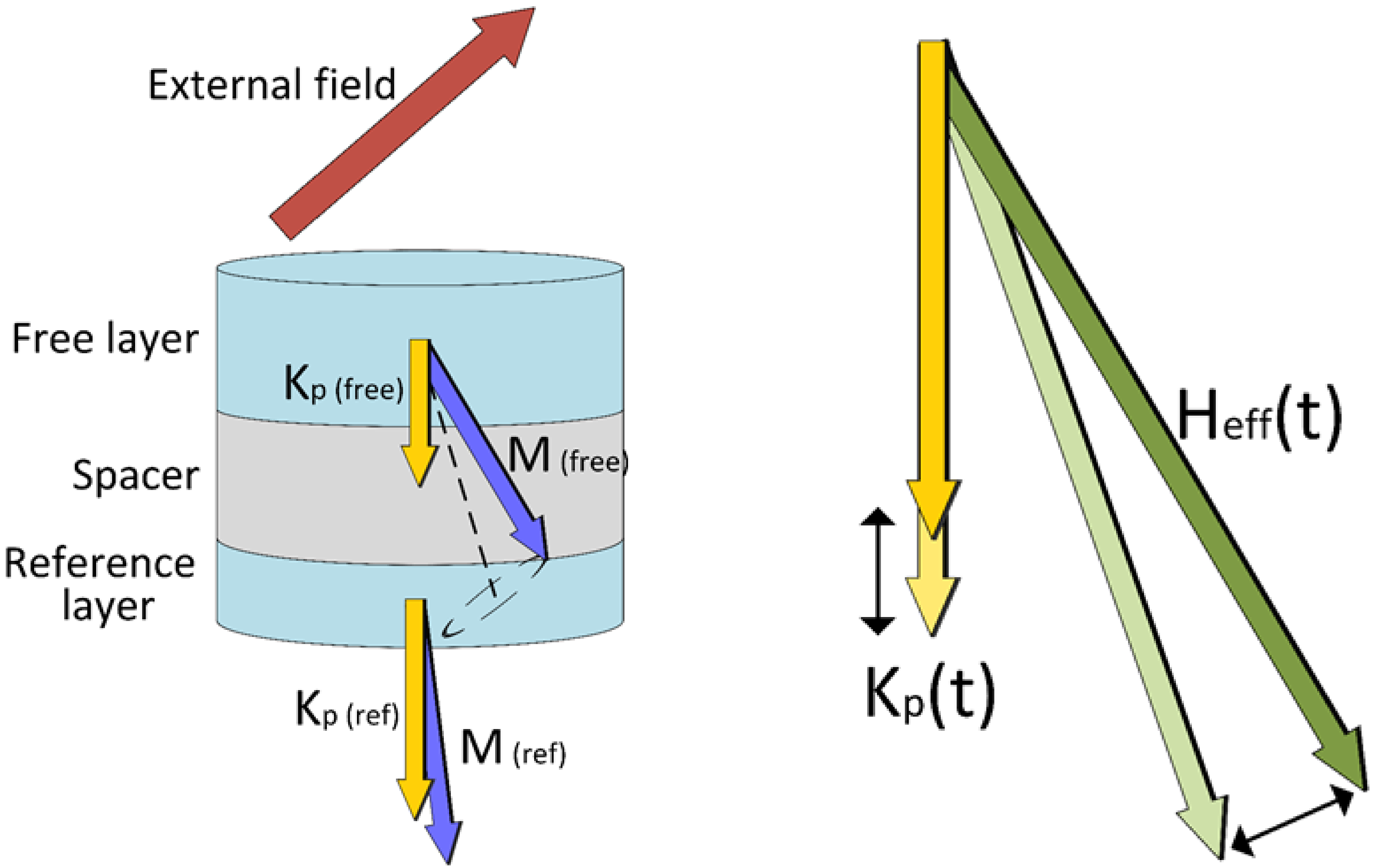
Outline

- Introduction to voltage-driven dynamics
- Effective anisotropy
- Approach and sample used
- Voltage-induced switching
- FMR lineshape
- Simulation results for different anisotropy regimes
- Summary and acknowledgements

Magnetization equilibrium manipulation



Voltage-driven dynamics

Junction with thick tunnel barrier
> 1.5 nm

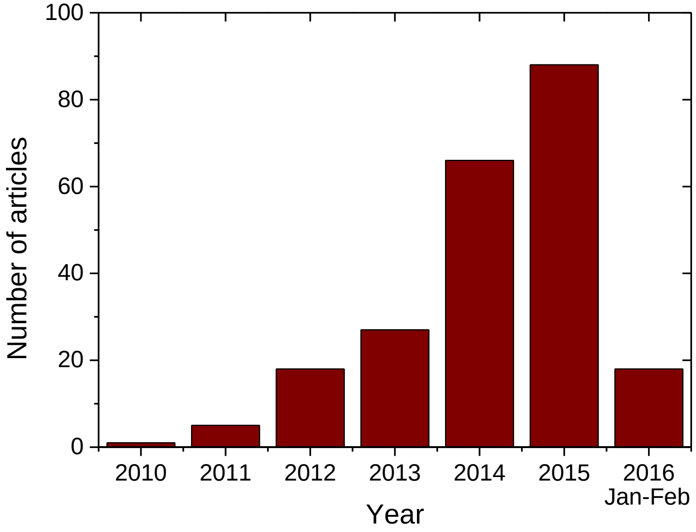
↓

High resistance of the device

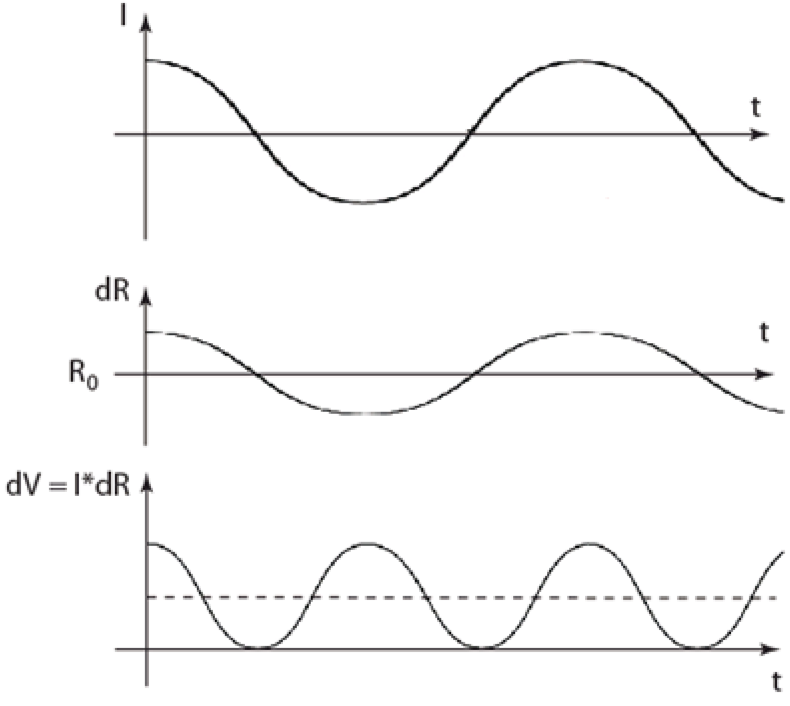
↓

Negligible current in comparison
to current-controlled devices

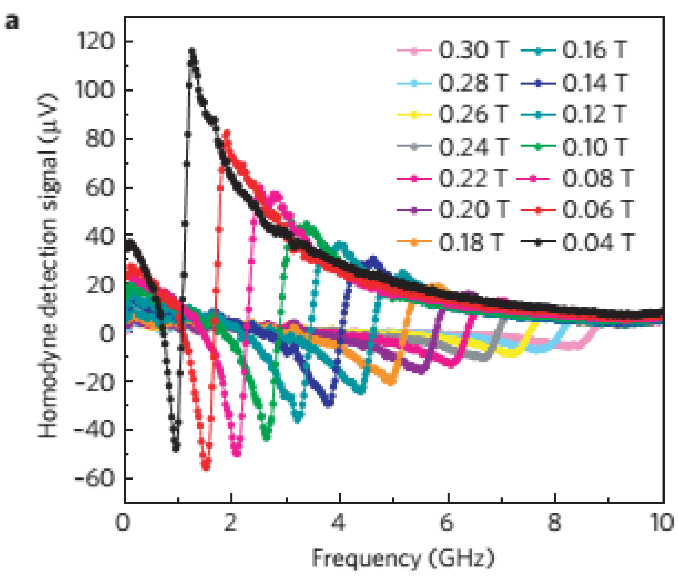
AC voltage control of anisotropy desired for low energy consumption applications



Detection via spin diode effect



- MTJ supplied with radio frequency signal
- Precession of magnetization in phase with input signal – mixing results in a DC signal generation



Tulapurkar et al. Nature 438, 339, 2005

Nozaki et al. Nature Phys 8, 491, 2012

PMA vs. in-plane anisotropy

Recently reported:
Skowroński et. al., APEX 8.5 (2015): 053003

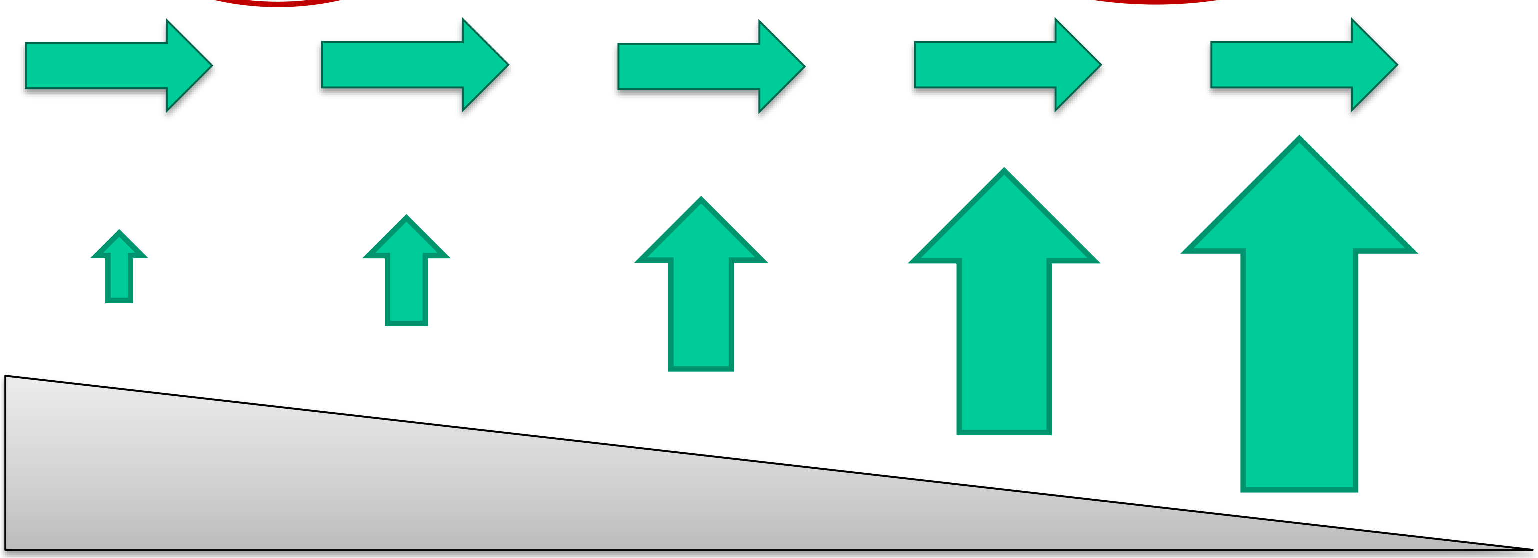
Commonly investigated in literature

Effective anisotropy	In-plane regime	Transition regime	Perpendicular regime

In-plane component

PMA component

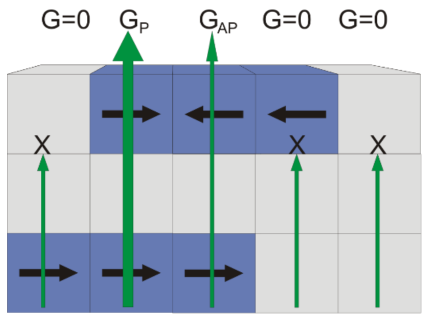
Layer thickness



Micromagnetic approach

OOMMF-based simulations

$$\frac{d\vec{m}}{dt} = -\gamma_0 \vec{m} \times \vec{H}_{eff} + \alpha \vec{m} \times \frac{\partial \vec{m}}{\partial t}$$



M.J. Donahue, D.G. Porter, NIST Report (1999).
M. Frankowski et. al. Phys. B 435, 105–108 (2014).

Ferromagnetic free layer: 1.4 nm (2 cells), Ms 1200 kA/m, K out-of-plane VARIABLE kJ/m^3

MgO barrier: 1.4 nm (2 cells)

Ferromagnetic reference layer: 0.7 nm (1 cell), Ms 1000 kA/m, K out-of-plane 1500 kJ/m^3

- **Custom OOMMF extension installed on the PL-Grid infrastructure**
- **Intrinsic (Gilbert) damping constant 0.017**
- **Alternating anisotropy contributes to the effective field H_{eff}**

Calculations of lineshape

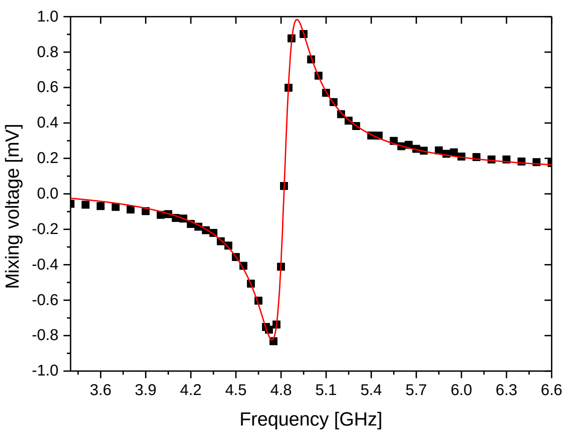
Resonance frequency calculations for different external field values

50-100 simulations for a single set of parameters generated automatically

Parallel computations give raw simulation result

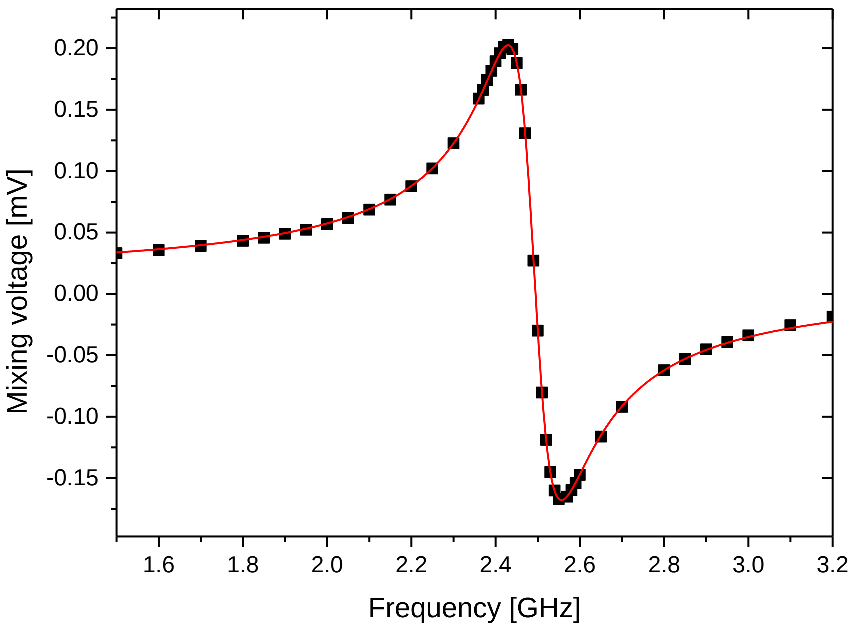
Post-processing to obtain the final lineshape

f_1
f_2
...
f_r
...
f_{n-1}
f_n

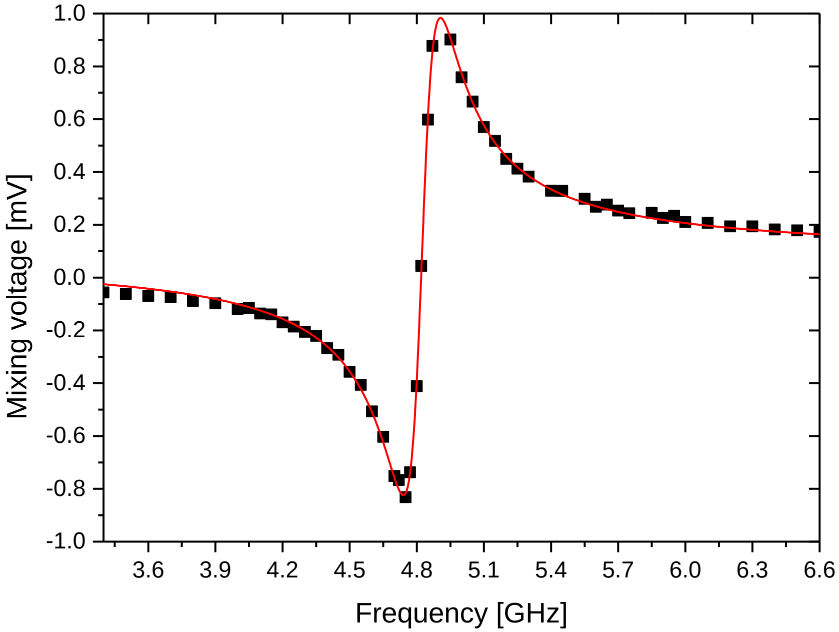


Calculations of lineshape

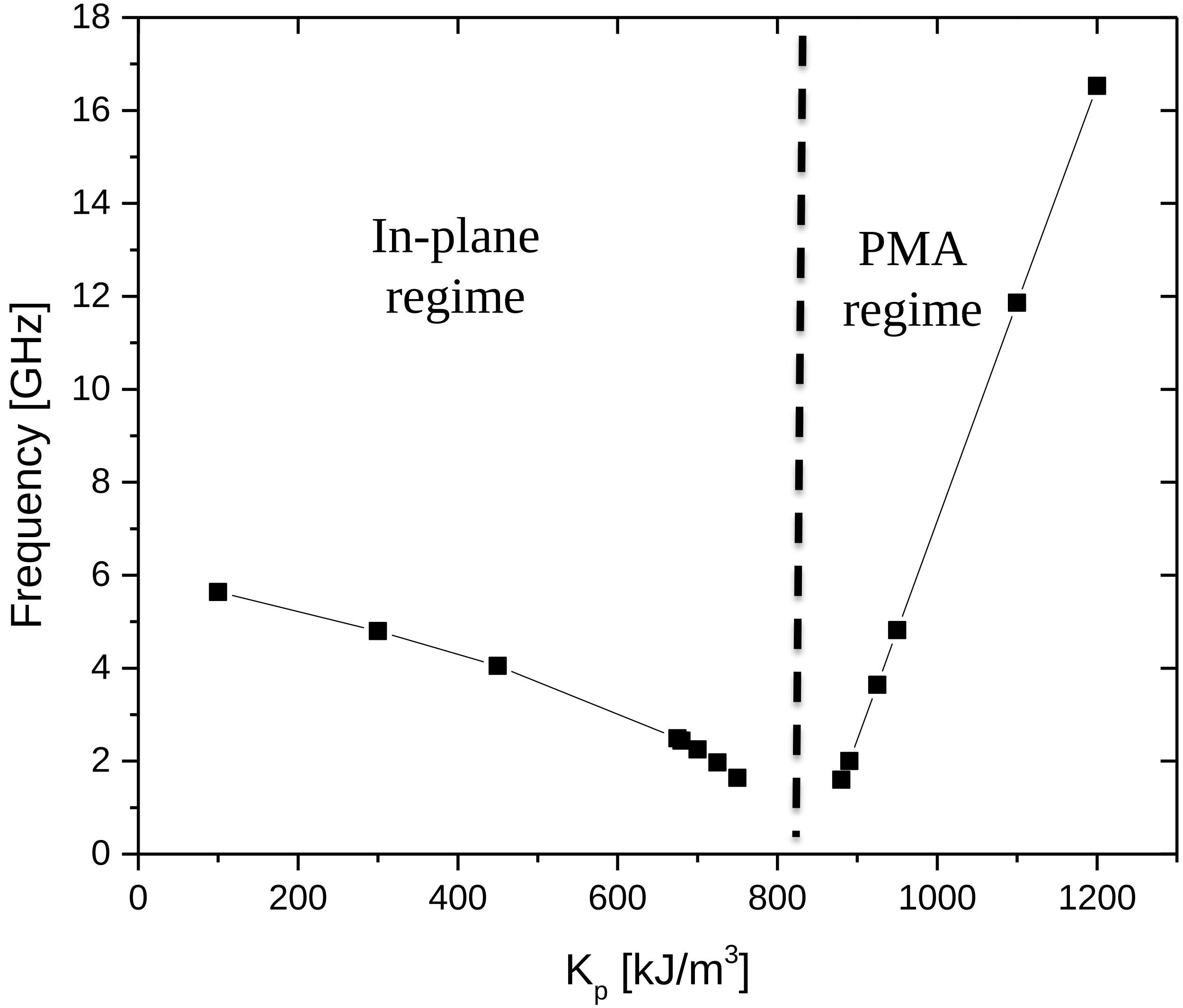
K_p=675kJ/m^3
$K_{effective}$: in-plane



K_p=950kJ/m^3
$K_{effective}$: PMA

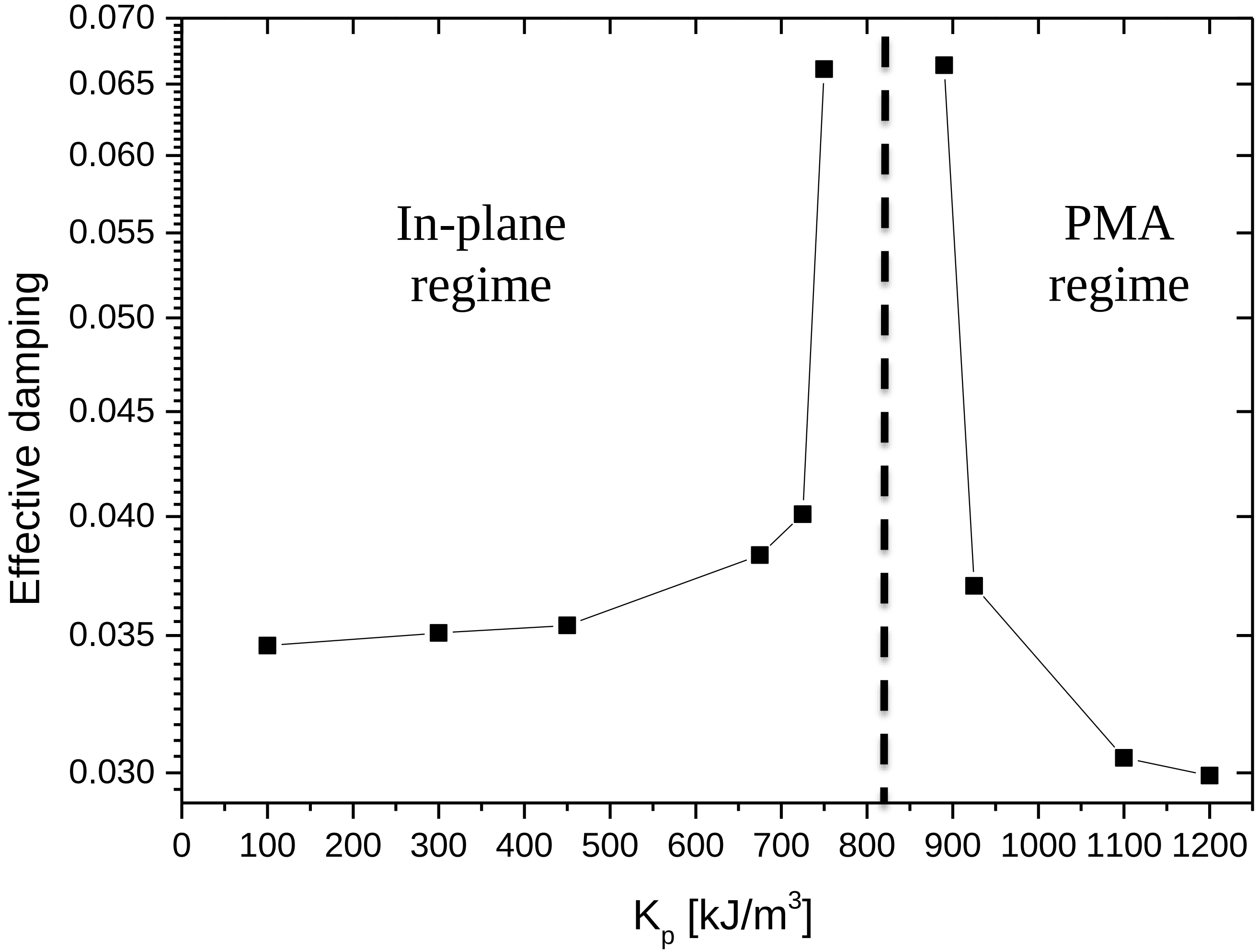


Frequency

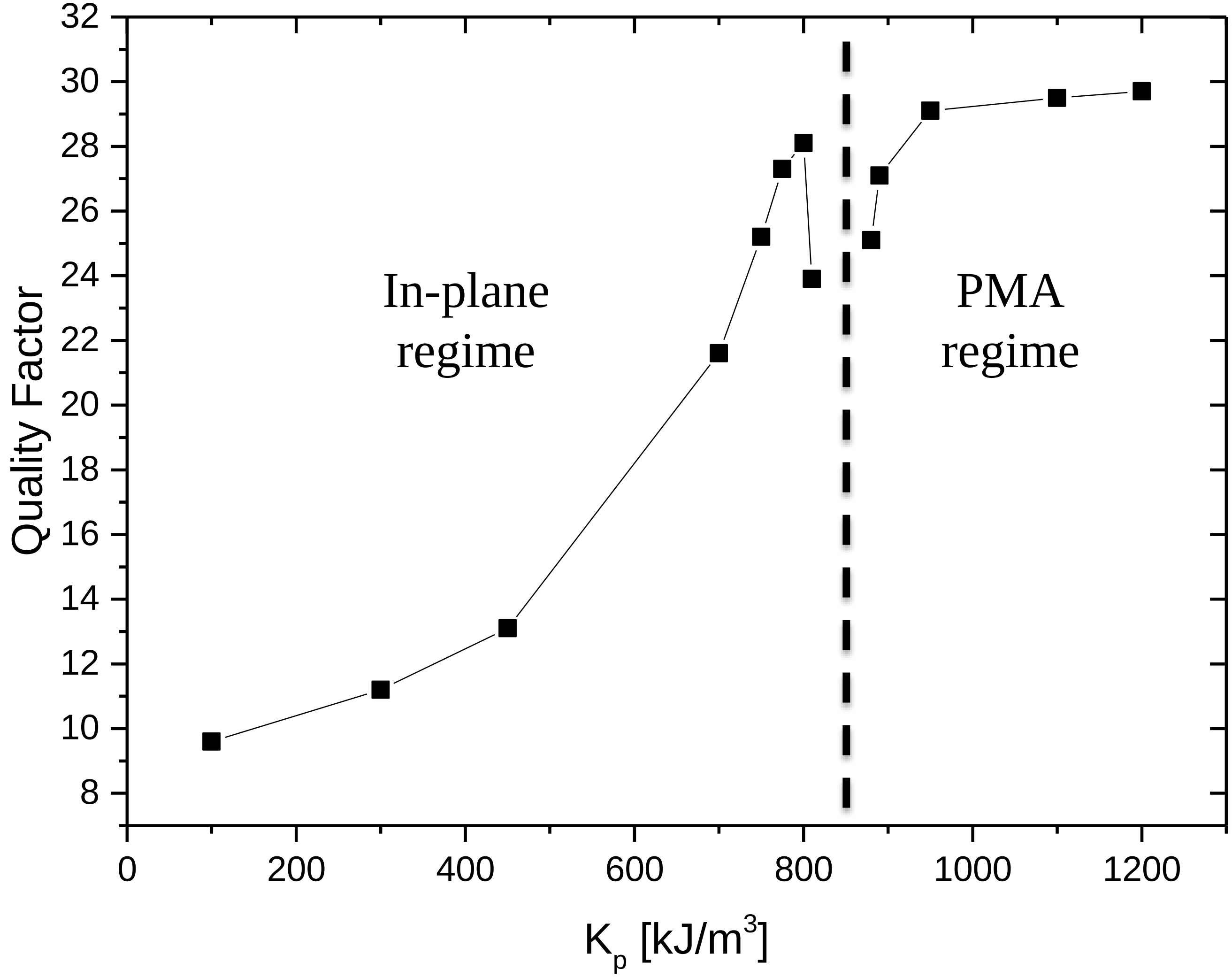


In-plane
regime
PMA
regime
Frequency [GHz]
K_p [kJ/m^3]
0
2
4
6
8
10
12
14
16
18
0
200
400
600
800
1000
1200

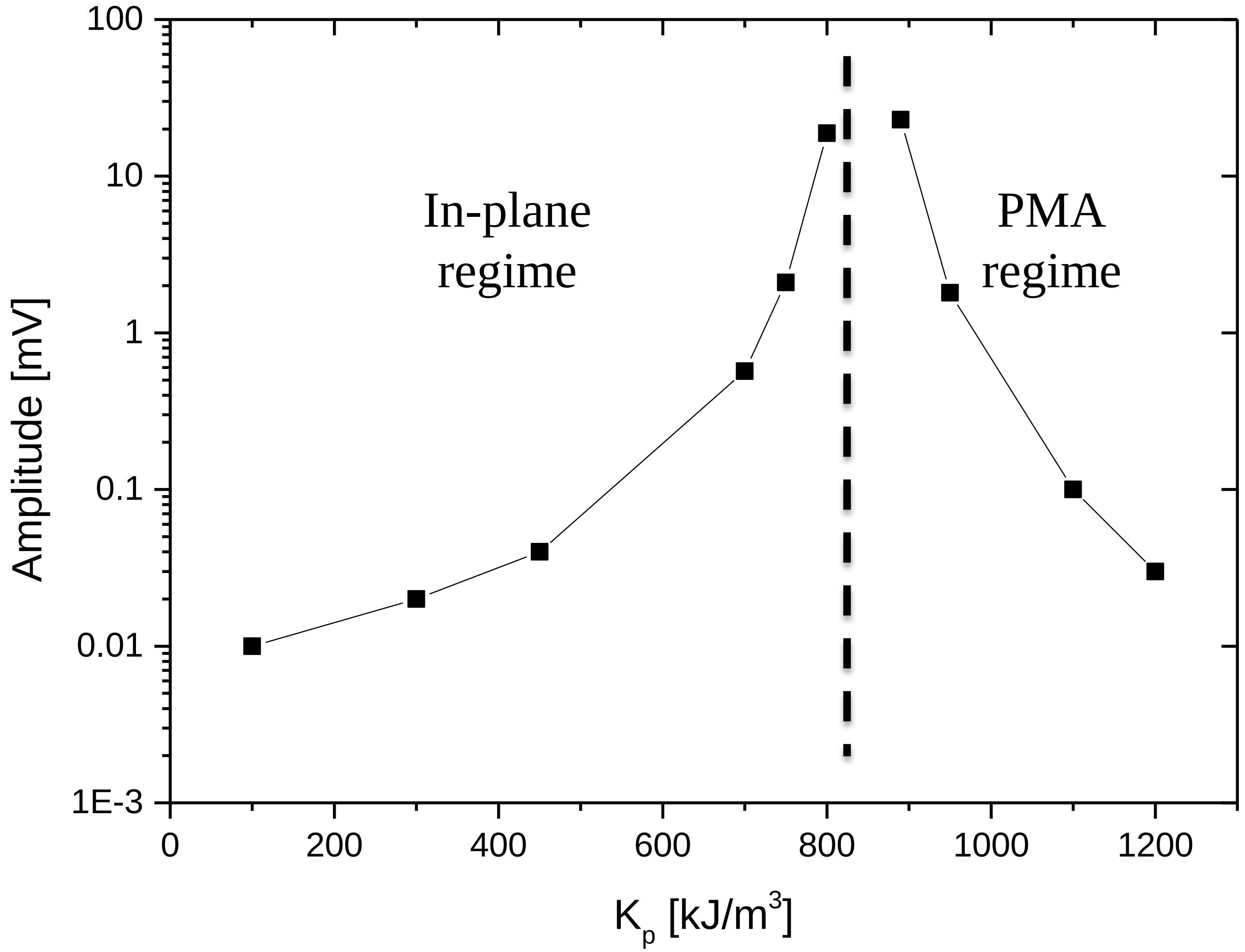
Effective damping



Quality factor



Peak-to-peak amplitude



Summary

- Our approach allows for modelling of voltage-induced spin-diode effect and ferromagnetic resonance lineshape
- Both in-plane and PMA anisotropy regimes are characterized by antisymmetric lineshape
- We find that the amplitude of oscillations and effective damping increase as the effective anisotropy moves towards the transition point.
- The quality factor is the largest in the case of a strong perpendicular anisotropy, but the amplitude of the response is very low in this regime

Acknowledgements

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- J.Ch. acknowledges the scholarship under Marian Smoluchowski Krakow Research Consortium KNOW programme.

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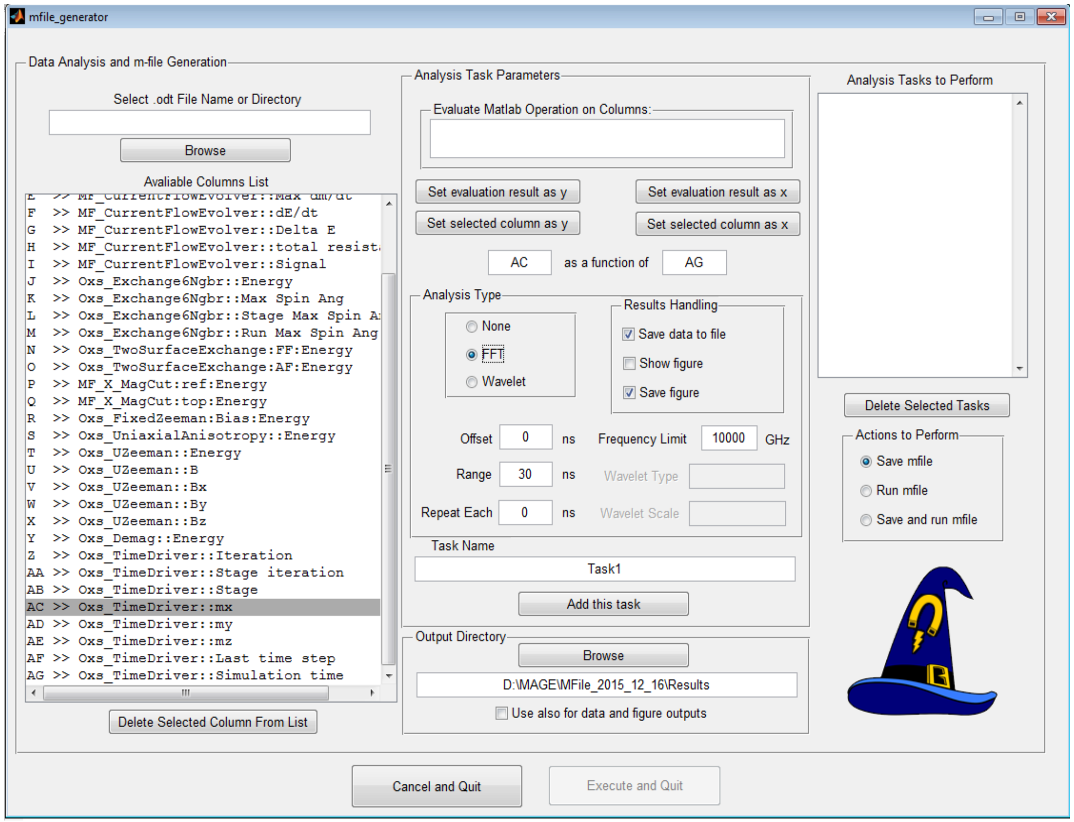
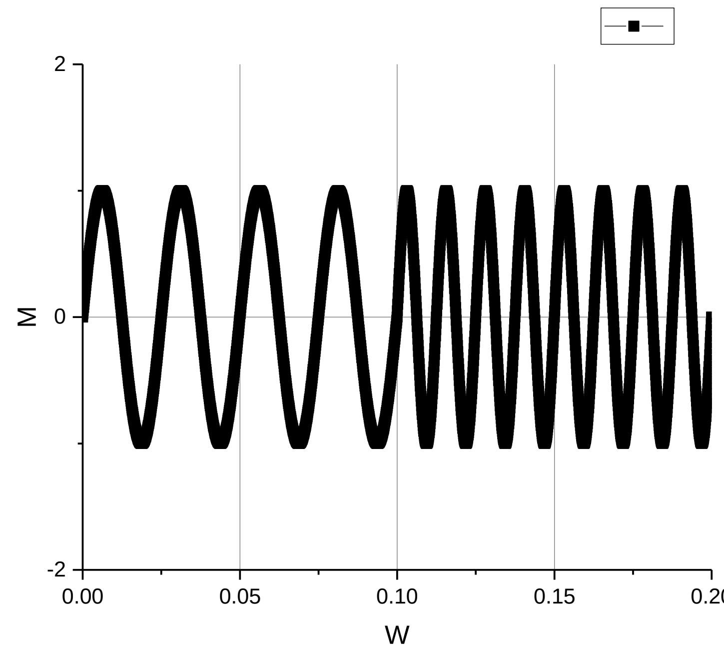
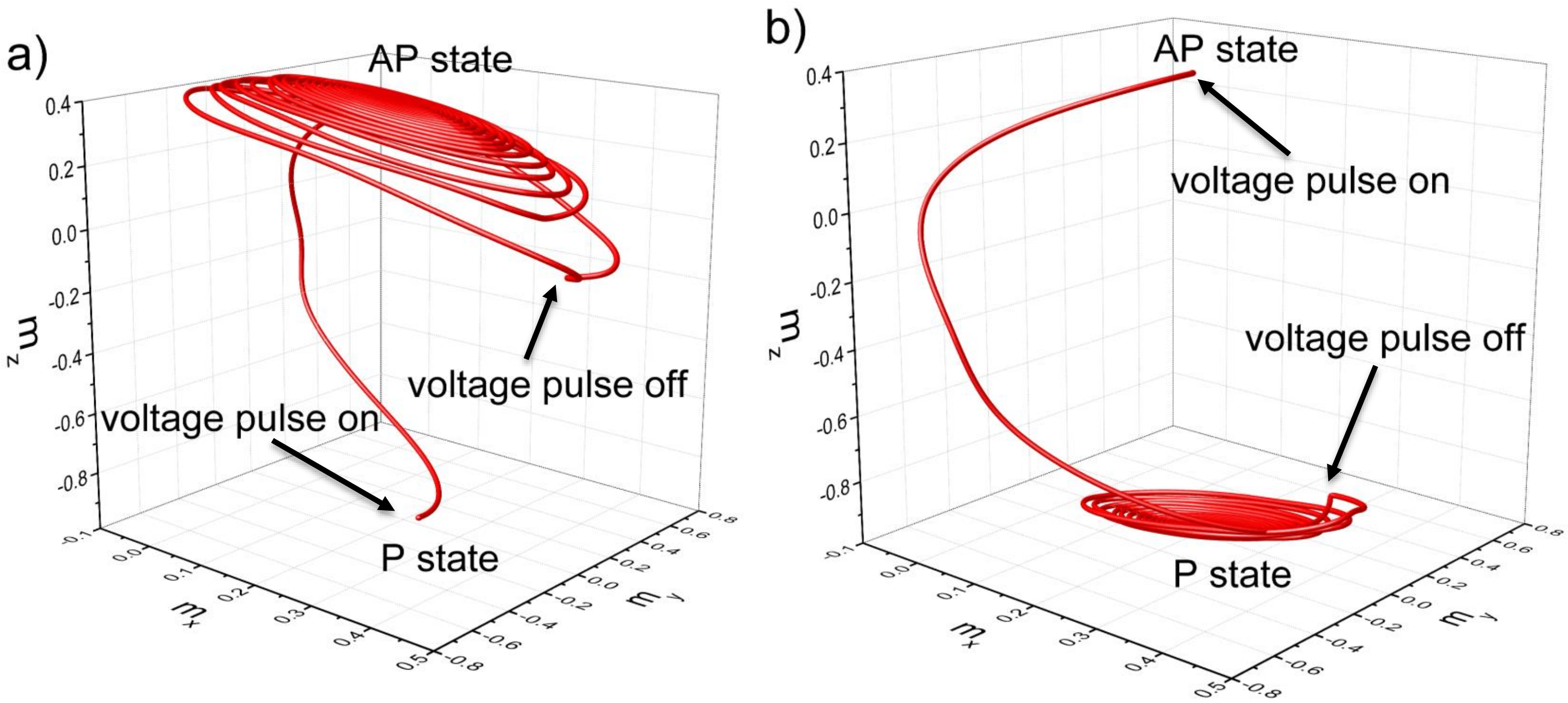
Appendix: custom software





Appendix: voltage-induced switching



Magnetization trajectories for voltage-induced switching, single pulse (duration of 0.55 ns) and amplitude 100 kJ/m^3, field bias 40 mT 45° to sample plane

Appendix: how is the effective damping calculated?

$$\alpha_{eff} = \frac{\sqrt{3}\Delta f_{pp}}{\frac{\gamma}{2\pi}(H_1+H_2)}$$, where

$$H_1 = \left(H_{ext} + H_{ref}\right)\sin(\theta_H - \theta_M) - H_d sin^2\theta_M$$

$$H_2 = \left(H_{ext} + H_{ref}\right)\sin(\theta_H - \theta_M) + H_d cos2\theta_M$$

are fitted from the $f = \frac{\gamma}{2\pi}\sqrt{H_1 H_2}$ relationship,

and Δf_{pp} is obtained from fitting the antisymmetric Lorentz formula to the simulated lineshape.

based on: *Nozaki, Takayuki, et al., APEX 7.7 (2014): 073002.*