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Micromagnetic simulations of voltage-controlled spintronics devices for microwave applications

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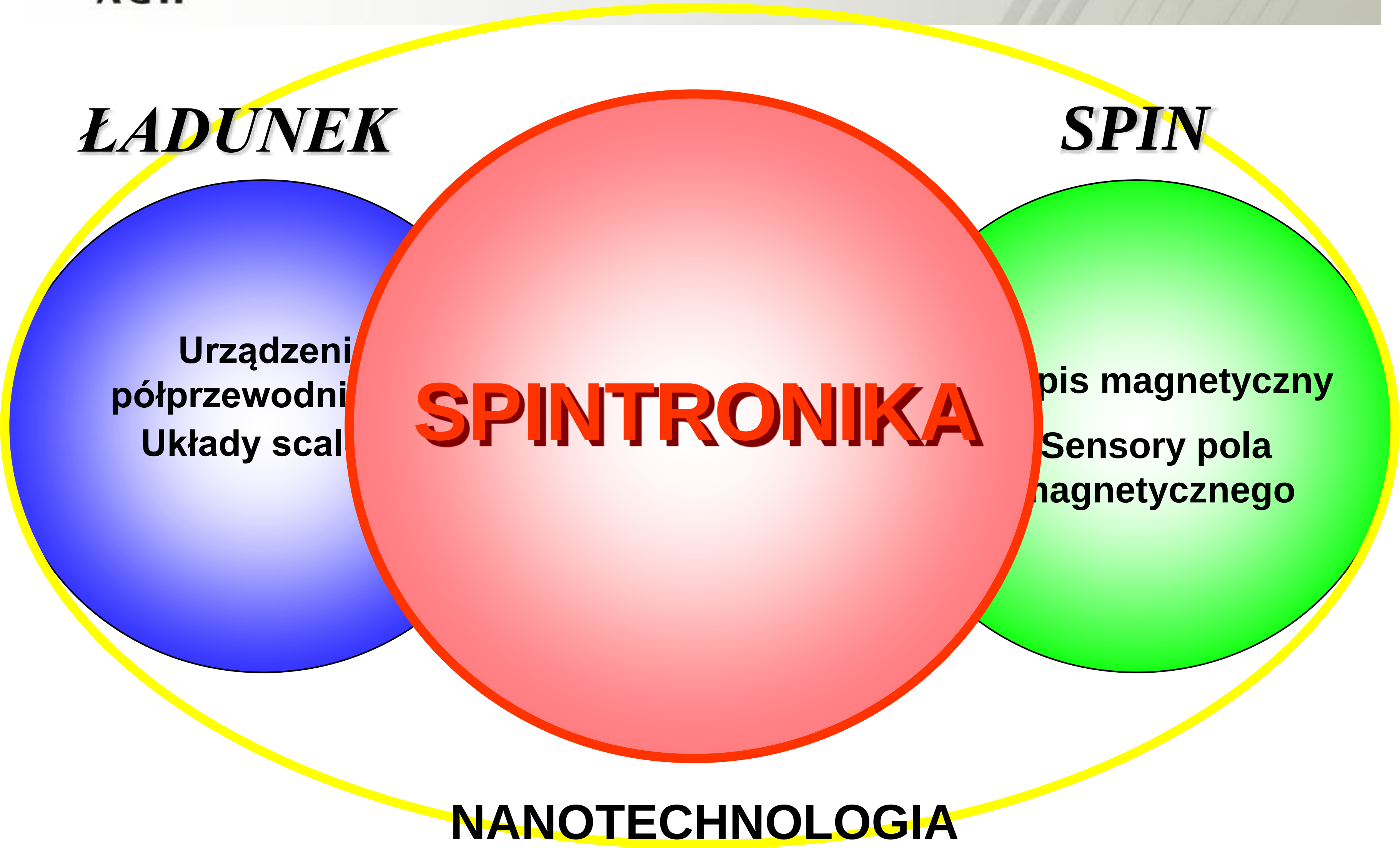
Outline

- Introduction to spintronics and micromagnetic simulations
- Spin-diode (SD) effect
- SD in magnetic tunnel junction
- SD in PMN-PT/NiFe heterostructure
  - experiment
  - simulations
- Summary

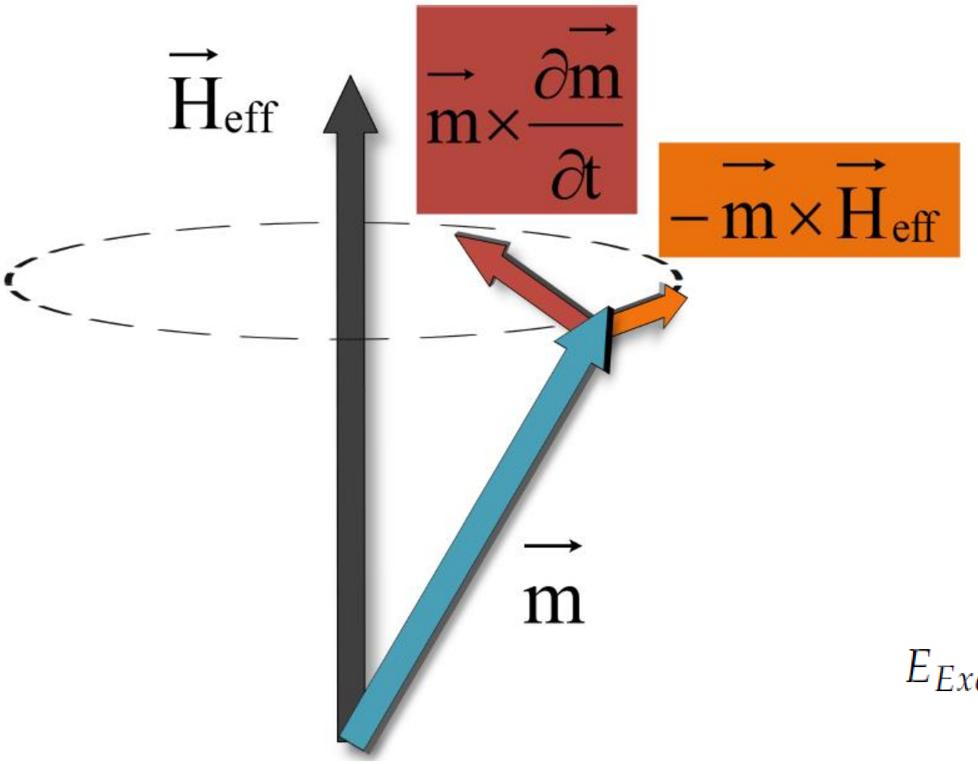
Elektronika spinowa



Micromagnetic simulations

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

$$\vec{H}_{\text{eff}} = -\frac{1}{\mu_0 M_s V} \frac{\partial E}{\partial \vec{m}}$$



$$E_{Zeeman} = -\mu_0 M_s \int_V \vec{m} \cdot \vec{H}_{ex} dV$$

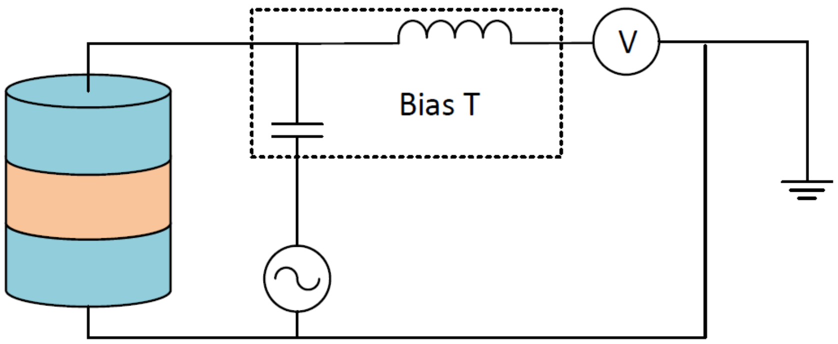
$$E_{Anisotropy} = \int_V (K_1 sin^2\alpha + K_2 sin^4\alpha) dV$$

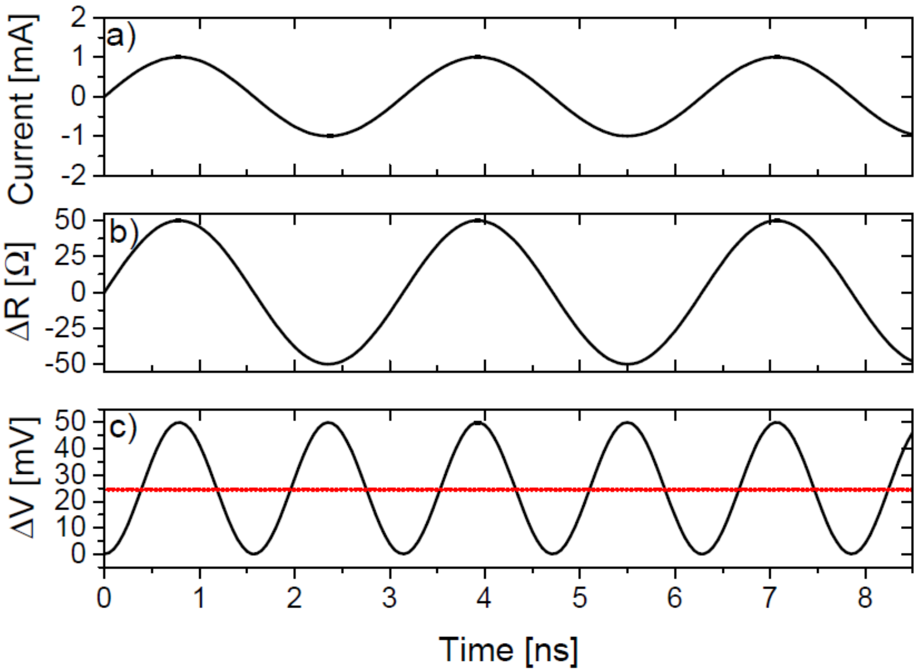
$$E_{Demag} = -\frac{1}{2}\mu_0 M_s \int_V \vec{m}(\vec{r}) \cdot \vec{H}_{Demag}(\vec{r}) dV$$

$$E_{IEC} = -\int_S J_1 \vec{m}_1 \cdot \vec{m}_2 dS - \int_S J_2 (\vec{m}_1 \cdot \vec{m}_2)^2 dS$$

$$E_{Exchange} = -A \int_V \vec{m} \cdot \left(\frac{\partial^2 \vec{m}}{\partial x^2} + \frac{\partial^2 \vec{m}}{\partial y^2} + \frac{\partial^2 \vec{m}}{\partial z^2} \right) dV$$

Spin-diode (SD) effect

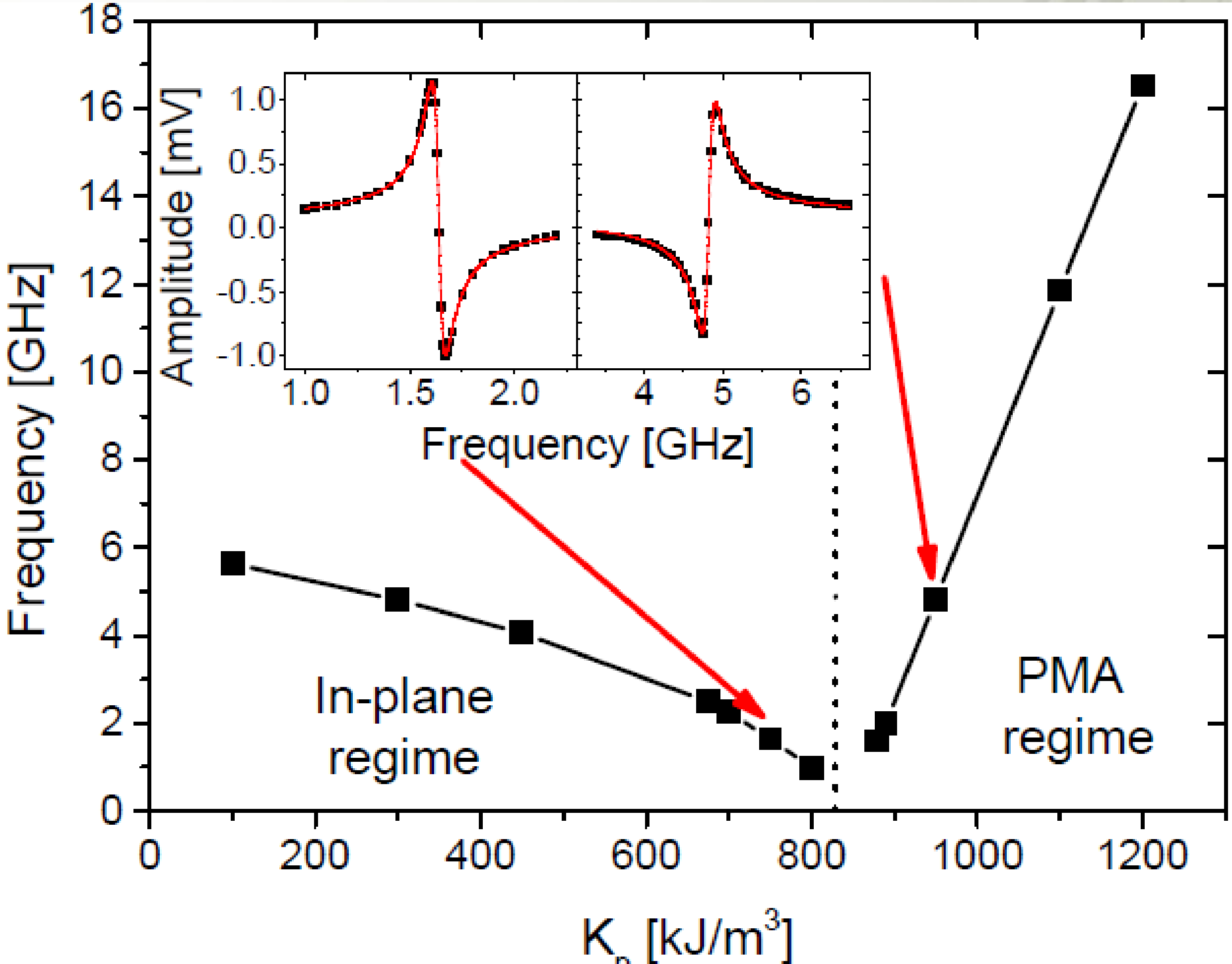




$$V_{out} = \delta R cos(\omega t + \beta) \times I_0 cos(\omega t) =$$

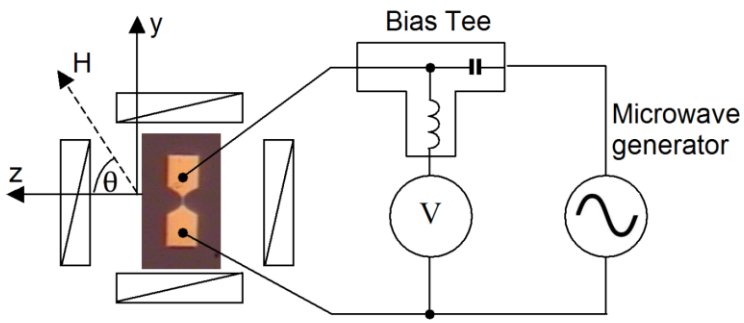
$$= \frac{\delta R I_0}{2} (cos\beta + cos(2\omega t + \beta)) = V_{DC} + V_{AC}$$

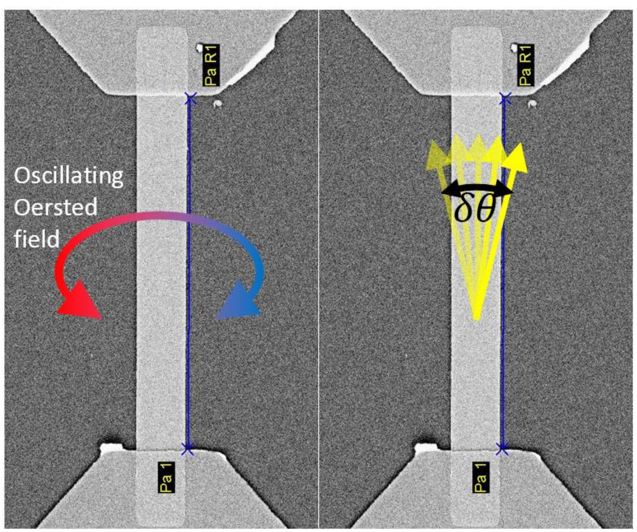
SD in magnetic tunnel junction

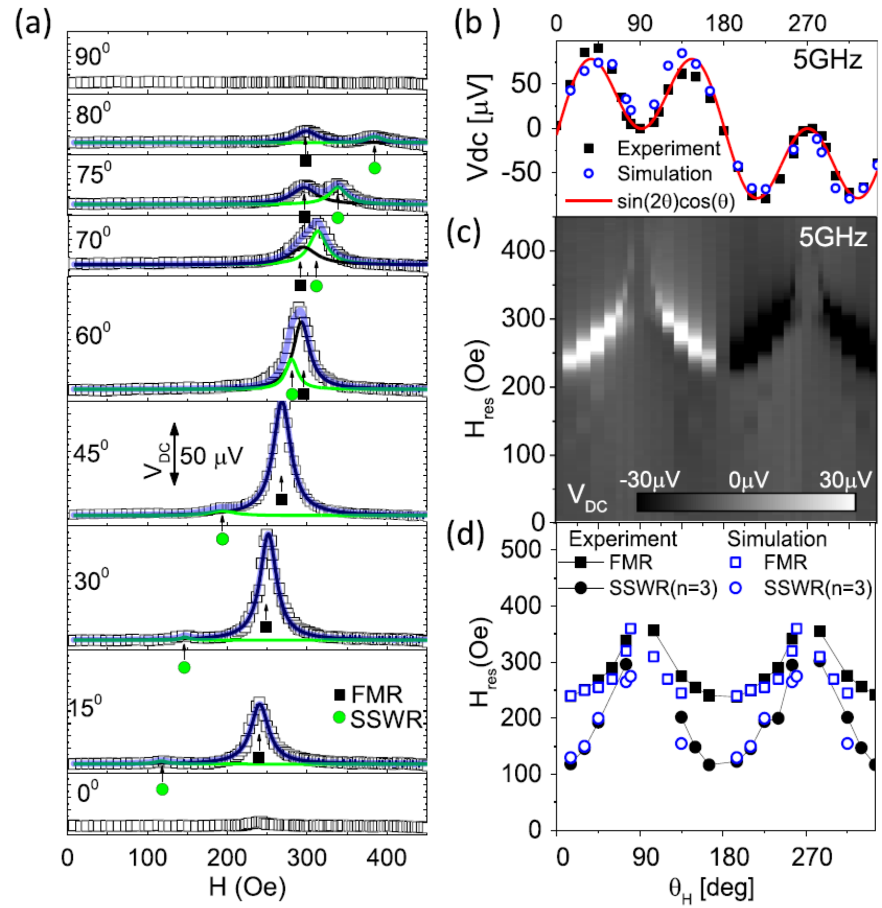


M. Frankowski et al. *Perpendicular magnetic anisotropy influence on voltage-driven spin-diode effect in magnetic tunnel junctions: a micromagnetic study*, Journal of Magnetism and Magnetic Materials 429 (2017) 11–15.

SD in PMN-PT/NiFe heterostructure



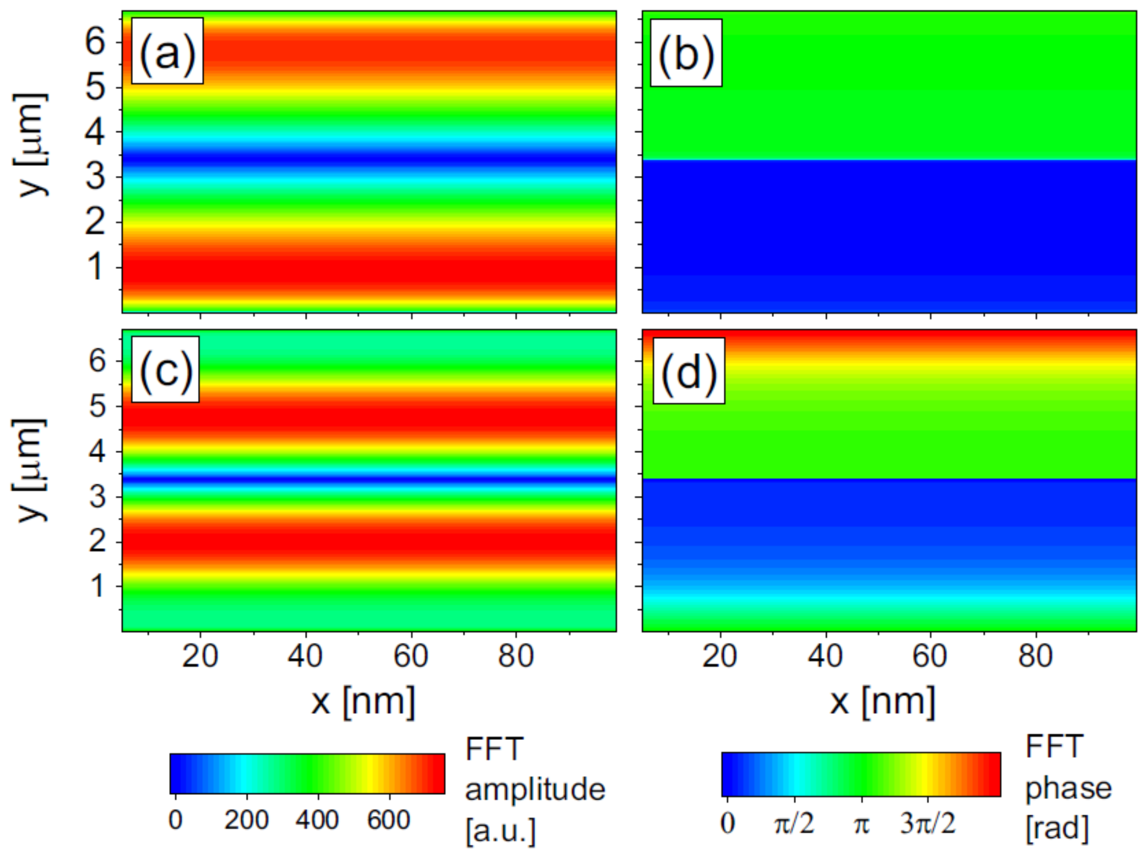




S. Ziętek, J. Chęciński, M. Frankowski et al. Electric-field tunable spin waves in PMN-PT/NiFe heterostructure: Experiment and micromagnetic simulations, Journal of Magnetism and Magnetic Materials 428 (2017) 64–69

SD in PMN-PT/NiFe heterostructure

- 1-D periodic boundary conditions
- 107200 cells per simulation
- 25 ns
- 250 000 integration steps
- 100 CPU hours per single simulation



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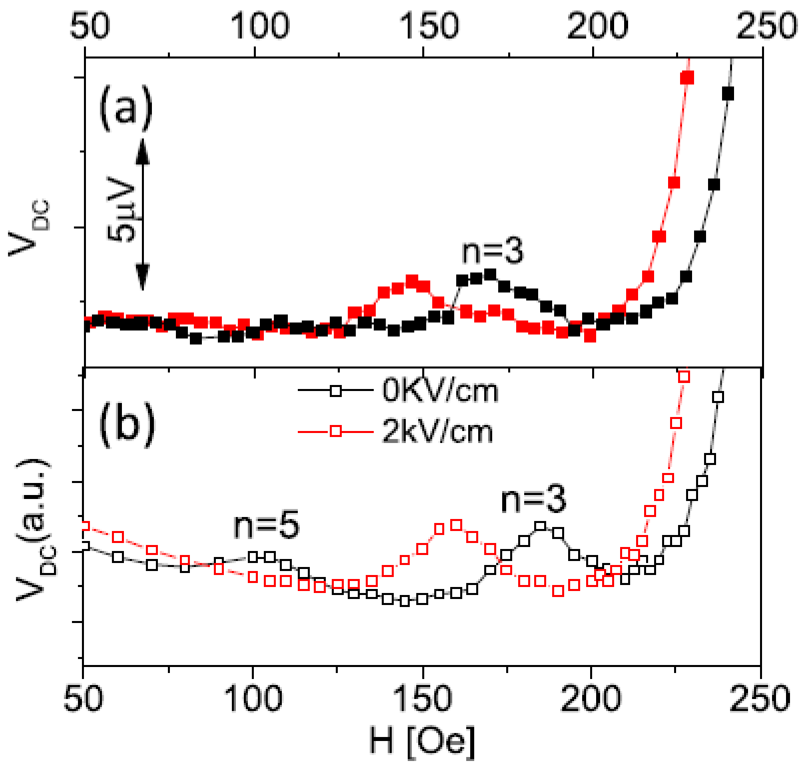

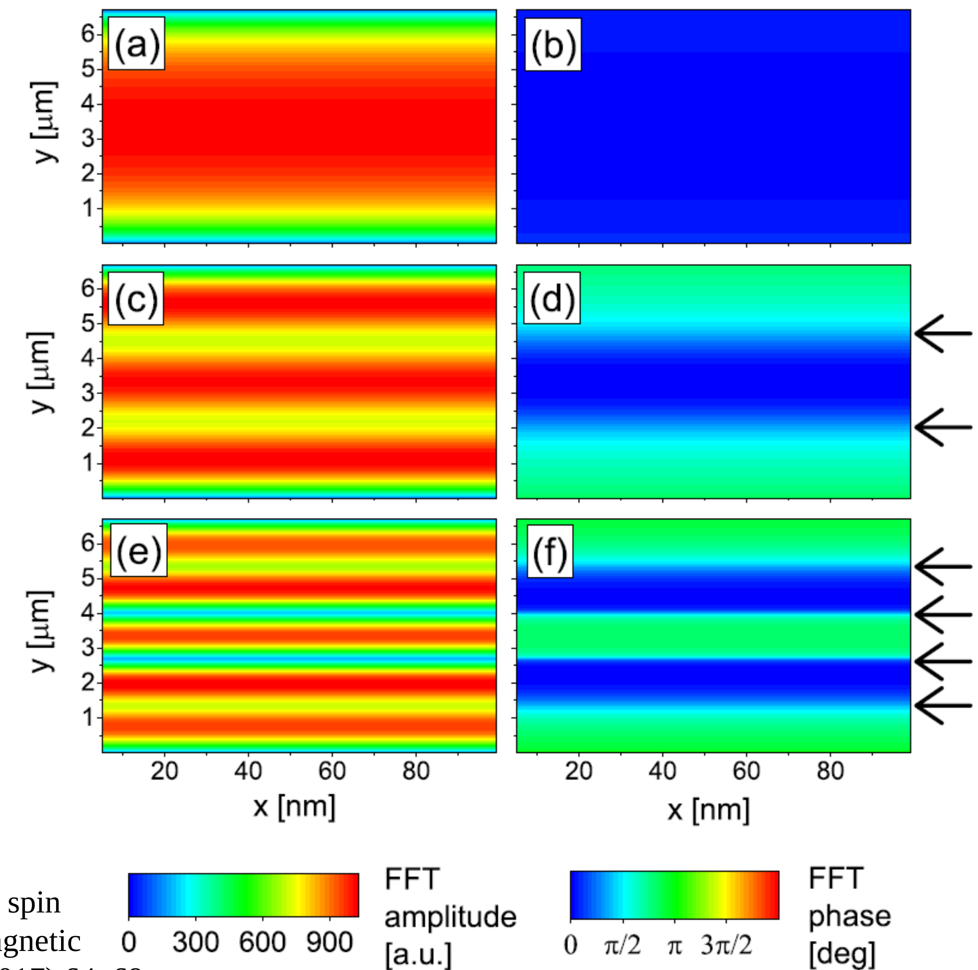

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Summary

- Numerous parallel simulations necessary
- Quantitative agreement between experiment and simulations
- Micromagnetic simulations – insight into details of magnetization distribution and dynamics

Thank you for your attention.