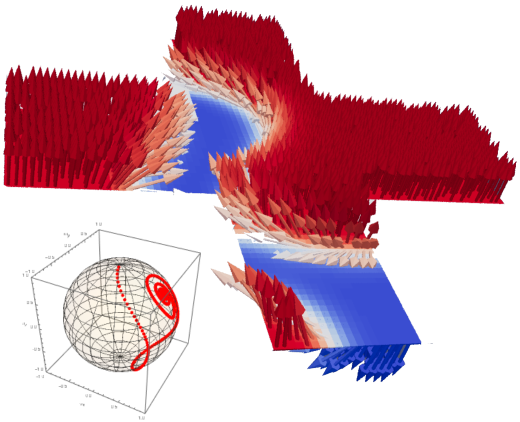
The Landau-Lifshitz-Gilbert equation and the next generation spintronic devices: towards a trillion dollars industry.



Saturday, 28.01.2023

Meeting w/*Club de física computacional @ YT*:
online research seminar

Joshua M. Salazar Mejía
prae-doc researcher
Physics of functional materials

Under supervision of:
Dieter Suess

About today

Presentation outline

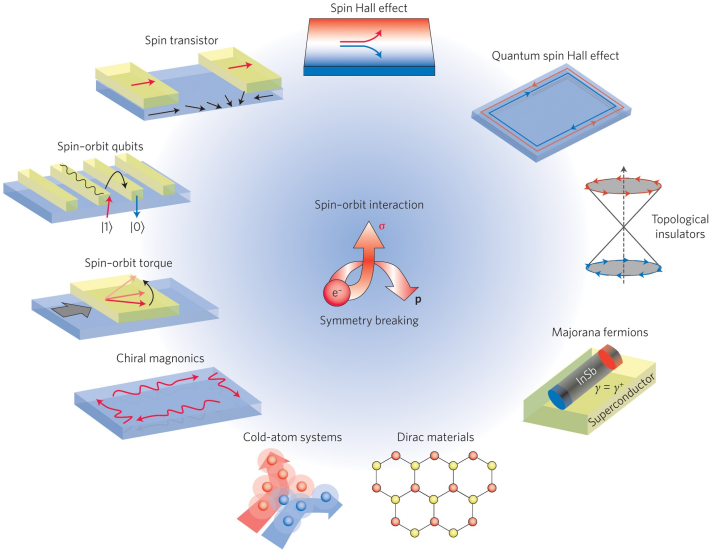
University of Vienna

- Spintronics vs. Electronics: Physical principles, current devices, challenges and potential growth.
- The analytical models for solving magnetic problems in the semi-classical regime
- Offset-free sensing principle on FM/HM interfaces
- Solving the characterization of effective torques
- Highlights and further research

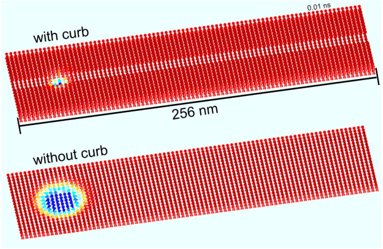
Spintronics vs. Electronics

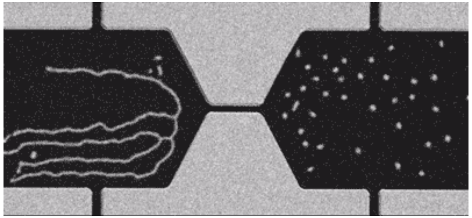
■ **Magnetic models and industry-academia synergy** — **University of Vienna**

- Effects: [10.1016/j.jmmm.2020.166711](https://doi.org/10.1016/j.jmmm.2020.166711)

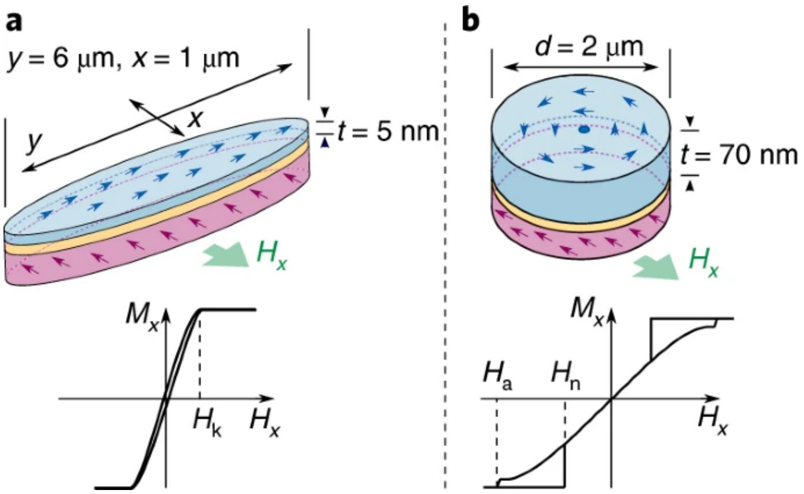


- Spin textures: [10.1016/j.jmmm.2020.166711](https://doi.org/10.1016/j.jmmm.2020.166711)





Spintronics vs. Electronics



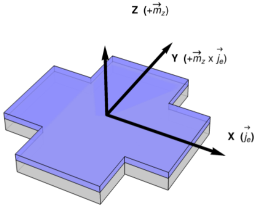
- Vortex sensors, current Infineon key sensor product for automotive applications.
- 45% of the worlds's market of sensors
- Current collaboration for experiments with:

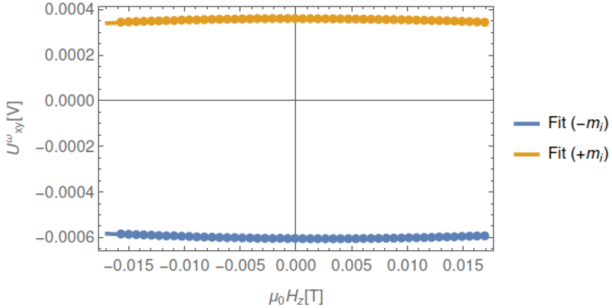
- Software, theory and simulations in UW

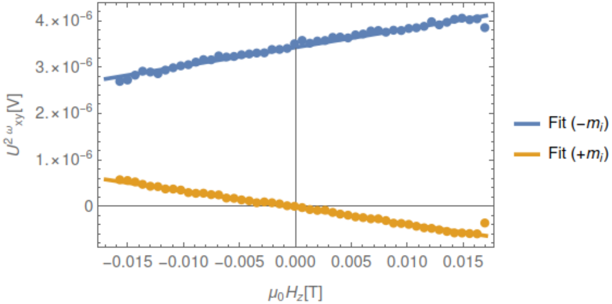
[1] Suess, D., Bachleitner-Hofmann, A., Satz,at. al, (2018). Topologically protected vortex structures for low-noise magnetic sensors with high linear range. Nature Electronics, 1(6), 362-370

Spintronics vs. Electronics

- -Miniaturization and low power consumption.
  -Offset problem

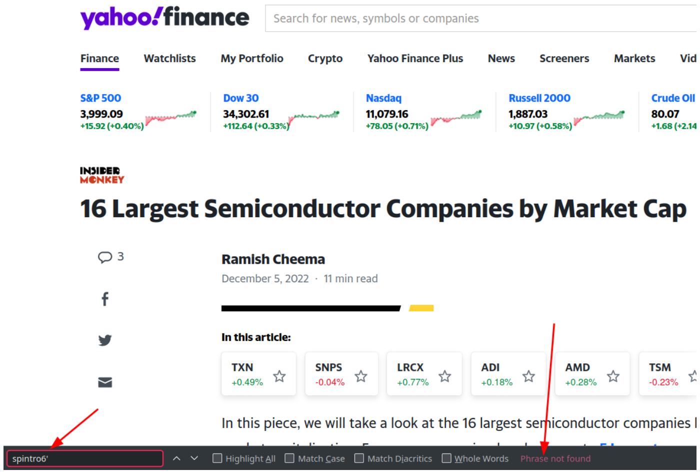






Spintronics vs. Electronics

- Current semiconductor industry market cap: 3.4 T USD
  Spintronics market size: ~5 B USD



Next section…

- Spintronics vs. Electronics: Physical principles, current devices, challenges and potential growth.
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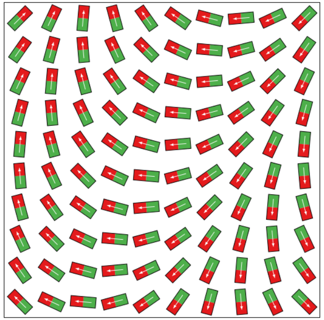
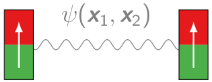
Theoretical models

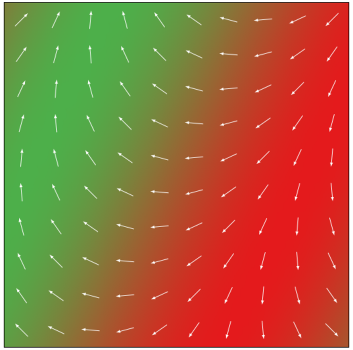
Micromagnetism

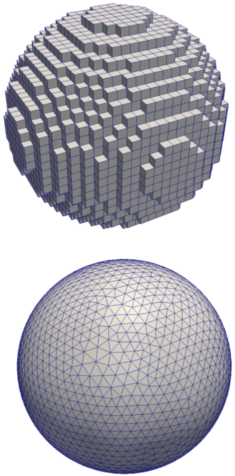
University of Vienna

- The analytical models for solving magnetic problems in the semi-classical regime









Theoretical models

YACHAY TECH — CompNano research group — Infineon — universität wien

Micromagnetism

University of Vienna

- The single spin model and applications

$$\frac{\partial \vec{m}}{\partial t} = -\frac{\gamma}{1+\alpha^2}(\vec{m}\times\vec{H}_{\text{eff}}) - \frac{\gamma\alpha}{1+\alpha^2}\,\vec{m}\times(\vec{m}\times\vec{H}_{\text{eff}})$$

$$\vec{H}_{\text{eff}} = \vec{H}_{\text{ext}} + \vec{H}_{\text{k}} + \vec{H}^{\text{SOT}}_{\text{FL}} + \vec{H}^{\text{SOT}}_{\text{DL}}$$

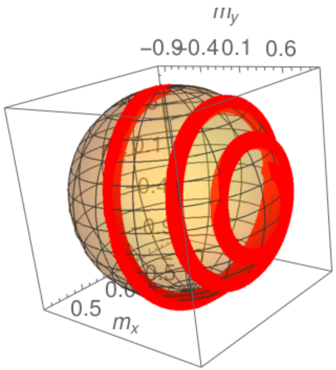
$$\vec{H}_{\text{k}} = \frac{2\vec{K}_1}{Js} \qquad \vec{K}_1 = \begin{pmatrix} 0 \\ 0 \\ K_1 \end{pmatrix}$$

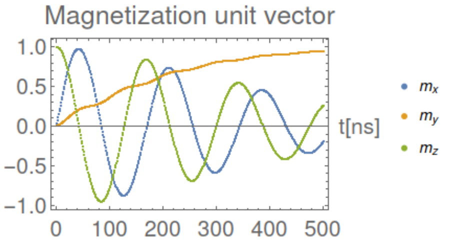
$$\vec{H}^{\text{SOT}}_{\text{FL}} = \eta_{\text{FL}}\frac{j_e\hbar}{2et\mu_0 M_s}\,\vec{m}\times(\vec{m}\times\vec{p}) \qquad \vec{p} = \begin{pmatrix} 0 \\ -1 \\ 0 \end{pmatrix}$$

$$\vec{H}^{\text{SOT}}_{\text{DL}} = \eta_{\text{DL}}\frac{j_e\hbar}{2et\mu_0 M_s}\,(\vec{m}\times\vec{p})$$

$$m_{z,\pm DC}(H_x) = \sqrt{\frac{\sqrt{1-d} - 2c(c+b) - \eta^2 t^2\sqrt{1-d}}{\sqrt{1-d} - 2c(c+b) + (c+b)^2/\sqrt{1-d}}}, \quad [1]$$

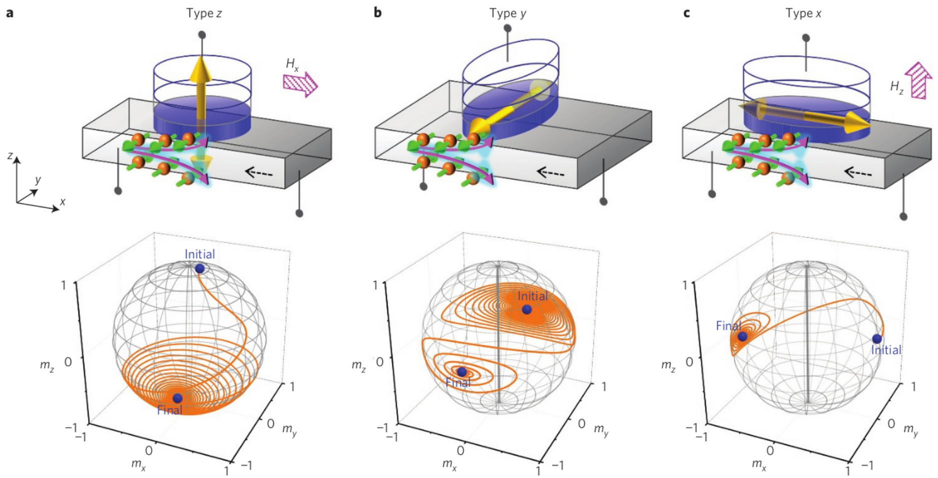
$$b = H_x/H_{K,\text{eff}},\ c = H^{\text{DL}}_{\text{SOT}}/H_{K,\text{eff}},\ d = (1+\eta^2)c^2 + 2bc + b^2$$





Theoretical models

- FM/HM interfaces



DOI: 10.1038/NNANO.2016.29

Next section...

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Sensing fields

Differential sensitivity principle

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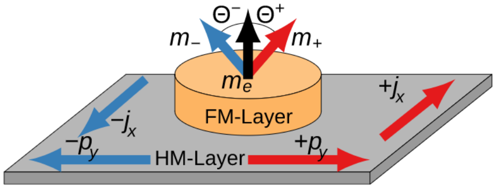
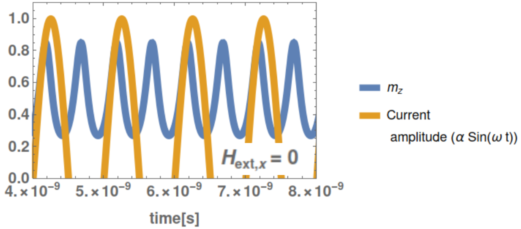
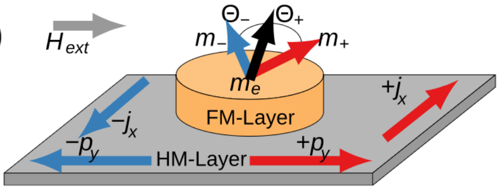
- Offset-free sensing principle on FM/HM interfaces

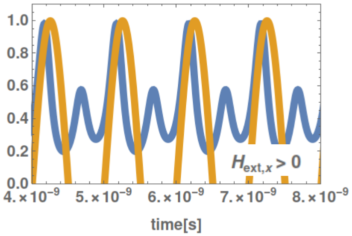
a)





b)





Sensing fields

Differential sensitivity principle

$$\frac{\partial \vec{m}}{\partial t} = -\frac{\gamma}{1+\alpha^2}(\vec{m}\times\vec{H}_{\mathrm{eff}}) - \frac{\gamma\alpha}{1+\alpha^2}\,\vec{m}\times(\vec{m}\times\vec{H}_{\mathrm{eff}})$$

$$\vec{H}_{\mathrm{eff}} = \vec{H}_{\mathrm{ext}} + \vec{H}_{\mathrm{k}} + \vec{H}^{\mathrm{SOT}}_{\mathrm{FL}} + \vec{H}^{\mathrm{SOT}}_{\mathrm{DL}}$$

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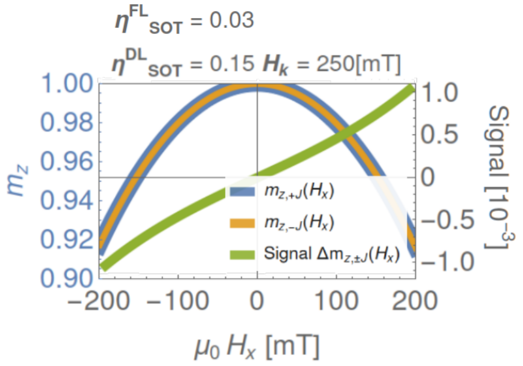
$$\vec{H}^{\mathrm{SOT}}_{\mathrm{FL}} = \boxed{\eta_{\mathrm{FL}}}\frac{j_e\hbar}{2et\mu_0 M_s}\,\vec{m}\times(\vec{m}\times\vec{p})$$

$$\vec{H}^{\mathrm{SOT}}_{\mathrm{DL}} = \boxed{\eta_{\mathrm{DL}}}\frac{j_e\hbar}{2et\mu_0 M_s}\,(\vec{m}\times\vec{p})$$

$$m_{z,\pm DC}(H_x) = \sqrt{\frac{\sqrt{1-d} - 2c(c+b) - \eta^2 t^2\sqrt{1-d}}{\sqrt{1-d} - 2c(c+b) + (c+b)^2/\sqrt{1-d}}}, \quad [1]$$

$$b = H_x/H_{K,\mathrm{eff}},\ c = H^{\mathrm{DL}}_{\mathrm{SOT}}/H_{K,\mathrm{eff}},\ d = (1+\eta^2)c^2 + 2bc + b^2$$



[1] Zhu, Daoqian, and Weisheng Zhao. "Threshold Current Density for Perpendicular Magnetization Switching Through Spin-Orbit Torque." Physical Review Applied 13.4 (2020): 044078.

Sensing fields

Differential sensitivity principle

University of Vienna

$$\frac{\partial \vec{m}}{\partial t} = -\frac{\gamma}{1+\alpha^2}(\vec{m}\times\vec{H}_{\text{eff}}) - \frac{\gamma\alpha}{1+\alpha^2}\,\vec{m}\times(\vec{m}\times\vec{H}_{\text{eff}})$$

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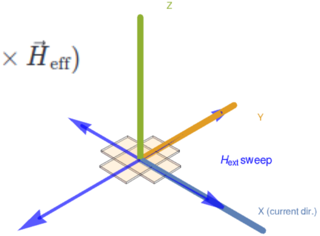

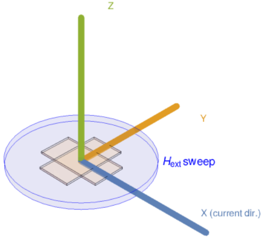

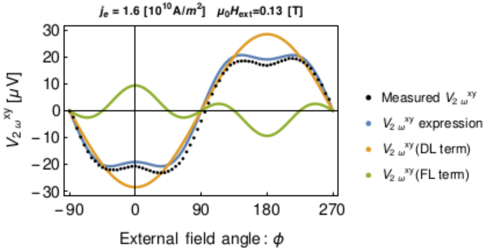

Temperature-dependent quantification of spin-orbit-torques for Ta/CoFeB/MgO interfaces at low and high current regime

J. Salazar-Mejía,[1] S. Koraltan,[1] C. Abert,[1] P. Flauger,[1] M. Agrawal,[2] S. Zeilinger,[1] A. Satz,[3] C. Schmitt,[4] G. Jakob,[4] R. Gupta,[4] M. Kläui,[4] H. Brückl,[5] J. Güttinger,[3] and D. Suess[1]

[1] *University of Vienna, Faculty of Physics, Physics of Functional Materials, Vienna, Austria*
[2] *Infineon Technologies AG, Am Campeon 1-15, 85579 Neubiberg, Germany*
[3] *Infineon Technologies Austria, Siemensstrasse 2, Villach, Austria*
[4] *Institute of Physics, Johannes Gutenberg-University Mainz, 55128 Mainz, Germany*
[5] *Universität für Weiterbildung Krems, Department für Integrierte Sensorsysteme, 2700 Wiener Neustadt Austria*

(Dated: 14 January 2023)

Next section…

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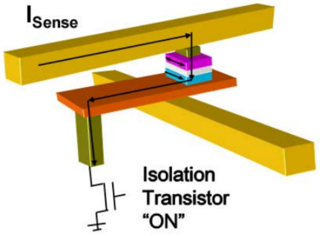
Further research

Current status and future

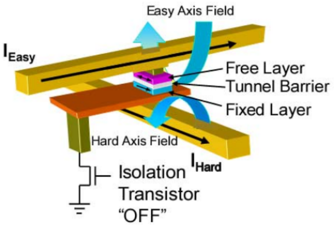
University of Vienna

- MRAM technology

Lesezugriff

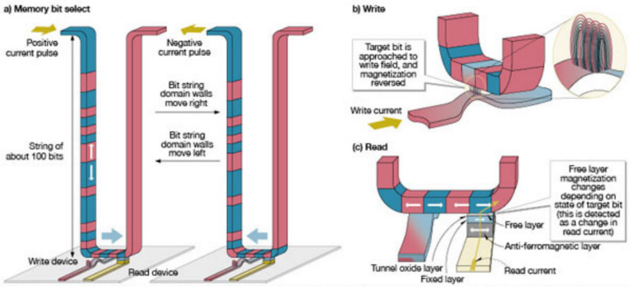


Schreibzugriff



-Sensing tech.
-Non-traditional computing: Neuromorphic, quantic, analog.
-Low-power degree-of-freedom

- DW motion: Ultra-dense storage

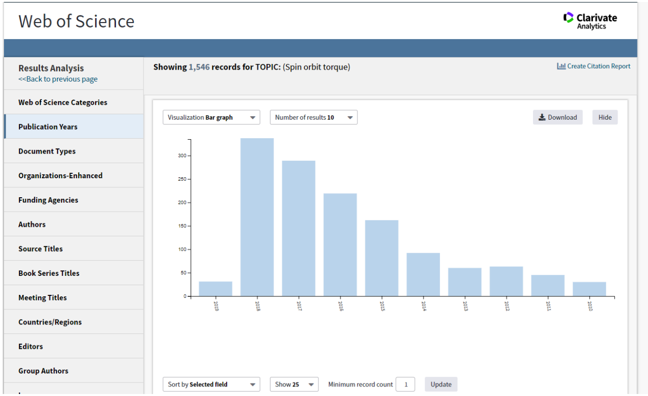


Further research

Current status and future

University of Vienna

- Spintronics and SOT is a hot topic



- in-silico characterization of SOT strengths

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$$\vec{H}^{\mathrm{SOT}}_{\mathrm{DL}} = \boxed{\eta_{\mathrm{DL}}} \frac{j_e \hbar}{2et\mu_0 M_s} (\vec{m} \times \vec{p})$$

Thank you for your attention!