Spin Orbit Torques in Permalloy Films with Shape-Induced High-Order Magnetic Anisotropy

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MULTISPIN.AI AI Co-Processor Research Project

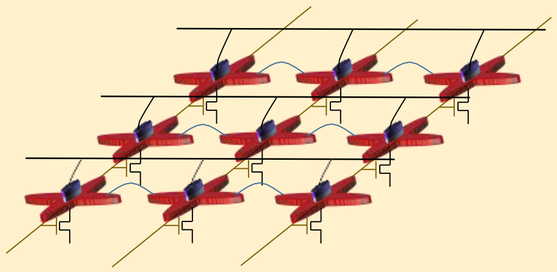
BINA

Bar-Ilan University

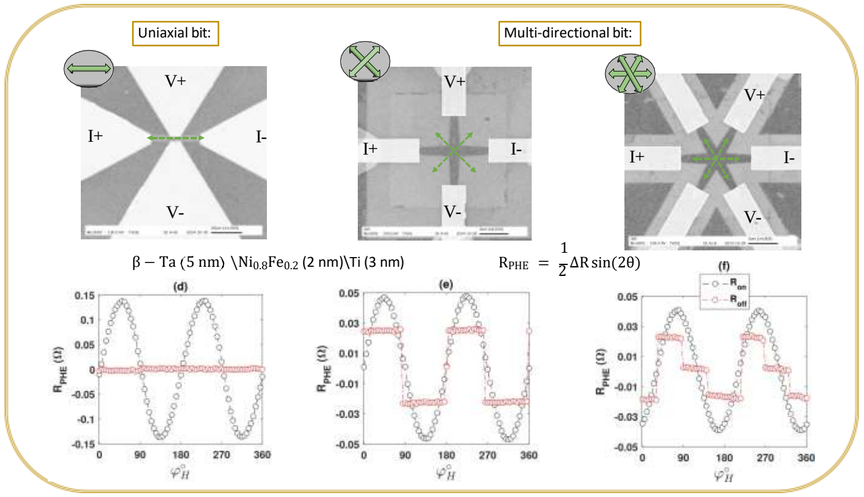
Funded by the European Union

Multispin-AI: N-ary spintronics-based edge computing co-processor for artificial intelligence

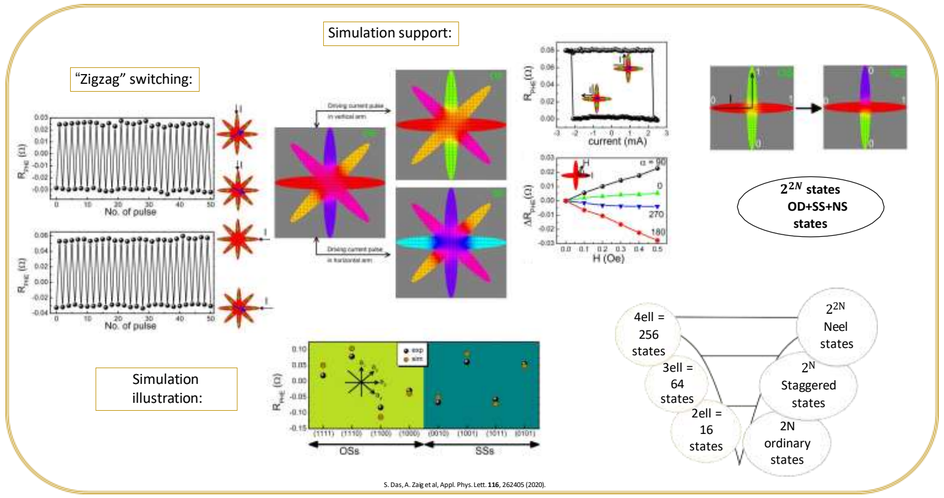
➢ This study is part of an effort to develop a new type of spintronic crossbar for AI computation. While current spintronic crossbars use binary magnetic tunnel junctions (MTJs), our goal is to use multi-state MTJs. We expect that the use of such MTJs will increase the computation speed and improve its energy efficiency dramatically.



Scanning electron microscopy and basic characterization

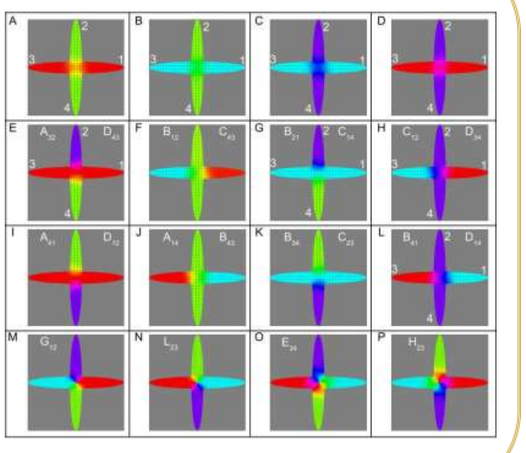


SOT-based field-free switching between all types of states



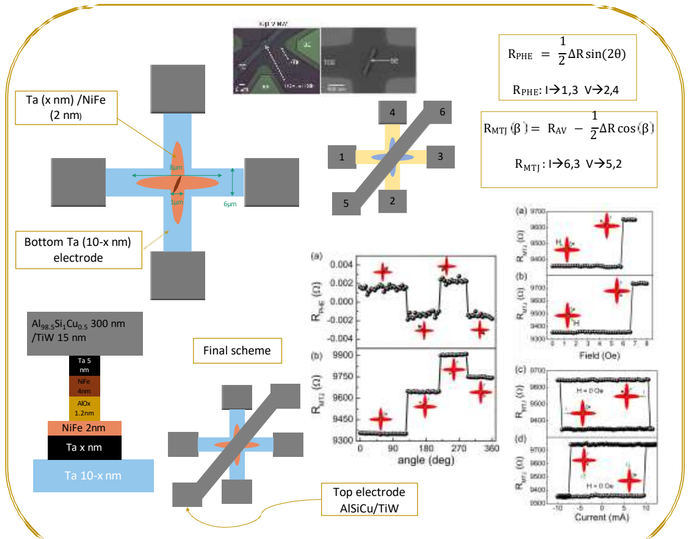
S. Das, A. Zaig et al, Appl. Phys. Lett. **116**, 262405 (2020).

Micromagnetic simulation fully mapping the two-crossing ellipses structures



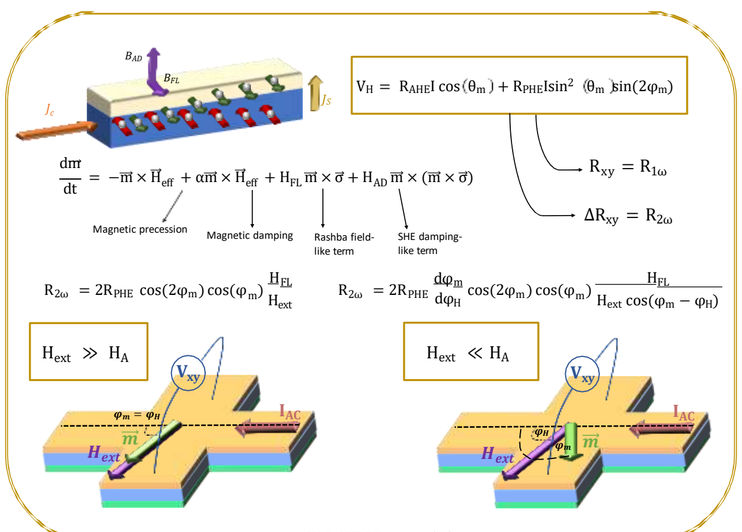
S. Das, A. Zaig et al, Appl. Phys. Lett. **116**, 262405 (2020).

The integration of the elliptical structures in MTJ – multi-level MRAM



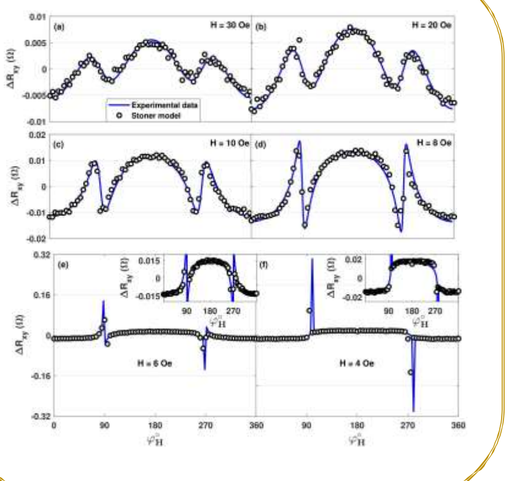
S. Das, A. Zaig et al., Appl. Phys. Lett. **117**, 072404 (2020)

The spin-orbit torque phenomenon and the harmonic Hall characterization measurements



A. Zaig et al, Physical Review B **106**, 214401 (2022)

Giant response to SOTs in the low-field limit of the second order harmonic signal



A. Zaig et al, Physical Review B **106**, 214401 (2022)

➢ To investigate the spin-orbit torque (SOT) we have performed harmonic Hall voltage measurements which are typically employed to determine the current-induced SOTs in HM/FM heterostructures with in-plane magnetic anisotropy.

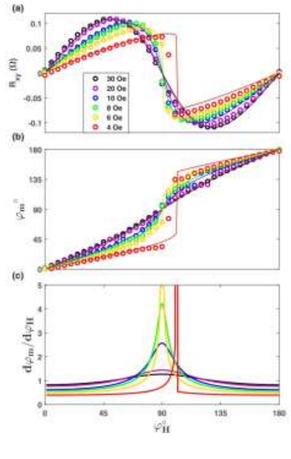
➢ Previous harmonic Hall measurements were performed in the field limit when $H_{ext} \gg H_A$ applies. Modified form of the harmonic Hall term is required when H_A is dominant.

➢ We derived a generalized form of the second-order harmonic Hall term, and we present its behavior above and below the critical value of H_A. Giant response of the uniaxial magnetic domain to the SOTs is confirmed by the second-order harmonic signal at the magnetic transition between the two easy axes, when $H_{ext} \leq H_A$.

➢ **Current research**: Recently, we have found out that the first-order harmonic matches well with the assumption that the non-uniform magnetization can be replaced by the average magnetization, however, in the second-order harmonic Hall measurement this assumption fails.

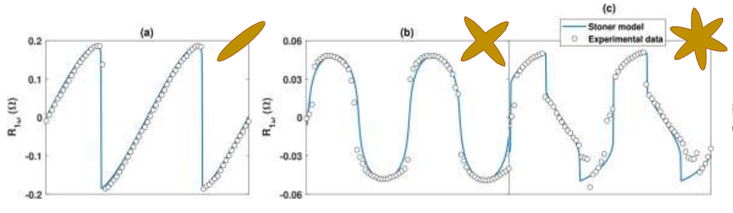
➢ **Current Breakthrough**: The results suggest that the effect of non-uniformity on the SOTs should be considered, both experimentally and theoretically.

The magnetic dynamics of the single ellipse structure

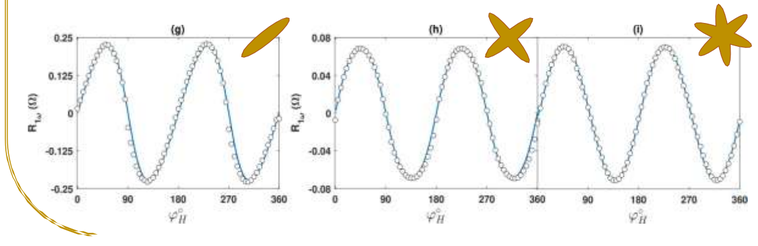


A. Zaig et al, Physical Review B **106**, 214401 (2022)

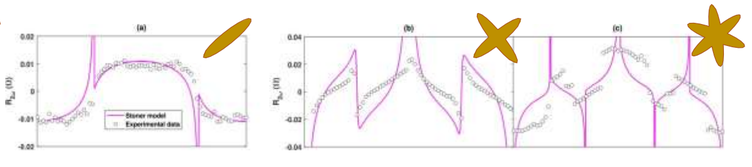
First-order harmonic of single, two-crossing, and three crossing ellipses



➢ While the first-order harmonic Stoner's simulation matches closely to the experimental data, the second-order harmonic shows a much lower degree of agreement with our previous formalism.



Second-order harmonic of single, two-crossing, and three crossing ellipses



➢ These findings challenge existing assumptions regarding SOTs and open the door to further exploration of non-uniform magnetic systems in the context of SOT research.