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Exploring Magnetization Switching: Insights from Macrospin and Atomistic Simulations

In 1935, Landau and Lifshitz proposed an equation to describe the dynamics of a single magnetic moment under the influence of external magnetic fields. In 1955, Gilbert extended this theory by modifying the damping term, resulting in the Landau-Lifshitz-Gilbert equation. This is the foundation of the macrospin and atomistic models. The macrospin model simplifies a magnetic system as a single, uniform magnetic moment, which is particularly useful for small magnetic systems like nanoparticles or single-domain magnets. However, this simplification is insufficient for modeling the complex magnetic behaviors observed in the experiments. In contrast, the atomistic model provides a more realistic picture, capturing complex magnetization dynamics such as domain wall motion. It is also particularly suitable for studying magnetization dynamics in antiferromagnets.

In this study, we first revisit the analytical solution of spin-orbit torque induced switching in nanoscale perpendicular ferromagnets based on the macrospin model. Previous analytical models assumed that the switching occurs in two steps, leading to a significant discrepancy with the experimental results. However, our observations reveal that the magnetization trajectory follows a smooth, continuous transition. Based on this refined understanding of the switching process, we propose a new analytical model that aligns well with experimental results [1]. Next, we turn to the atomistic model and investigate the switching behavior of ferrimagnets. We show that the nonuniform switching process is intrinsically linked to the random distribution of atoms, emphasizing the critical role of atom distribution in the switching dynamics [2]. Our results demonstrate that these models are essential for understanding the complex magnetic dynamics observed in experiments, highlighting their significance in advancing both theoretical predictions and practical applications in magnetic devices.

[1] X. Zhang, Z. Xu and Z. Zhu, Phys. Rev. B 110, 184428 (2024).
[2] X. Zhang, Z. Xu, J. Ren, Y. Qiao, W. Fan and Z. Zhu, Appl. Phys. Lett. 124, 012405 (2024).

Primary author: ZHANG, Xue (上海科技大学)

Co-author: Prof. ZHU, Zhifeng (上海科技大学)

Presenter: ZHANG, Xue (上海科技大学)