Nucleation and Arrangement of Abrikosov Vortices in Hybrid Superconductor-Ferromagnetic Nanostructure

S. Memarzadeh[1], M. Gołębiewski[1], M. Krawczyk[1], and J. W. Kłos[1]

[1]*Institute of Spintronics and Quantum Information, Faculty of Physics and Astronomy, Adam Mickiewicz University Poznań, Uniwersytetu Poznańskiego 2, 61-614 Poznań, Poland*

The ferromagnetic (FM) and superconducting (SC) nanoelements can be coupled not only by direct contact [1], but also by electromagnetic fields [2]. In these hybrid structures, the Abrikosov vortices experience creep-like deformations, gradually settling into steady curved shape [3] due to the interplay of Lorentz forces, vortex interactions, and the system's geometry. By numerically solving the time-dependent Ginzburg-Landau equations coupled with Maxwell's equations, we examine the behavior of Abrikosov vortices in SC-FM hybrid nanostructures under inhomogeneous magnetic field [4]. Unlike uniform magnetic fields, the hybrid system exhibits stronger vortex pinning and more complex vortex configurations. The interplay between inhomogeneous fields and geometric constraints results in competing energy landscapes, helping the system lock into various local minima. Our findings are essential for optimizing superconducting nanodevices operating on Abrikosov vortices.

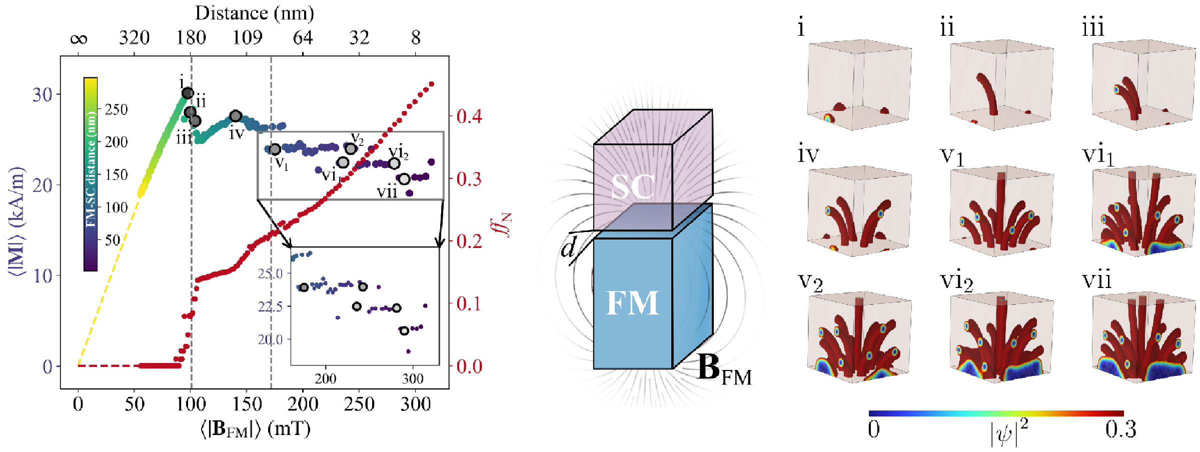

Fig. 1: *The left graph shows the average magnetization* ⟨|M|⟩ *for SC prism (yellow-green-blue points and left edge of the frame) and the volume fraction of Abrikosov vortices ff_N (red points and right edge of the frame), plotted versus the average magnetic field* ⟨|B_{FM}|⟩ *produced by FM (bottom edge of the frame) and the corresponding SC-FM separation (top edge of the frame). The first gray dashed line represents the first critical field, and the second gray dashed line indicates where the first curved vortex becomes straight. The middle graph shows the geometry of the system: the SC prism has a* 350 × 350 nm^2 *cross-section and is* 320 nm *in high. On the right, the visualizations (i–viii) of the static vortex configurations at selected field values are presented.*

References

1. A. I. Buzdin, Rev. Mod. Phys. 77, 935 (2005).
2. Bespalov, Physica C: Supercond. 595, 1354032 (2022)
3. E. Zhakina et al., *arXiv preprint*, arXiv:2404.12151 (2024).
4. S. Memarzadeh, et al., *arXiv preprint*, arXiv:2411.12486 (2024)