Enhancing the visibility of Majorana Zero Modes in vortex core via non-magnetic impurity

V.D. Neverov[1,*], T. Karabassov[1], A V. Krasavin[1,2,3], D. Roditchev[4], V. S. Stolyarov[1], A. Vagov[1,3]

[1] *Moscow Institute of Physics and Technology, Dolgoprudny, Russian Federation*
[2] *National Research Nuclear University MEPhI, Moscow, Russian Federation*
[3] *HSE University, Moscow, Russian Federation*
[4] *ESPCI Paris – PSL, CNRS, Sorbonne University, France*
**email: slavesta10@gmail.com*

Key words: Majorana, superconductivity, vortex, impurity

The experimental detection of Majorana zero modes (MZMs), which are promising for quantum computing, is a major challenge in condensed matter physics. These states appear at near-zero energy in the vortex cores of topological superconductors [1] but are notoriously difficult to distinguish because they are extremely close in energy to other, non-topological vortex states. This small energy separation often makes the definitive identification of MZMs ambiguous [2].

Contrary to the common belief that only ultra-clean materials are suitable for finding MZMs, this work demonstrates that intentionally introduced non-magnetic impurities can significantly improve their detectability. We show through numerical solutions of the Bogoliubov-de Gennes (BdG) equations that a carefully chosen impurity potential, which acts as a pinning site for a vortex, can push the energy levels of the non-topological states away from zero energy. Crucially, the MZM itself remains pinned at zero energy due to its topological protection.This effect creates a much larger energy gap between the MZM and its nearest excitations, making the MZM's signature zero-bias peak in local density of states measurements more pronounced and isolated.

These findings suggest a practical new direction for experiments. Instead of focusing solely on difficult-to-grow ultrapure crystals, researchers can more reliably observe MZMs in engineered systems with strategic impurity placement. This approach relaxes the stringent material purity requirements and provides a clearer pathway to unambiguous Majorana detection.

Bibliography

[1] G. Volovick, JETP Letters 70, 609 (1999).

[2] E. J. H. Lee, X. Jiang, M. Houzet, R. Aguado, C. M. Lieber, and S. De Franceschi, Nature Nanotechnology 9, 79 (2014).