Switching currents limited by the inverse proximity effect in a flux-tunable superconductor

Gabriel Moraes Oliveira1*

Ignacio Casal Iglesias1, Mario Gómez1, Ángel Ibabe1, Gorm O. Steffensen2, Thomas Kanne3, Jesper Nygård3, Alfredo Levy Yeyati2, and Eduardo J. H. Lee1

1. Condensed Matter Physics Department, Universidad Autónoma de Madrid, 28049 Madrid, Spain
2. Department of Theoretical Condensed Matter Physics, Universidad Autónoma de Madrid, 28049 Madrid, Spain
3. Center for Quantum Devices & Nano-science Center, Niels Bohr Institute, Univ. of Copenhagen, Copenhagen, Denmark

*gabriel.moraes@uam.es

Hybrid superconductor-semiconductor nanodevices have been intensively explored in the past decade in the context of topological superconductivity [1, 2] and for the development of hybrid superconducting qubits [3]. For these directions, the field has relied on the development of nanostructures with a clean superconductor-semiconductor interface, to ensure a strong superconducting proximity effect. This is typically achieved by the in-situ deposition of superconductors, e.g., by the epitaxial growth of Al shells [4-5].

Of particular interest to this work are so-called full-shell InAs-Al nanowires, whose superconductivity can be tuned by the Little-Parks effect. These wires have received a lot of attention as a potential platform for generating topological superconductivity [6-7]. Interestingly, a recent work [8] addressing the properties of the Al shell in such wires has reported on an anomalous metallic phase in the Little-Parks regime, suggesting that the superconductivity in these systems is interesting in its own. In this work, we perform a thorough study of the superconductivity of the Al layer in similar full-shell nanowires. We have found that the switching current of these wires is typically limited by the inverse proximity effect imposed by the electrical leads, being several times lower than the expected value due to depairing. In addition, we observe that such a premature switching can either trigger a thermal runaway, in which the entire Al shell turns normal due to Joule heating, or to the stabilization of a normal region within the shell, reflected by the appearance of an intermediate resistance state. Remarkably, this intermediate resistance state displays a behavior typically associated with Josephson junctions, most notably the onset of Shapiro Steps when applying AC radiation [9].

References

[1] Kitaev, A. Yu. *Physics-uspekhi* 44.10S (2001): 131.
[2] Prada, Elsa, et al. *Nature Reviews Physics* 2.10 (2020): 575-594.
[3] Aguado, Ramón. *Applied Physics Letters* 117.24 (2020): 240501.
[4] Krogstrup, P., et al. *Nature materials* 14.4 (2015): 400-406.
[5] Kanne, Thomas, et al. *Nature Nanotechnology* 16.7 (2021): 776-781.
[6] Vaitiekėnas, S., et al. "Flux-induced topological superconductivity in full-shell nanowires." *Science* 367.6485 (2020): eaav3392.
[7] Valentini, Marco, et al. "Majorana-like Coulomb spectroscopy in the absence of zero-bias peaks." *Nature* 612.7940 (2022): 442-447.
[8] Vaitiekėnas, S., Peter Krogstrup, and C. M. Marcus. *Physical Review B* 101.6 (2020): 060507.

[9] Bae, Myung-Ho, et al. *Nano letters* 9.5
(2009): 1889-1896.