Non-local Transport Signatures of Topological Superconductivity in Planar Josephson Junctions

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Finding signatures of topological superconductivity and the appearance of elusive Majorana-bound states has become one of the most significant challenges of modern solid-state physics. Josephson junctions, realized as hybrid nanostructures defined in a two-dimensional electron gas proximitized by a superconductor, have been considered promising candidates for the realization of well-controlled and scalable topological elements [1,2]. In this work, we propose and theoretically study a new method for probing the topological features of these systems. Instead of typical tunneling spectroscopy, which is sensitive only to states localized in the vicinity of the tunneling barrier [3] and prone to disorder-induced effects, we propose using a technique that probes the system in an open regime via non-local transport. In this configuration, the non-local conductance corresponds to the band structure of the system and enables elucidating the closing and reopening of the gap upon an increase in the phase difference, which is associated with the topological transition. This, however, happens only when the non-local signal reveres its sign when crossing zero energy and occurs due to the change of quasiparticle character of the bands at zero momentum. Moreover, we demonstrate that phase evolution is highly dependent on the strength of the indispensable Zeeman interaction, significantly changing the full phase diagram available for measurement in realistic experiments on hybrid Josephson junctions.

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