Topological superconductivity in a Josephson junction mediated by magnetic domains

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Topological superconductors are appealing building blocks for robust and reliable quantum information processing [1]. Most platforms for engineering topological superconductivity rely on a combination of materials with intrinsic spin-orbit coupling and external magnetic fields, which are usually challenging to manipulate [2]. We propose and describe a setup (Fig. 1) without spin-orbit or magnetic fields where a conventional Josephson junction is linked by a narrow ferromagnetic insulator barrier with multi-domain structure [3]. Sequences of magnetic domains that preserve the net magnetization's rotation direction are sufficient for generating topological superconductivity in a wide range of parameters and degrees of disorder. The topological phase transition depends on the magnitude and rotation period of the net magnetization. Interestingly, a phase bias ϕ across the junction can control the localization of a pair of Majorana zero-energy modes (MZMs) at the edges of the junction interface, with an observable effect on the current-phase relation (Fig. 2).

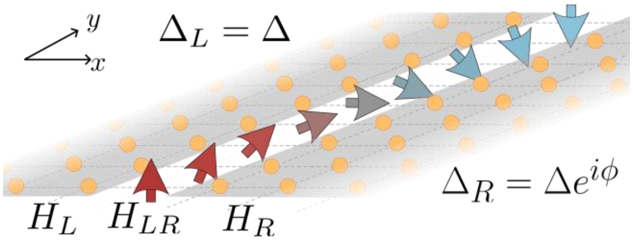

Figure 1: Superconductors L and R are separated by a ferromagnetic insulator barrier, so that the hopping between them is spin dependent. The magnetization direction of the insulating barrier changes in space, as depicted by the arrows, akin to a magnetic domain wall.

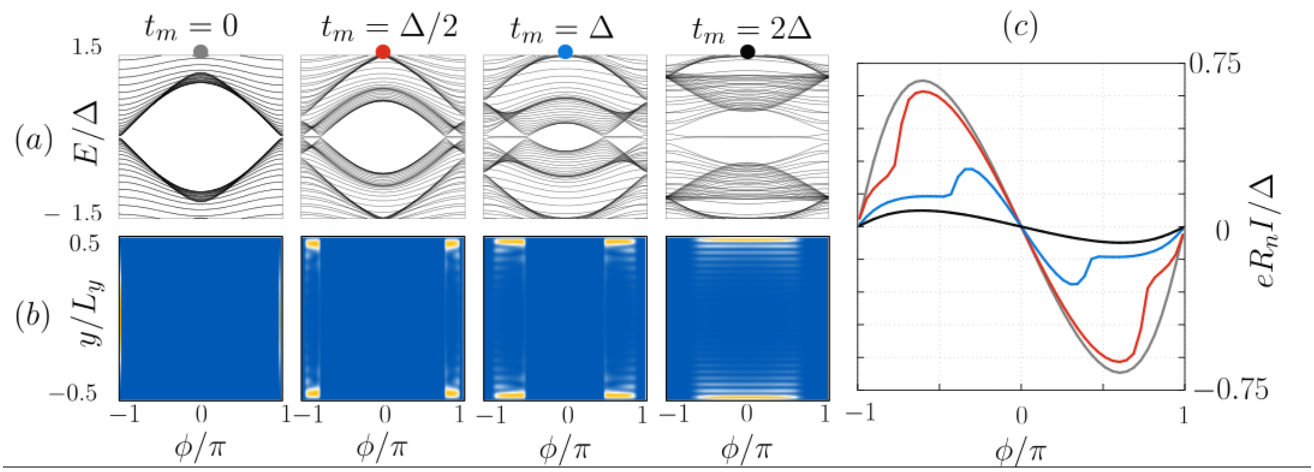

Figure 2: Localizing edge modes by phase biasing the junction. (a) Energy bands showing the gap reopening and MZMs at finite ϕ. (b) Local density of states (a.u.) at E = 0 vs junction width, showing the localization of a pair of topological edge states. (c) Current-phase relation for the parameters used on the left. Increasing the magnetization strength facilitates the topological phase transition.

References
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