Quantum dot detects Majorana modes of both chiralities

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A model of a tunneling junction between normal electrode and 1D-topological wire, mediated by a quantum dot (QD), is investigated. The semiconducting wire, subjected to an external magnetic field, is described by a tight-binding Hamilotnian with Rashba field term and induced s-wave superconductivity. Above the critical magnetic field, the wire can be driven into topological p-wave phase with end-state Majorana zero modes (MZMs). The dot is coupled to the one of its ends and a normal electrode, forming tunneling junction. The self-energy of the dot's Green"s function coming form the wire is calculated within recursive summation Green's function method. The model is investigated for topological as well as trivial state of the wire.

The present investigations are motivated by the recent experimental findings [1] showing that an unintentional quantum dots can be formed in the tunneling junction between normal electrode and superconducting wire. This feature changes considerably the picture of possible MZM spotting, as the trivial localized QD states close to Fermi energy, can be mistakenly regarded as Majorana modes. This casts a serious doubt on the previous conductance spectroscopy measurements of MZM detection [2].

We demonstrate that the presence of a quantum dot in the tunneling junction can itself be advantageous for MZM detection. Namely, we show that for the dot strongly coupled to the wire, both the Zeeman split QD levels $\epsilon_\downarrow$ and $\epsilon_\uparrow$, when subsequently tuned to Fermi energy by gate voltage, can detect MZMs. These modes belong to the different chiral sub-bands formed in the wire while in topological state [3] and originate form the Majorana Kramers pairs, present in time-reversal invariant superconductors [4]. The detection is manifested by characteristic three-peak structures in the density of states of the dot. The satellite peaks in this structure, adjacent to the MZM "leaked" into the dot, come from hybridization of QD spin-sublevels with MZM of appropriate chirality. The direction of magnetic field determines which chiral sub-band of the wire is stronger coupled to the dot. For this chirality the satellite peaks, whose positions are proportional to QD-wire coupling, can be pushed outside the superconducting gap, and the remaining MZM resonance can be hardly distinguished from an accidental state close to Fermi energy. However, the three-peak structure is still preserved in the second chiral sub-band, due to a weaker coupling to the dot, and it can be noticed in conductance spectroscopy. This behavior is in contrast to the presence of trivial states only, for which such structures never appear in any chirality.

References:

[1] M. Valentini *et.al.*, Science **373**, 82 (2021)
[2] M. Aghaee *et.al.*, arxiv: 2207.02472v3
[3] J. Alicea, Phys. Rev. B **81**, 125318 (2010)
[4] Fan Zhang, C.L. Kane and E.J. Mele , Phys. Rev. Lett. **111**, 056402 (2013)