Majorana states in $1D$-topological superconductor with on-site Coulomb interactions

Piotr Stefański[1]

[1] *Institute of Molecular Physics of the Polish Academy of Sciences, ul. Smoluchowskiego 17, 60-179 Poznań, Poland*

We consider theoretically a $1D$ semiconducting wire with strong Rashba interaction in proximity of s-wave superconductor. The wire is exposed to external magnetic field perpendicular to the effective Rashba field. Such a device configuration provides suitable conditions for the appearance of topological p-wave superconductivity.

The system is modeled by a tight binding Hamiltonian with Rashba hopping term and induced s-wave superconductivity. Additionally, we take into account short-range on-site Coulomb interactions inside the wire. The calculations are performed utilizing recursive Green's function method, and Coulomb interactions are treated selfconsistently within Hubbard I approximation.

We demonstrate that the presence of Coulomb interactions has a global and a local effect on superconducting topological state and Majorana state formation. Globally, the topological state is promoted by Coulomb interactions by opening the p-wave superconducting gap at lower magnetic fields as compared to the noninteracting case. Moreover, Coulomb interactions produce the Shiba-like Hubbard bands in the density of states of the wire when the II-nd Hubbard levels of each site enter the superconducting gap. Locally, at the particular site of the wire, Coulomb interactions induce the appearance of particle-hole pairs of sharp resonances associated with the II-nd Hubbard quasiparticle in-gap levels of this particular site. Due to quantum interference between Hubbard quasiparticle bands and sharp local resonances at the end-sites, a pair of Fano resonances appears in the particle and hole sector of the density of states. We show that quantum interference is governed by the competition between two-particle and single-particle tunneling processes, which has a decisive effect on the Majorana peak formation. Depending on the position of the sharp in-gap Hubbard levels, controlled by external magnetic field, one of the two types of tunneling prevails. Strikingly, for the dominance of two-particle processes the Majorana peak is strongly suppressed, whereas for the dominant single-particle tunneling it is not altered. Finally, for such a magnetic field value that the Hubbard levels cross at Fermi energy, the Majorana peak is destroyed completely.

As a side effect, we emphasize the difference in tunneling current between two superconductors with strong spin-orbit interaction, when an accidental quasiparticle level is residing at Fermi energy, and when the true Majorana resonance is present. This could be a hint for experimental verification of true topological end-states of the wire.