Majorana fermions in Josephson vortices

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Majorana fermions are equal to their own antiparticles and obey non-abelian statistics. Such unusual properties of Majorana fermions can be used for the topological quantum computations [1]. Majorana fermions can be realized as bound states in topological superconductors [2]. Recently, Majorana fermions have observed in the superconducting wires in the strong magnetic field [3].

One of the promising scheme for the topological quantum computations is the Josephson junction on the surface of the topological insulator [4]. In this case, topological quantum computations can be performed by the adjusting of the phase difference between the superconducting pieces by the local gates [5].
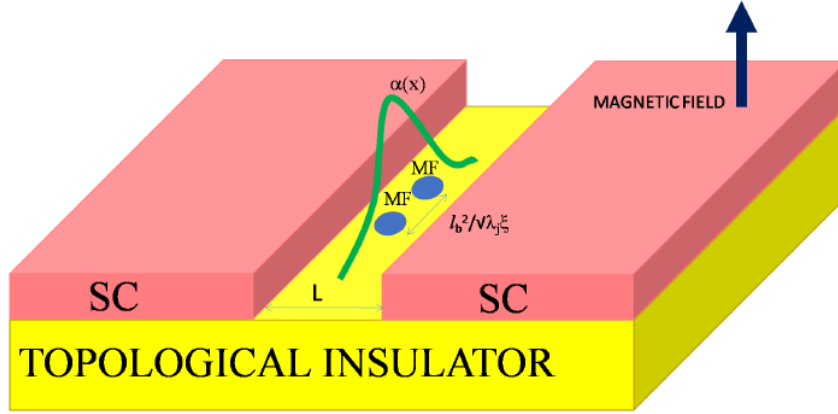

Figure 1: Scheme of the Josephson junction.

Model

Surface states of topological insulator with the induced superconductivity can be described by the Hamiltonian

$$H = \nu_F(\sigma p)\tau_z + \Delta(r)\tau_x e^{i\phi(r)\tau_z},$$

where ν_F is the Fermi velocity of the surface states of topological insulators, $\sigma_i(\tau_i)$ are Pauli matrices acting in the spin (particle-hole spaces), p is the quasiparticle momentum, $\Delta(r) = \Delta\Theta(y^2 - L^2)$ is the order parameter, Θ is the Heaviside step function, L is the length of the junction, $\xi = \nu_F/\Delta$ is the coherence length, $\phi(x,y)$ is the phase of the order parameter across the junction. Small external magnetic field induces Josephson vortices inside the junction. Thus, phase difference between the different sides of the junction is a soliton

$$\alpha(x) = 4\tanh(x/\lambda_j),$$

where λ_j is the Josephson length of the junction. Since phase gradient $\alpha'(x) \neq 0$ is finite, we get that Majorana fermions inside the junction are split inside each vortex by the distance $l_b^2/\sqrt{\lambda_j \xi}$. Such splitting can be tuned by the magnetic field. Thus, it allows to construct braiding algoritm for the quantum computations in this junctions [6].

References

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