Interplay of quantum spin Hall effect and spontaneous time-reversal symmetry breaking in electron-hole bilayers II: Zero-field topological superconductivity

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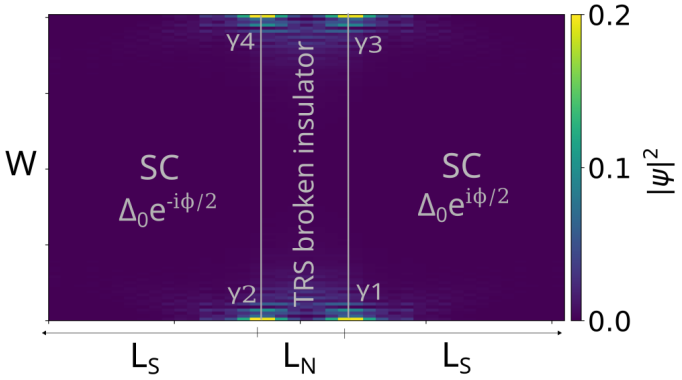
It has been proposed that band-inverted electron-hole bilayers support a phase transition from an insulating phase with spontaneously broken time-reversal symmetry to a quantum spin Hall insulator phase as a function of increasing electron and hole densities. Here, we show that in the presence of proximity-induced superconductivity it is possible to realize Majorana zero modes in the time-reversal symmetry broken phase in the absence of magnetic field. We develop an effective low-energy theory for the system in the presence of time-reversal symmetry breaking order parameter to obtain analytically the Majorana zero modes and we find a good agreement between the numerical and analytical results in the limit of weakly broken time-reversal symmetry. We show that the Majorana zero modes can be detected in superconductor/time-reversal symmetry broken insulator/superconductor Josephson junctions through the measurement of a 4π Josephson current. Finally, we demonstrate that the Majorana fusion-rule detection is feasible by utilizing the gate voltage dependence of the spontaneous time-reversal symmetry breaking order parameter.



Superconductor/TRS broken insulator/ superconductor Josephson junction for detection of the MZMs via the 4π Josephson effect. The system supports two MZMs γ_1 and γ_2 (γ_3 and γ_4) on the bottom (top) edge with the corresponding low-energy local density of states indicated with the colors. The hybridization of the MZMs across a TRS broken regime of length L_N gives rise to a 4π-periodic component in the Josephson current-phase characteristic I(ϕ).

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