Majorana Bound States in Semiconductor/Ferromagnetic insulator/Superconductor nanowire heterostructures

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1. Outline

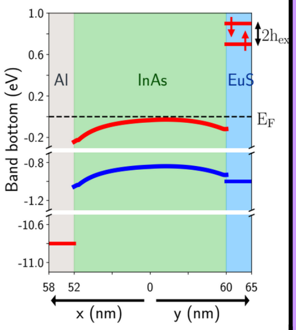
Hybrid semiconducting nanowire devices combining epitaxial superconductor and ferromagnetic insulator layers have been recently explored experimentally as an alternative platform for topological superconductivity at zero applied magnetic field. In this proof-of-principle work **we show that the topological regime can be reached in actual devices** depending on some geometrical constraints. To this end, we perform numerical simulations of InAs wires in which **we explicitly include the superconducting Al and magnetic EuS shells**, as well as the **interaction with the electrostatic environment** at a self-consistent mean-field level. **Our calculations indicate that the topological phase is robustly achieved** in significant portions of the phase diagram only in configurations where the Al and EuS layers overlap on some wire facet due to their rather local induced proximity effects. Moreover, **we find that the spin polarization induced directly in the semiconductor by the EuS is much stronger than the one induced indirectly through the superconductor.** Finally, we also show how the topological phase can be tuned and optimized using external gates.

2. Hamiltonian and Model

We include the three materials of the heterostructure in the Hamiltonian

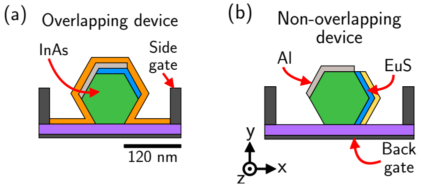
$$\mathrm{H}=\left[\frac{\hbar^2\vec{k}^2}{2m_{\mathrm{eff}}(\vec{r})}-E_{\mathrm{F}}(\vec{r})+e\phi(\vec{r})+ h_{\mathrm{ex}}(\vec{r})\sigma_z+\frac{1}{2}\vec{\alpha}(\vec{r})\cdot\left(\vec{\sigma}\times\vec{k}\right)\right]\tau_z+\Delta(\vec{r})\sigma_y\tau_y$$

We take realistic values for the parameters inside each material (effective mass, exchange field, SOC and pairing) . We also take into account the band offset and band bending at the interfaces.



We include the interaction with the electrostatic environment and charge. To this end we solve the Schrödinger-Poisson equation.

We compute the spectrum for the precise geometries of the experimental devices.

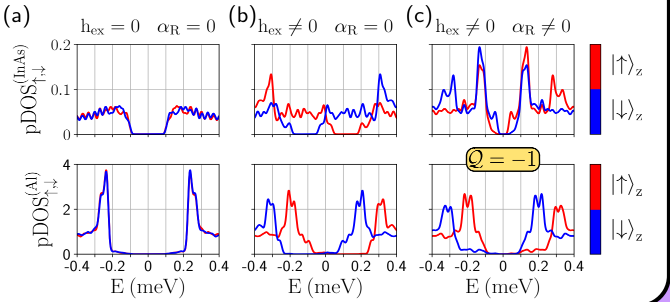


3. Results

We compute the spectrum and the DOS for the overlapping device. We find there is a strong induced gap and magnetization.

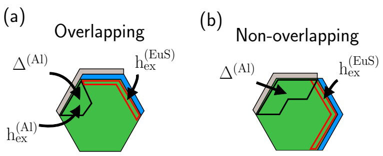
We also compute the topological invariant, finding that the wire is in a non-trivial topological phase.

We perform the same calculation for the non-overlapping device (not shown here), finding that there is *not* a strong enough induced exchange field to host a topological phase.



4. Effective model

We employ an effective model to compute the phase diagrams. We now include both proximity effects directly in the wire.



We find that the overlapping device has several robust and sizeable topological regions. On the other hand, the non-overlapping device, although it also shows topological regions, they are characterized by small minigaps, and one must fine-tune the potential gates.