Semiconductor-ferromagnet-superconductor planar heterostructures for 1D topological superconductivity

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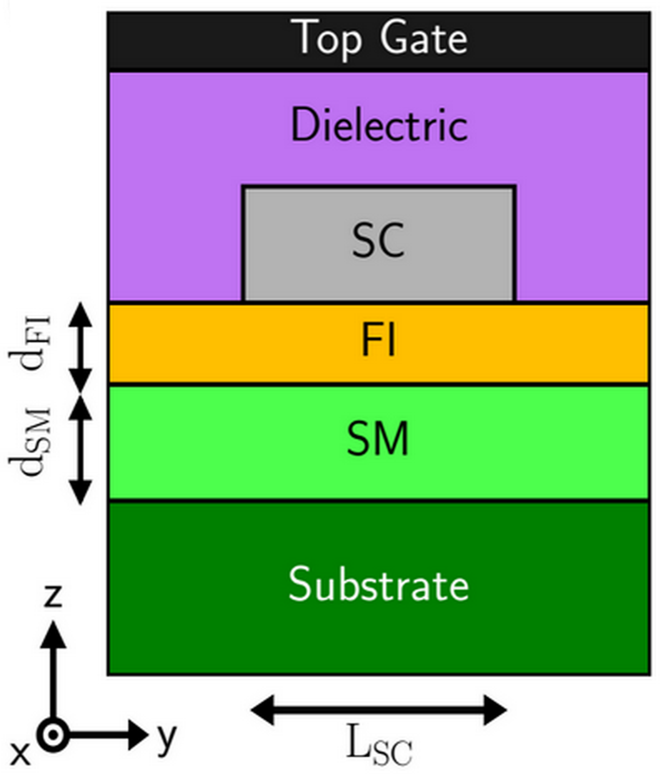
1. System

We want to know whether a planar semiconductor-ferromagnetic-superconductor heterostructure can support 1D topological states.

The SC is a stripe. It screens the top gate creating effectively a quasi-1D channel.

The ferromagnet is an insulator. If it is thin, electrons may tunnel from the SC to the SM.

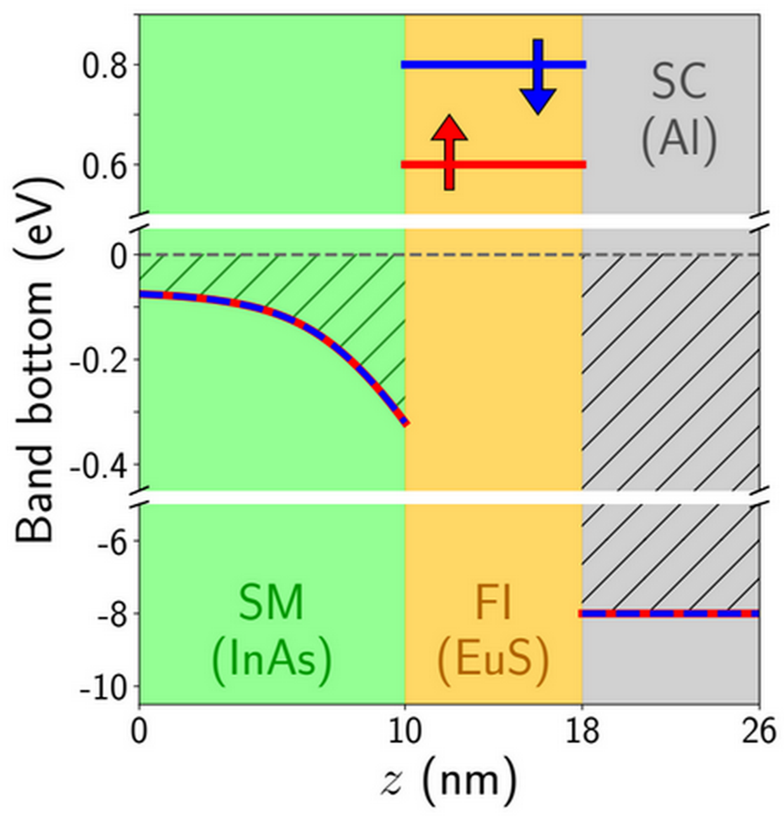


2. Hamiltonian

We include in the Hamiltonian the conduction band of the three materials and the electrostatic interactions

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

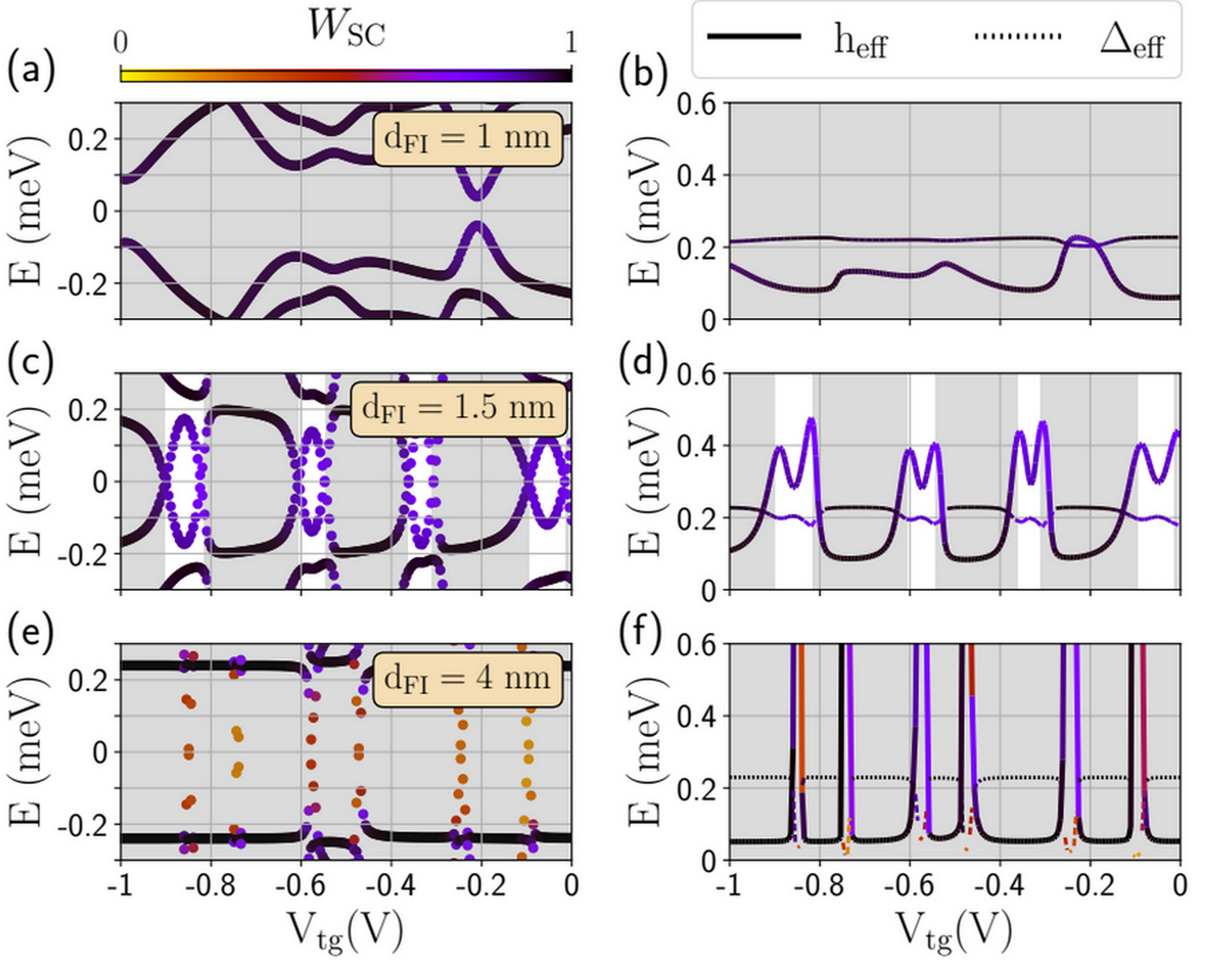
We solve the Schrödinger-Poisson equation taking into account a realistic device and using experimental parameters for the Hamiltonian.



3. Results

Spectrum at k_x=0 for three different FI thickness

Effective exchange energy and pairing potential for the lowest-energy state

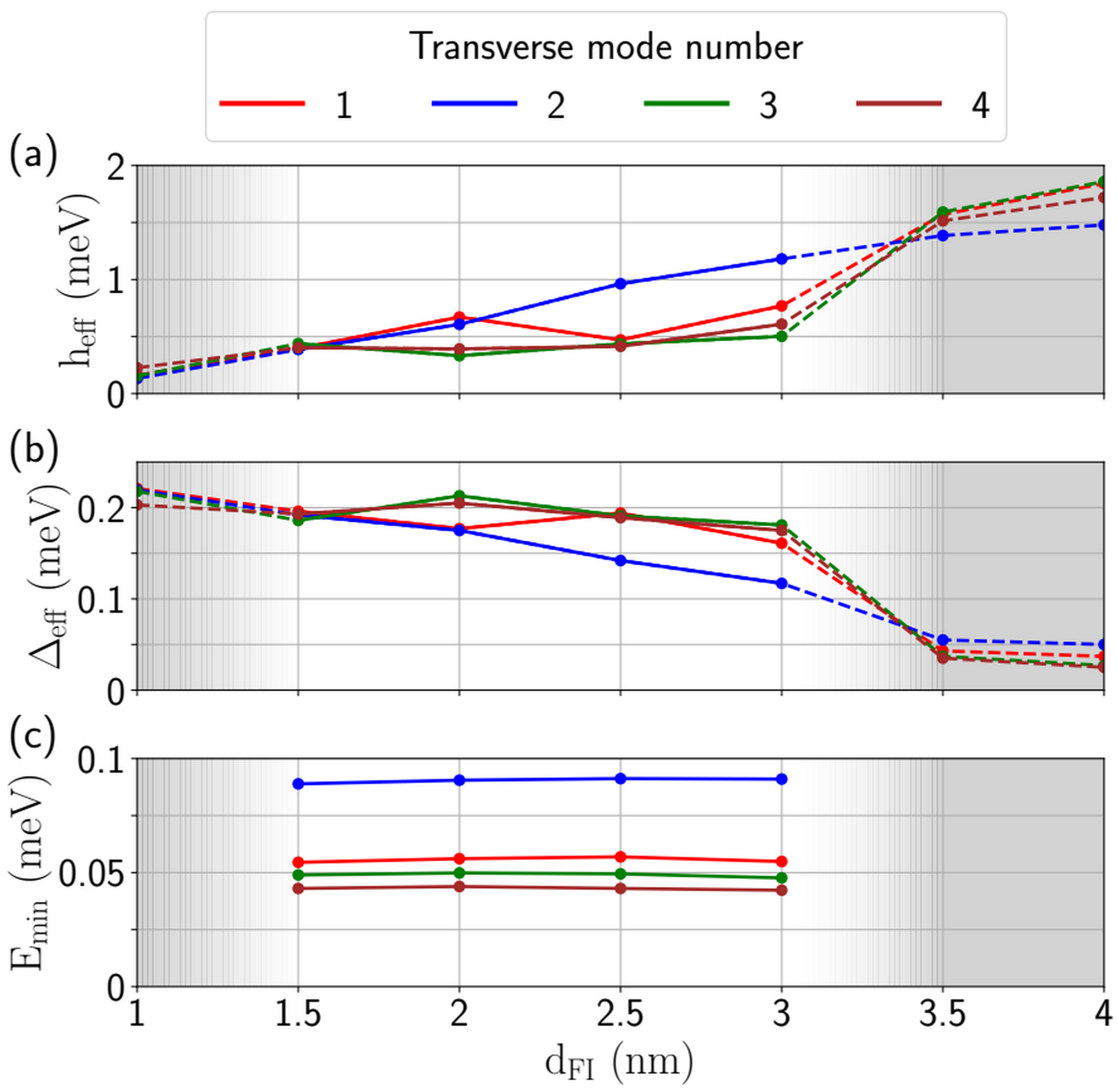


(a,b) For too thin FI layers, the effective Zeeman is not strong enough to drive the device into a topological phase.

(e,f) For too thick FI layers, electrons cannot tunnel to the SC, and therefore acquire a superconducting pairing amplitude.

(c,d) **For an intermediate FI thickness, we find topological states. Notice the regularity of the topological regions.**

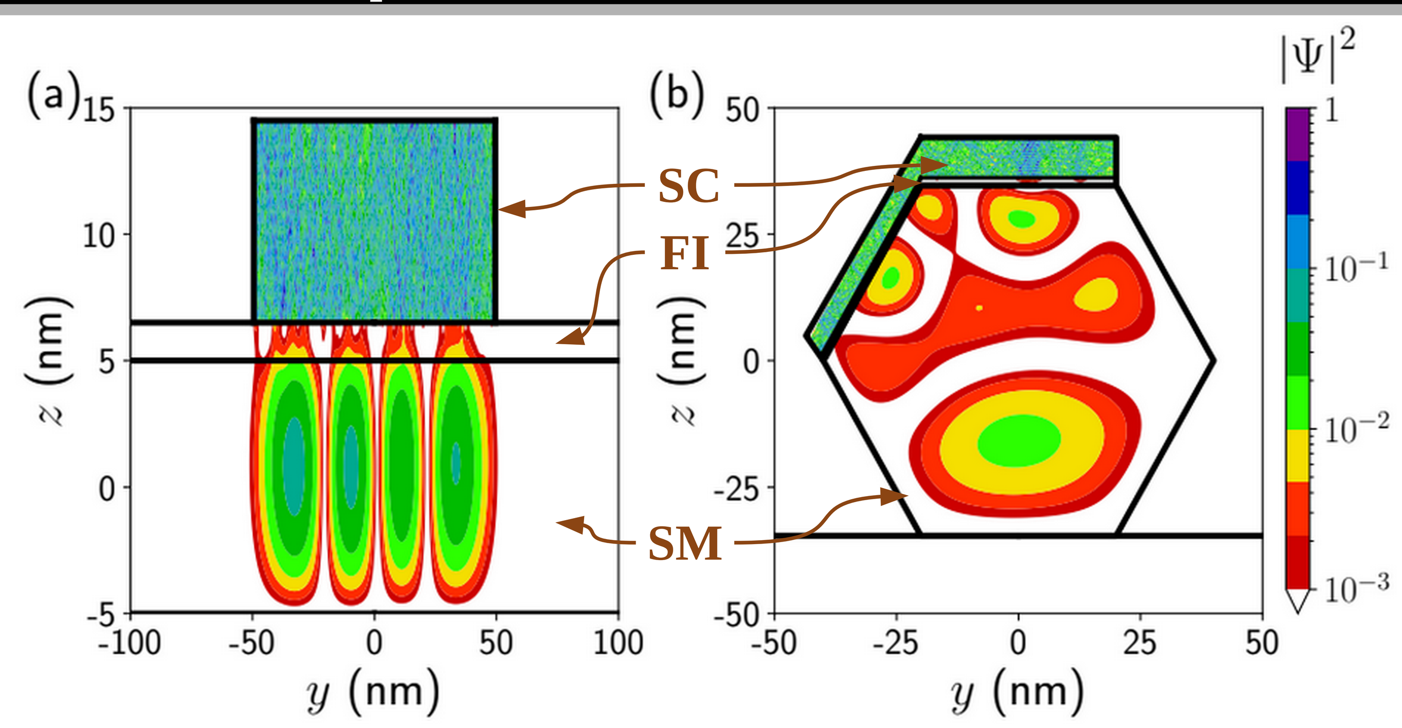
Topological parameters for the first four transverse subbands



We find 1.5-3 nm to be the ideal thickness to have topological states. We note that the penetration length into the FI layer is ~2 nm.

Notice that all the topological states exhibit similar effective parameters, i.e., **the phase diagram is predictable.**

4. Comparison to a wire device



In the wire geometry, the wavefunction spreads more across the wire section than in the planar geometry. This leads to **weaker proximity effects and less predictable and robust topological phases.**

5. Conclusions

- The SM-FI-SC planar platform supports predictable and robust topological states.
- Since they are based on 2DEG, they present reduced disorder in comparison to a wire.
- Because there is no need of a magnetic field, different effective wires could have different orientations.
- Hence, this geometry is promising for quantum computing and for 1D and 2D topological superconductivity.

Further details.-
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