SEMICONDUCTOR-FERROMAGNET-SUPERCONDUCTOR PLANAR HETEROSTRUCTURES FOR 1D TOPOLOGICAL SUPERCONDUCTIVITY

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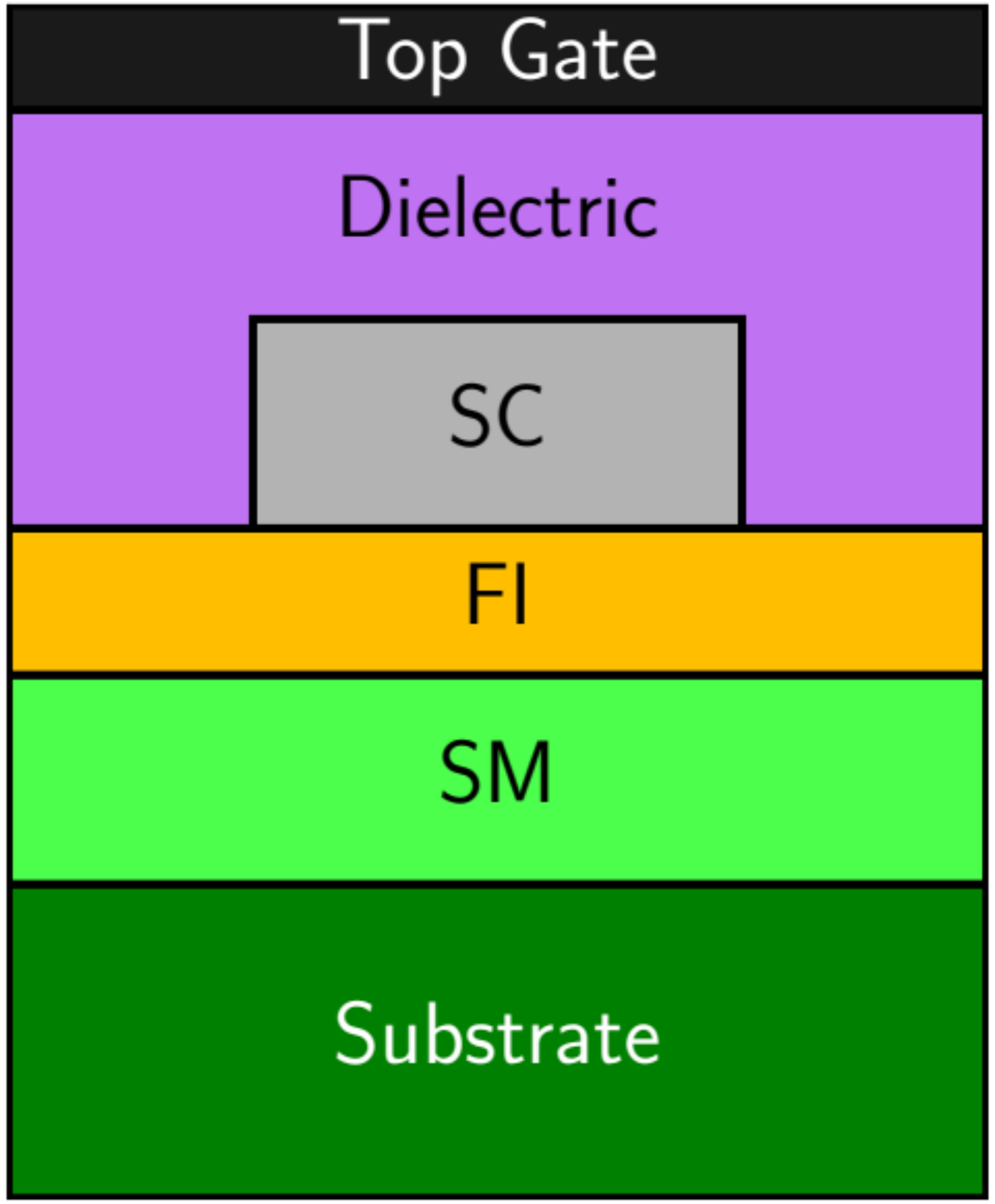

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SM-SC-FI planar wires

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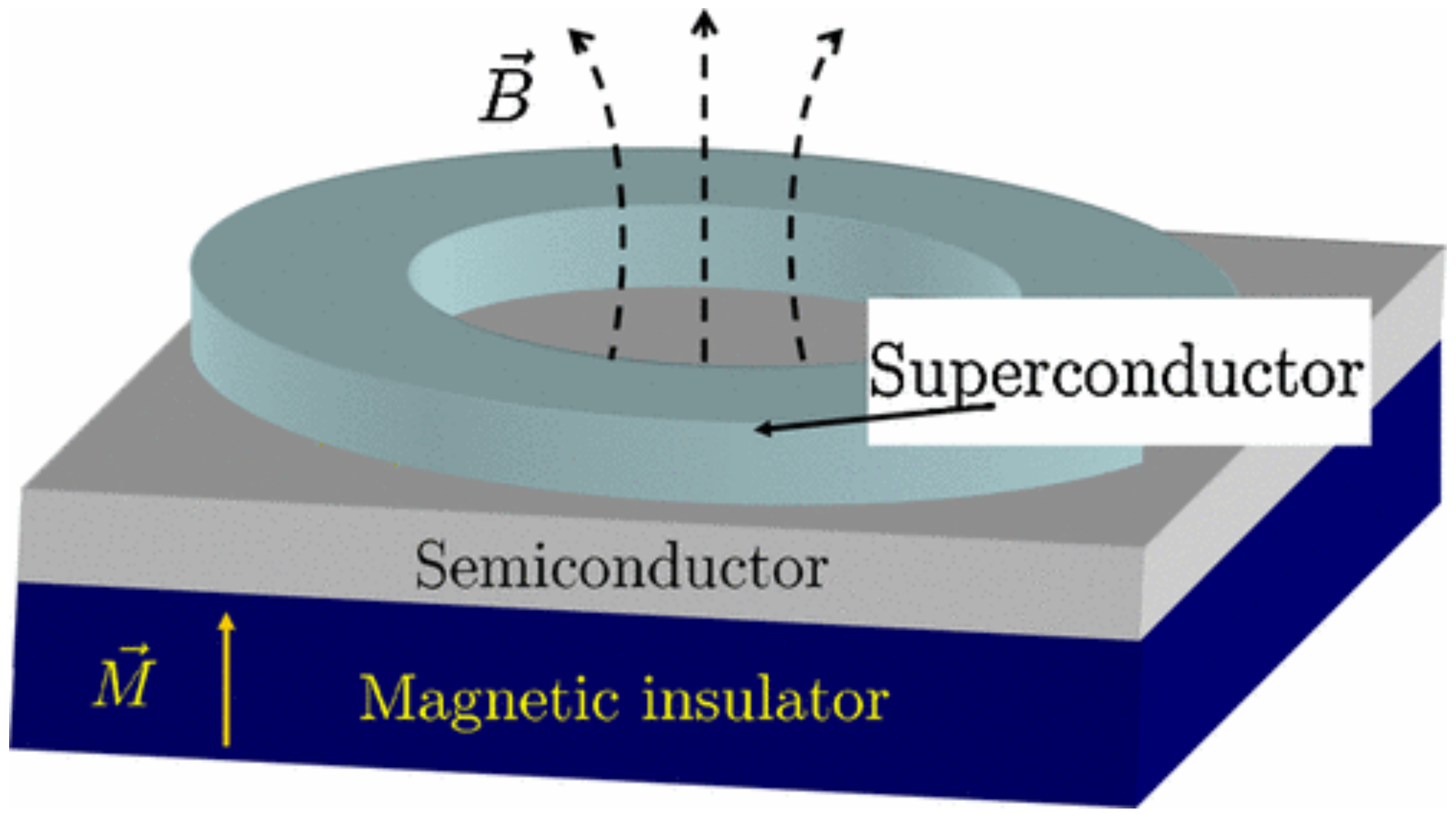
SM-SC-FI planar wires

J. D. Sau *et al.*, PRL **104**, 040502 (2010)

1D topological superconductivity (Majorana modes) can be achieved in heterostructures combining three materials:

Semiconductor with SO coupling + Superconductor + **Magnetic insulator**



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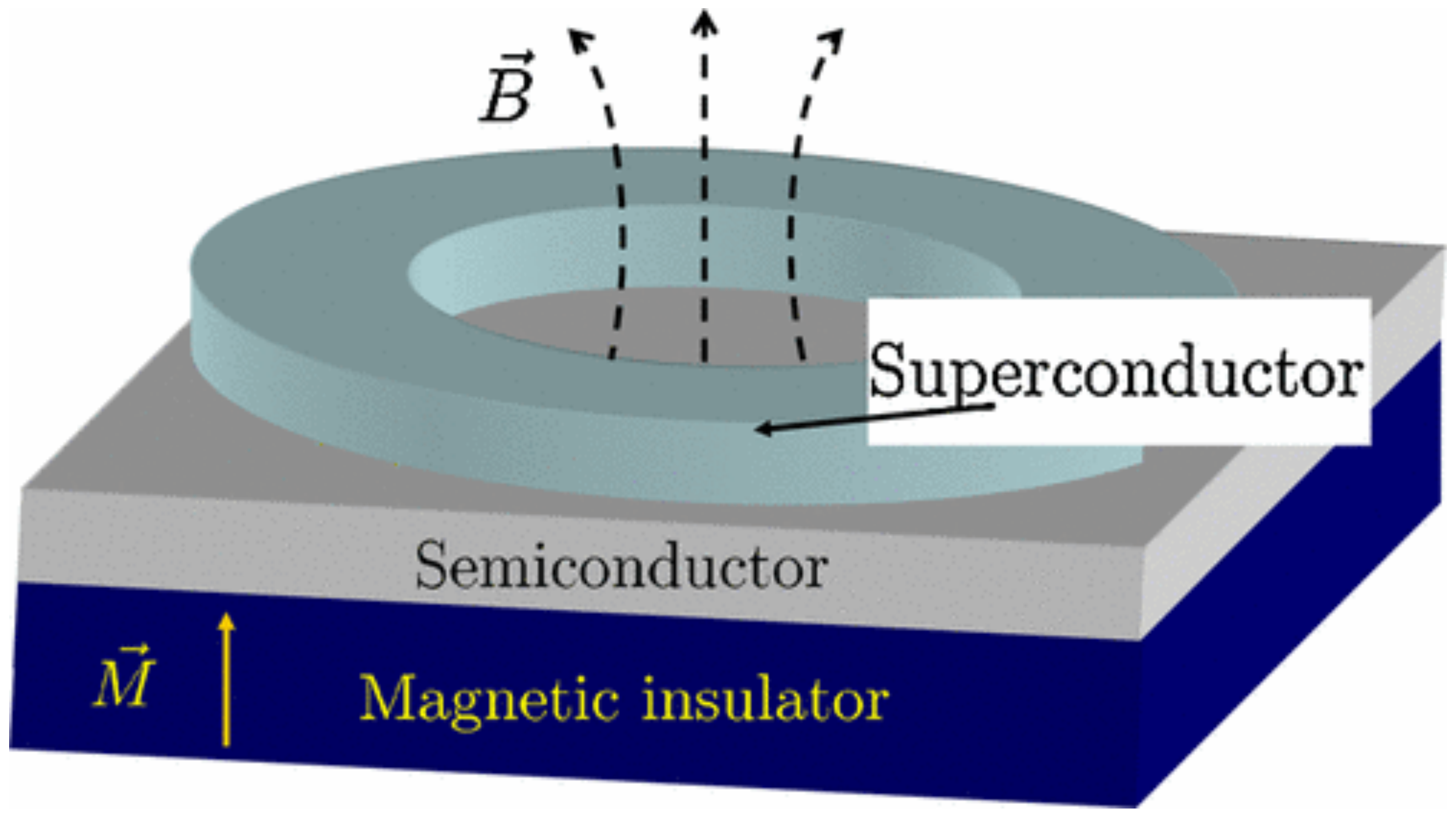
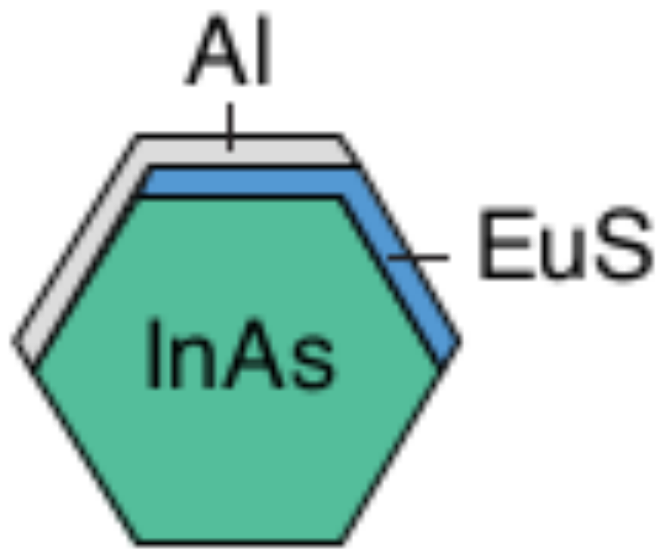
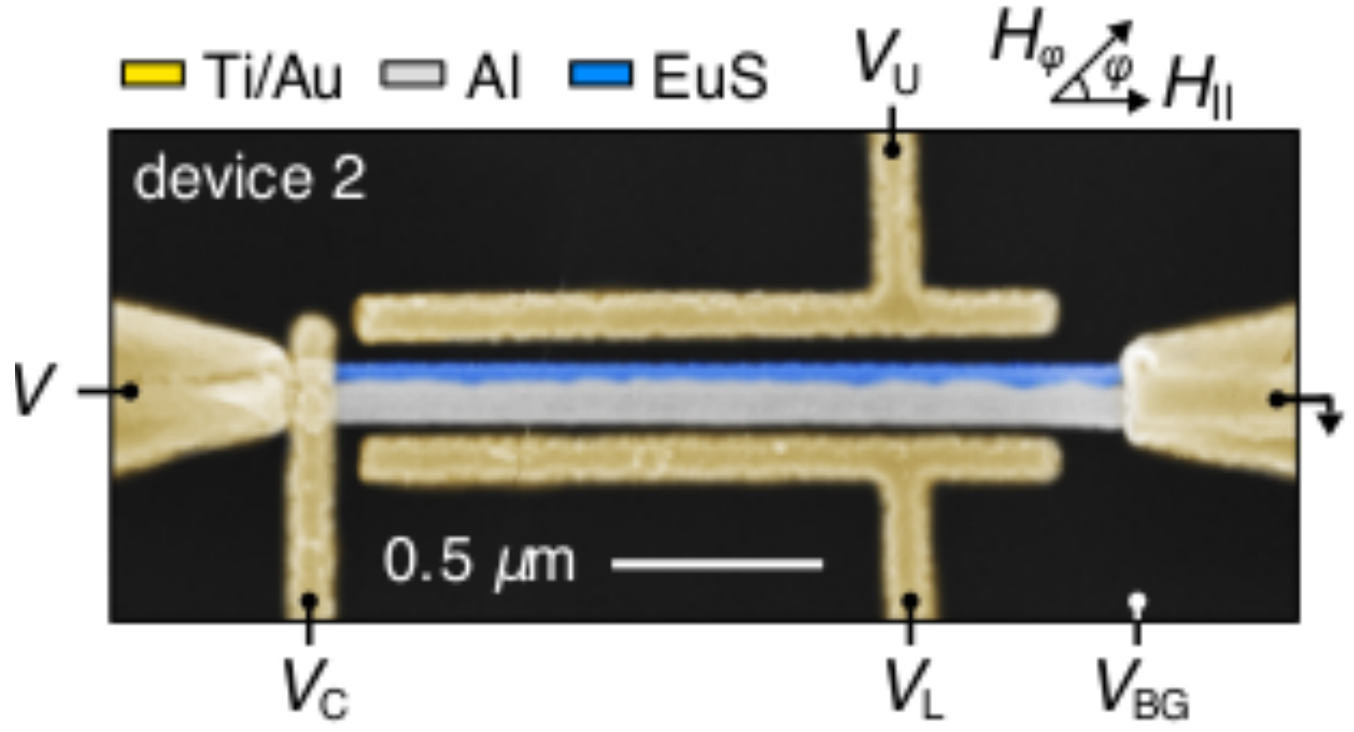
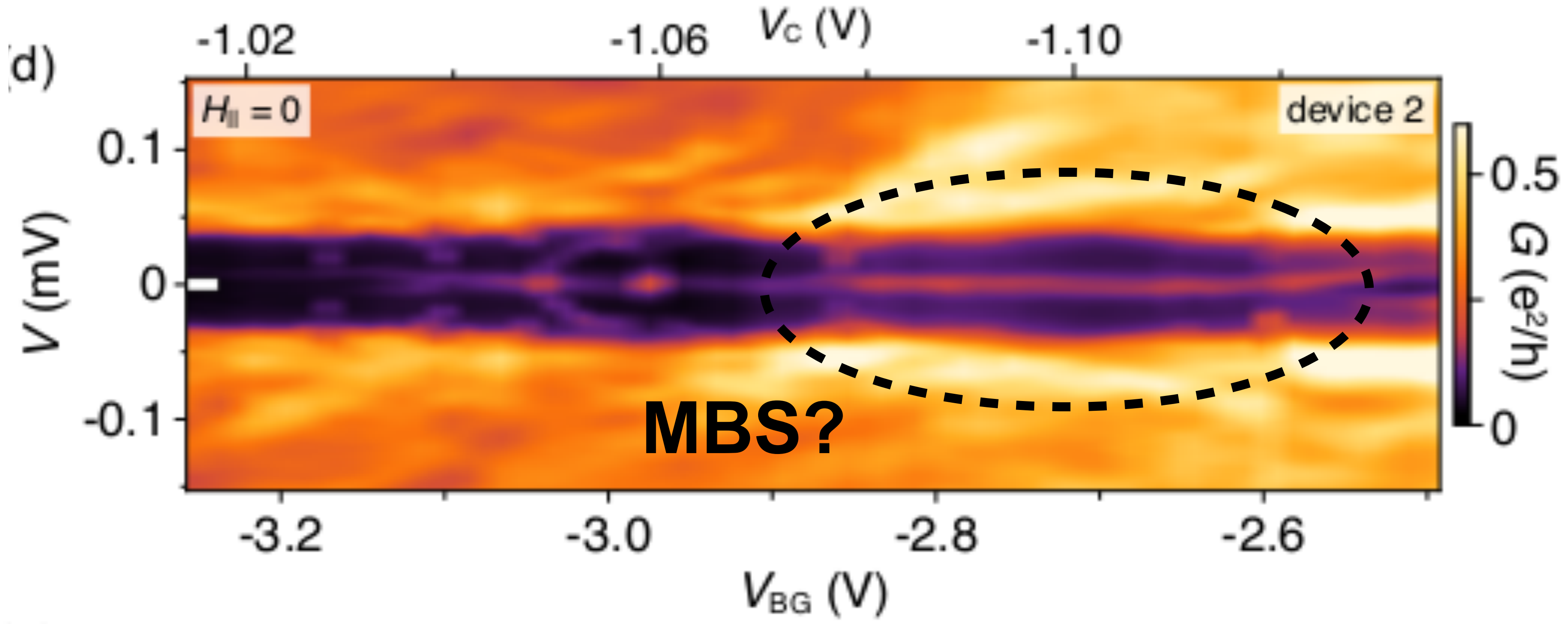


S. Vaitiekenas *et al.*, Nat. Phys. **17**, 43 (2021)







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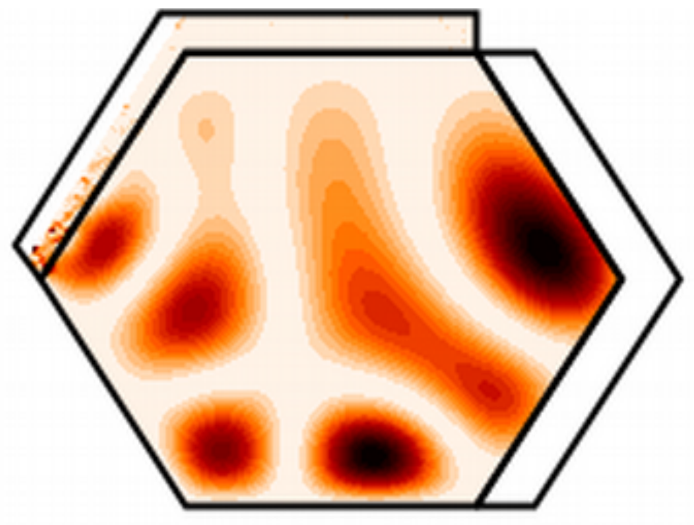
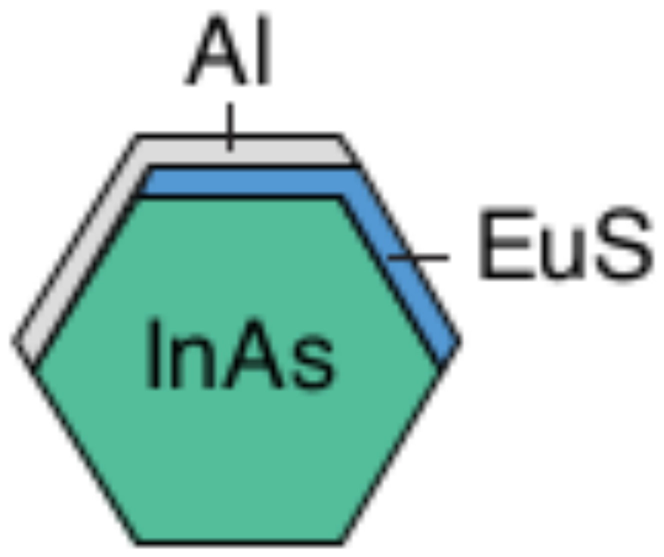
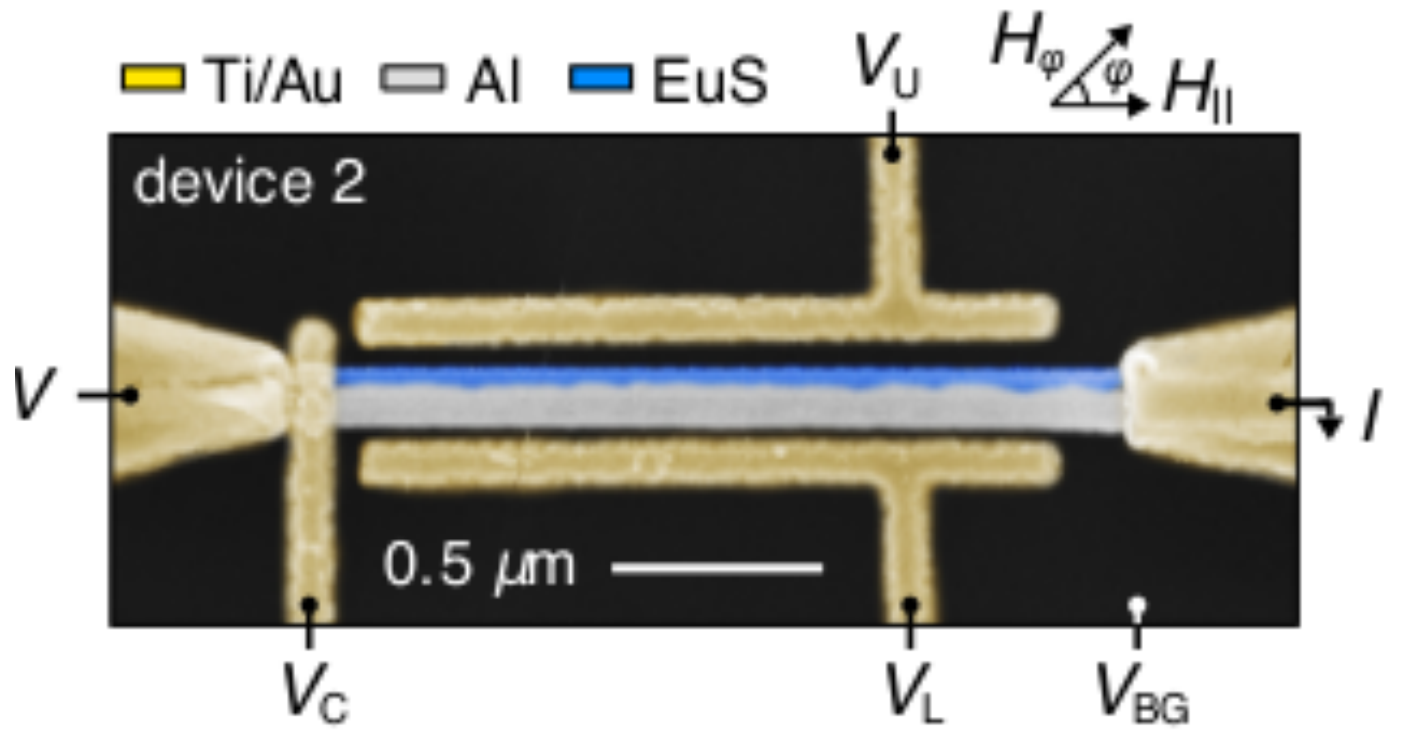
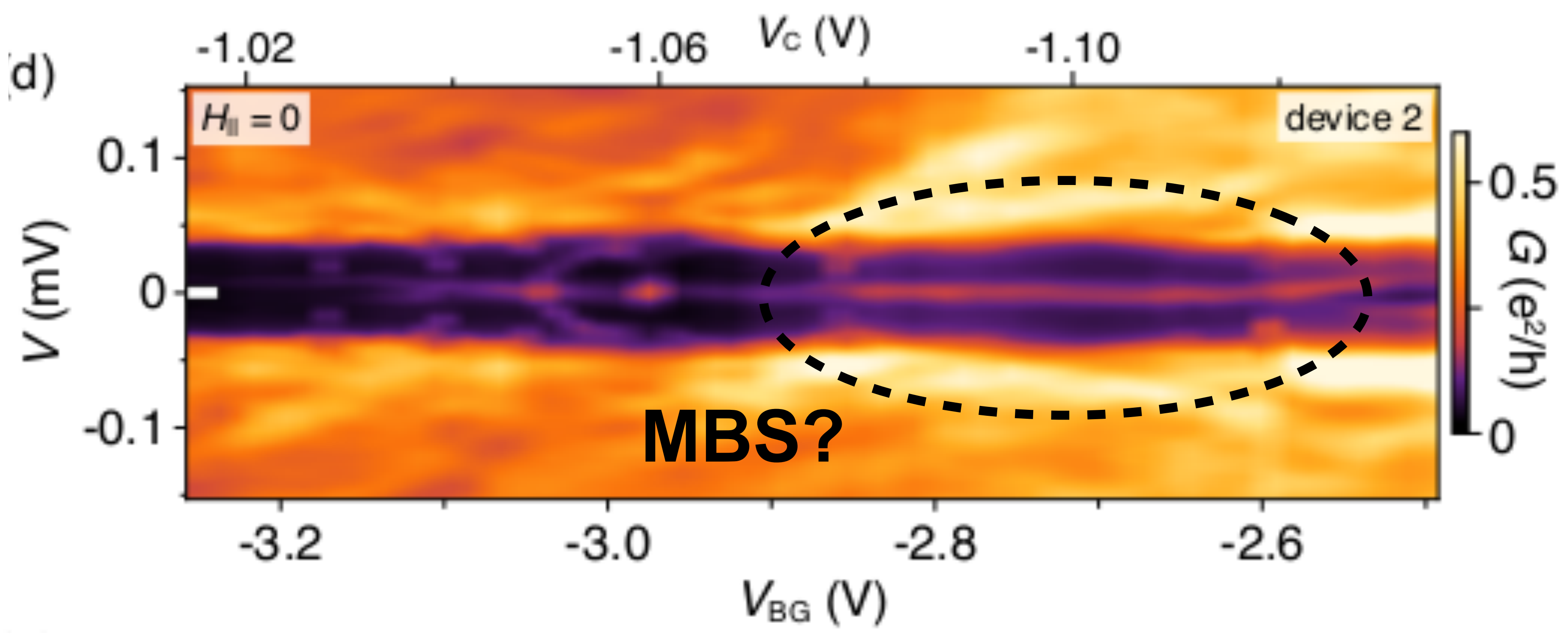


Proximity effects are very sensitive to layer disposition and gating!

S. Vaitiekenas *et al.*, Nat. Phys. **17**, 43 (2021)







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F. Nichele *et al.*,
Phys. Rev. Lett. **119**,
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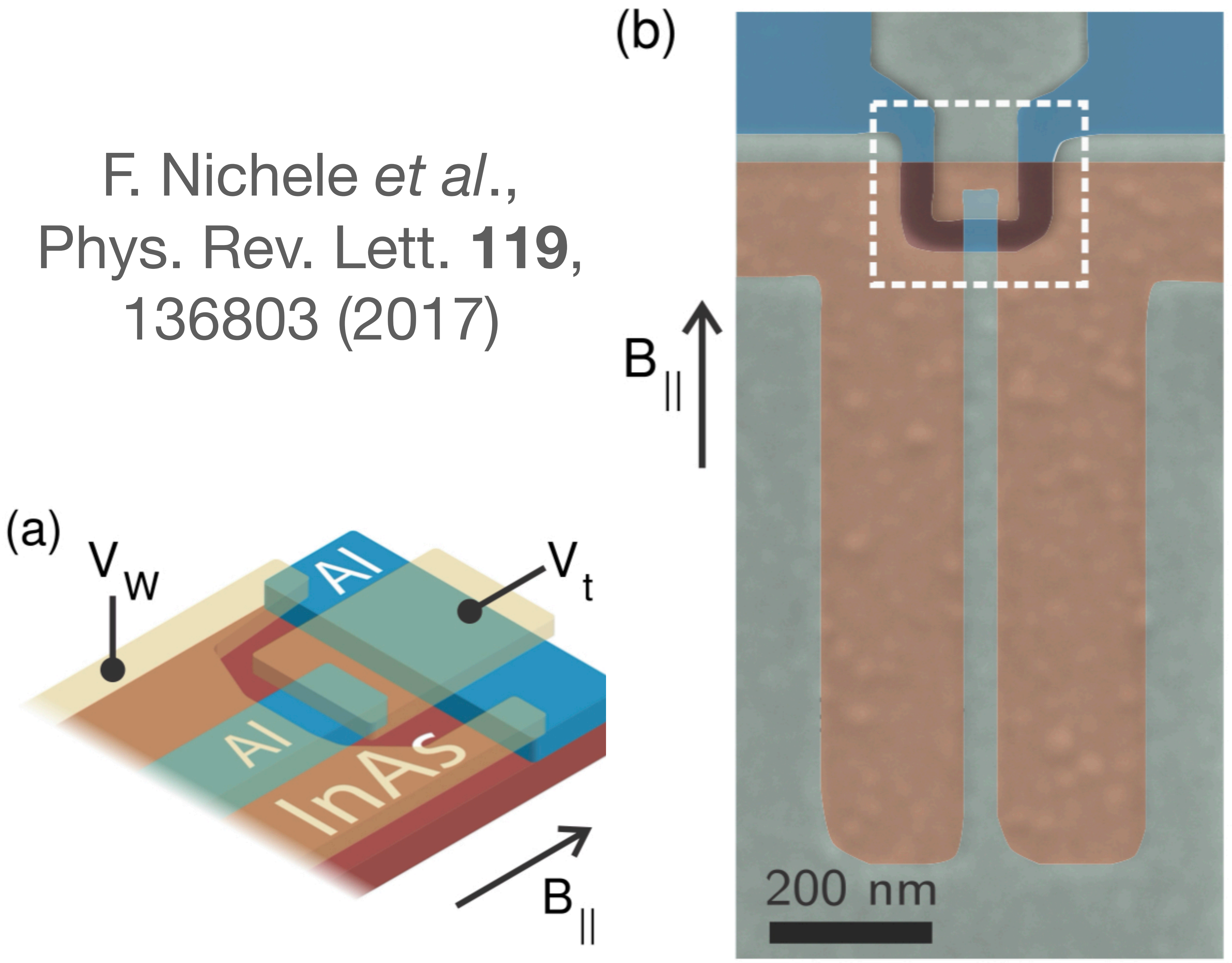

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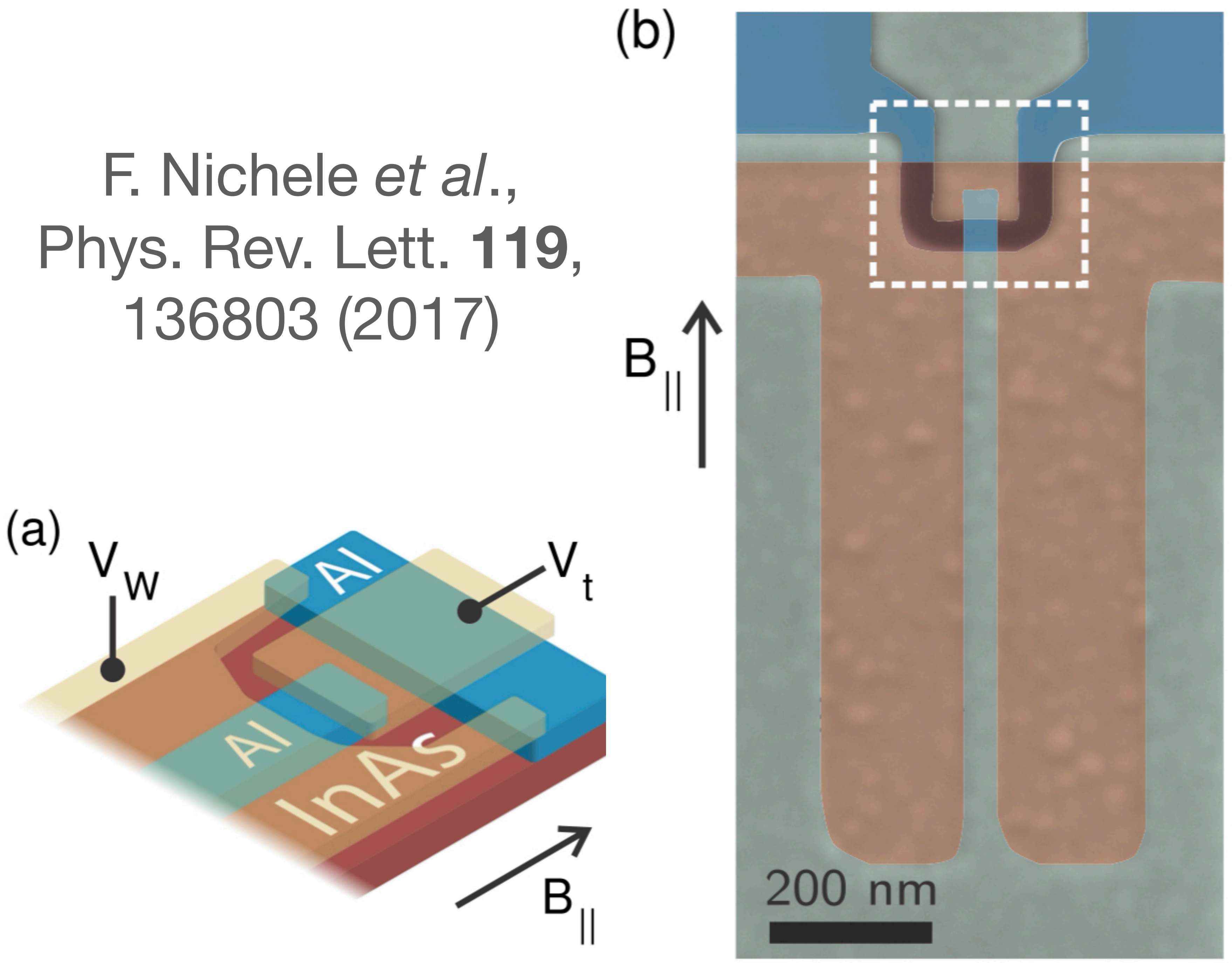

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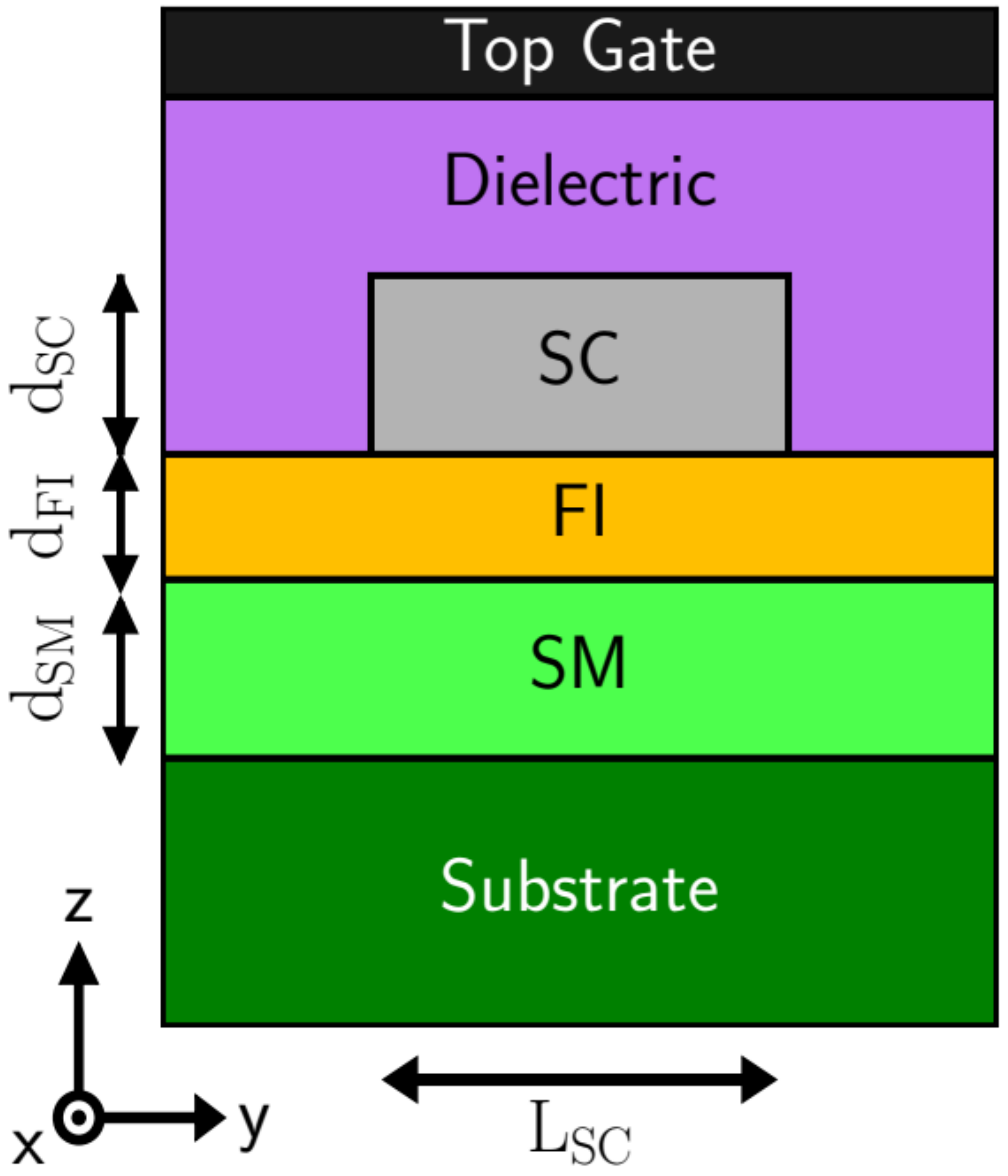


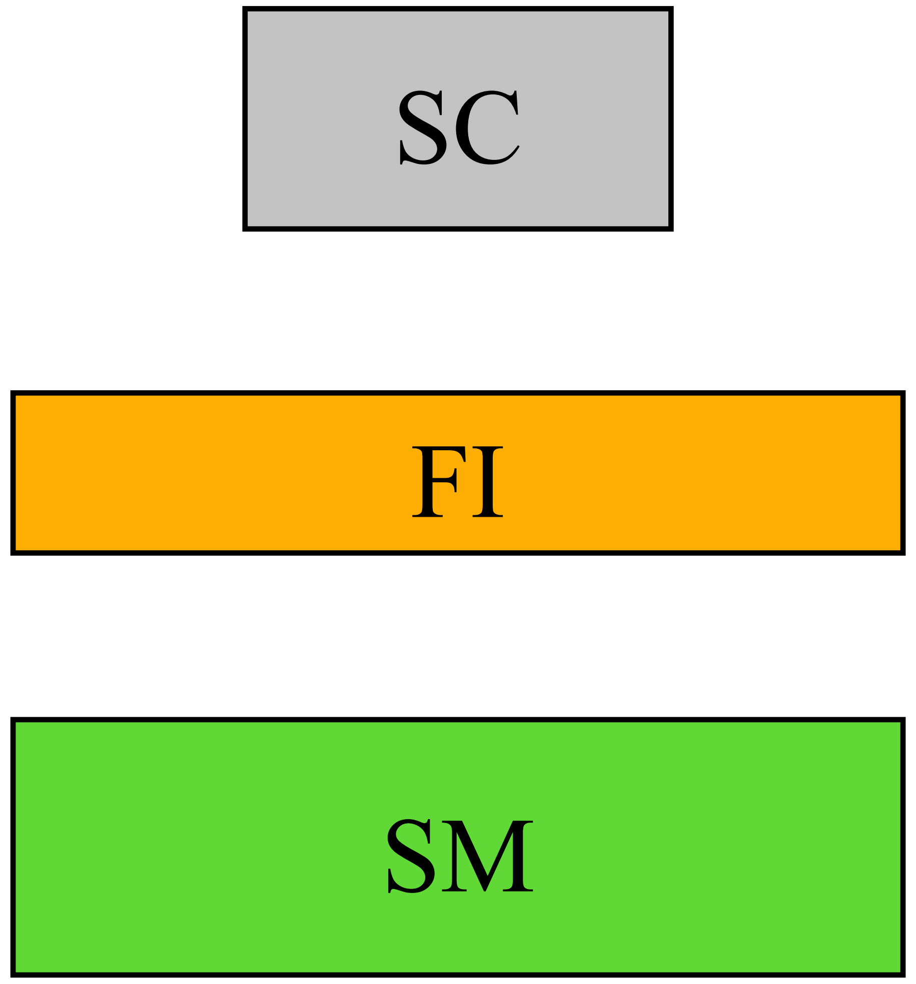
Gate-defined 1D channel in a planar SM-FI-SC heterostructure

The insulator should be thin enough to allow electrons to tunnel through

But thick enough to induce a strong magnetization

Optimal FI thickness?

SM-SC-FI planar wires



We describe each material separately. When joined together, we describe the system with a single Hamiltonian with spatial dependent parameters.

$$H_{SM},\ \ H_{FI},\ \ H_{SC}$$

SM-SC-FI planar wires

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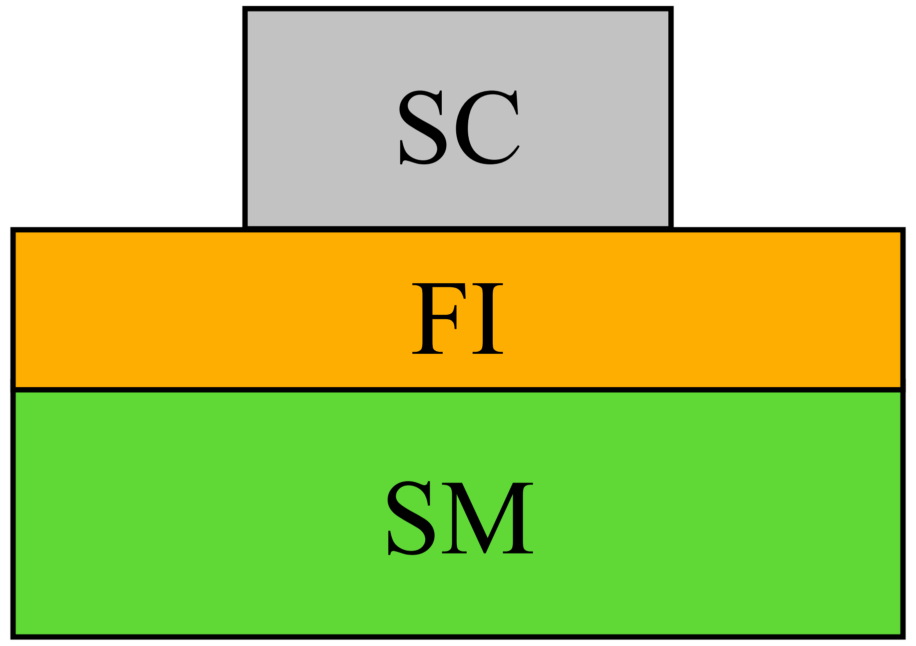
$$H = H_{SM} \oplus H_{FI} \oplus H_{SC}$$



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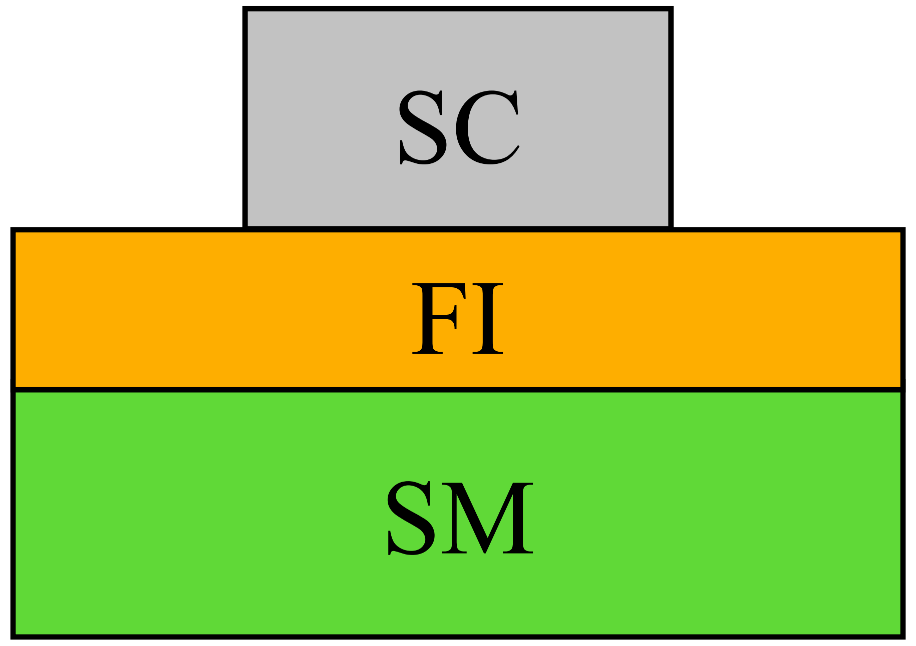

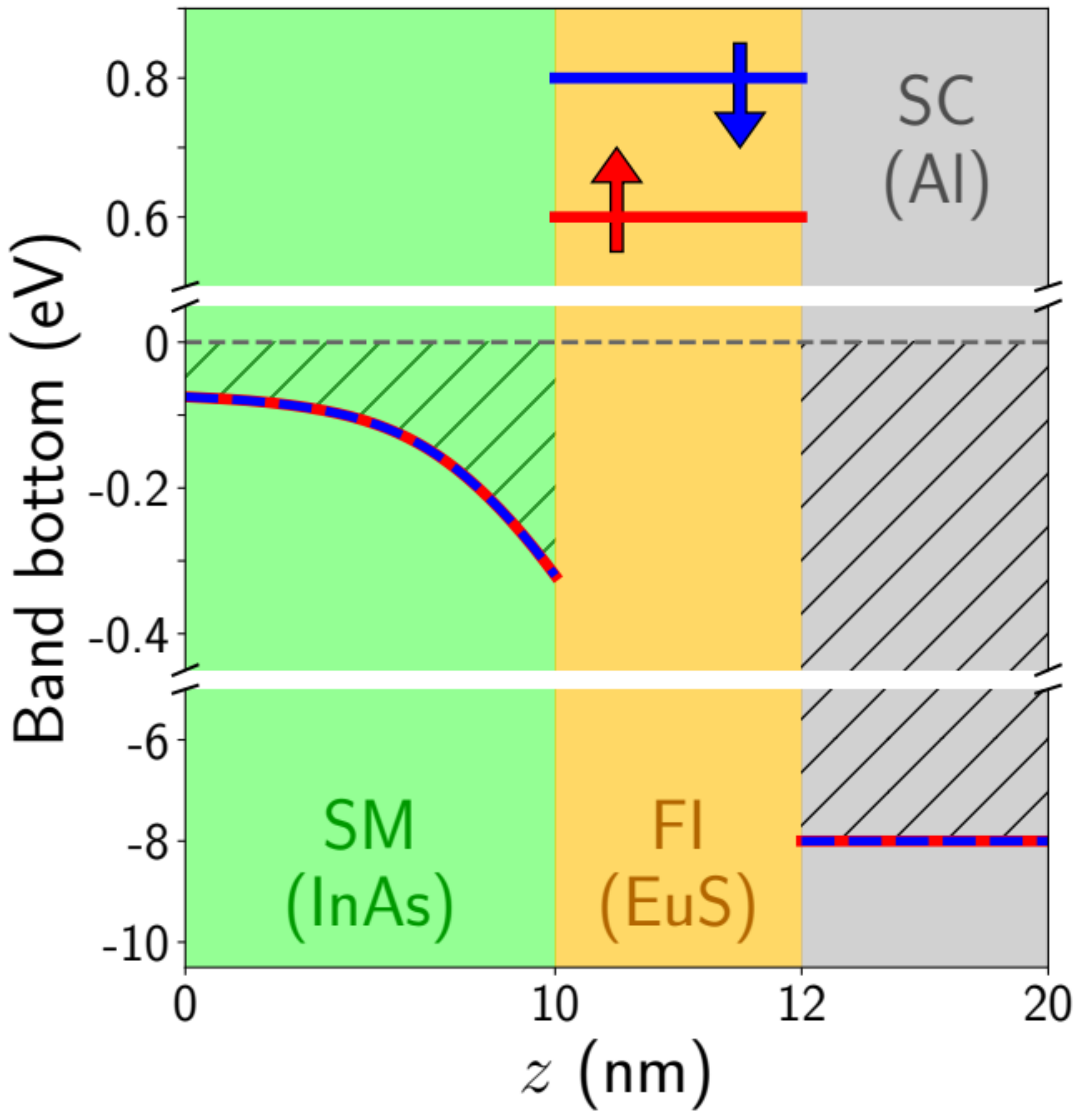

We describe each material separately. When joined together, we describe the system with a single Hamiltonian with spatial dependent parameters.

$$H = \left[\vec{k}^T \frac{\hbar^2}{2m^*(\vec{r})}\vec{k} + E_{\mathrm{F}}(\vec{r}) - e\phi(\vec{r}) + h_x(\vec{r})\sigma_x\right]\tau_z$$

$$+\frac{1}{2}\left[\vec{\alpha}_R(\vec{r})\cdot\left(\vec{\sigma}\times\vec{k}\right) + \left(\vec{\sigma}\times\vec{k}\right)\cdot\vec{\alpha}_R(\vec{r})\right]\tau_z$$

$$+\Delta(\vec{r})\sigma_y\tau_y$$

SM-SC-FI planar wires

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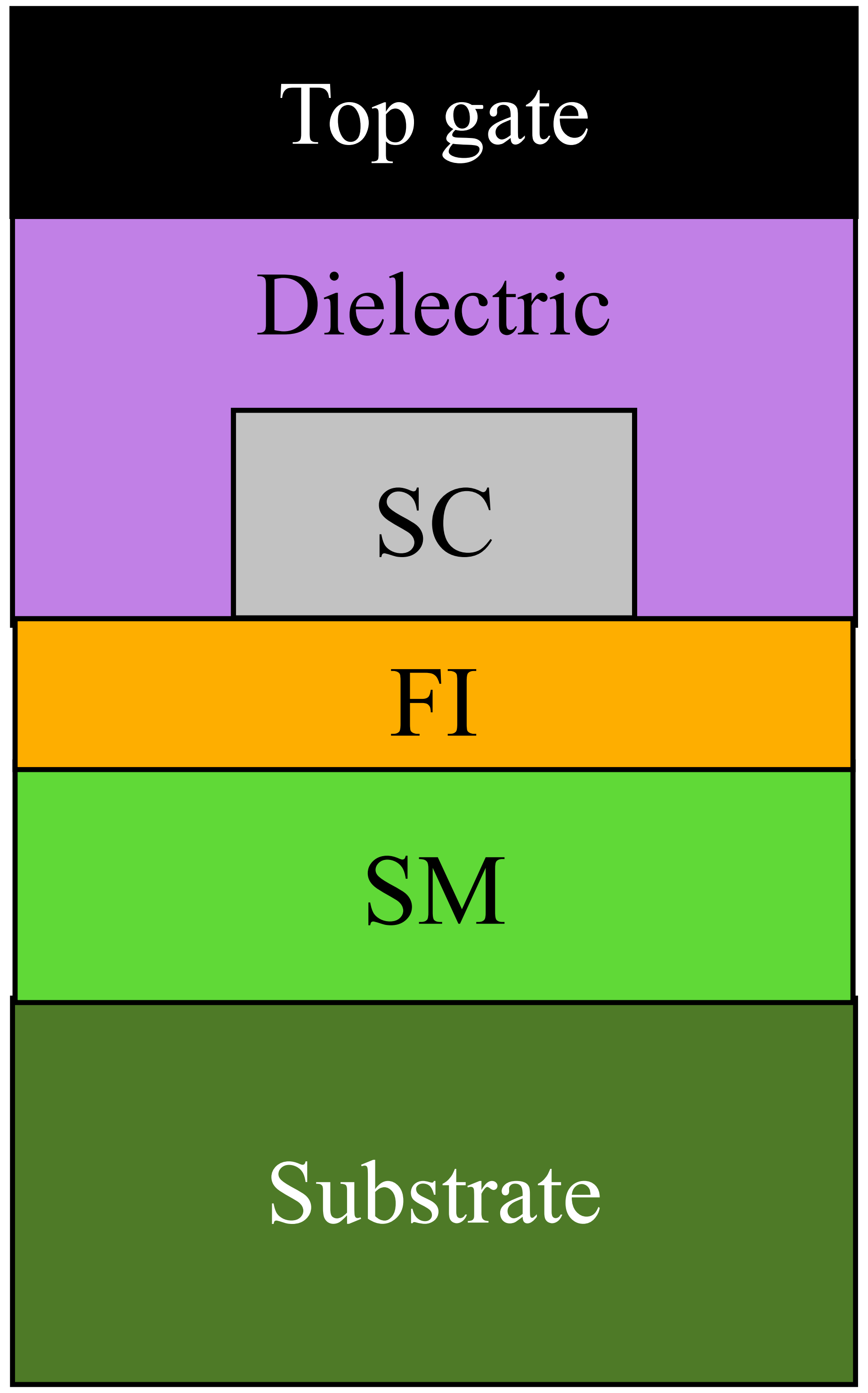
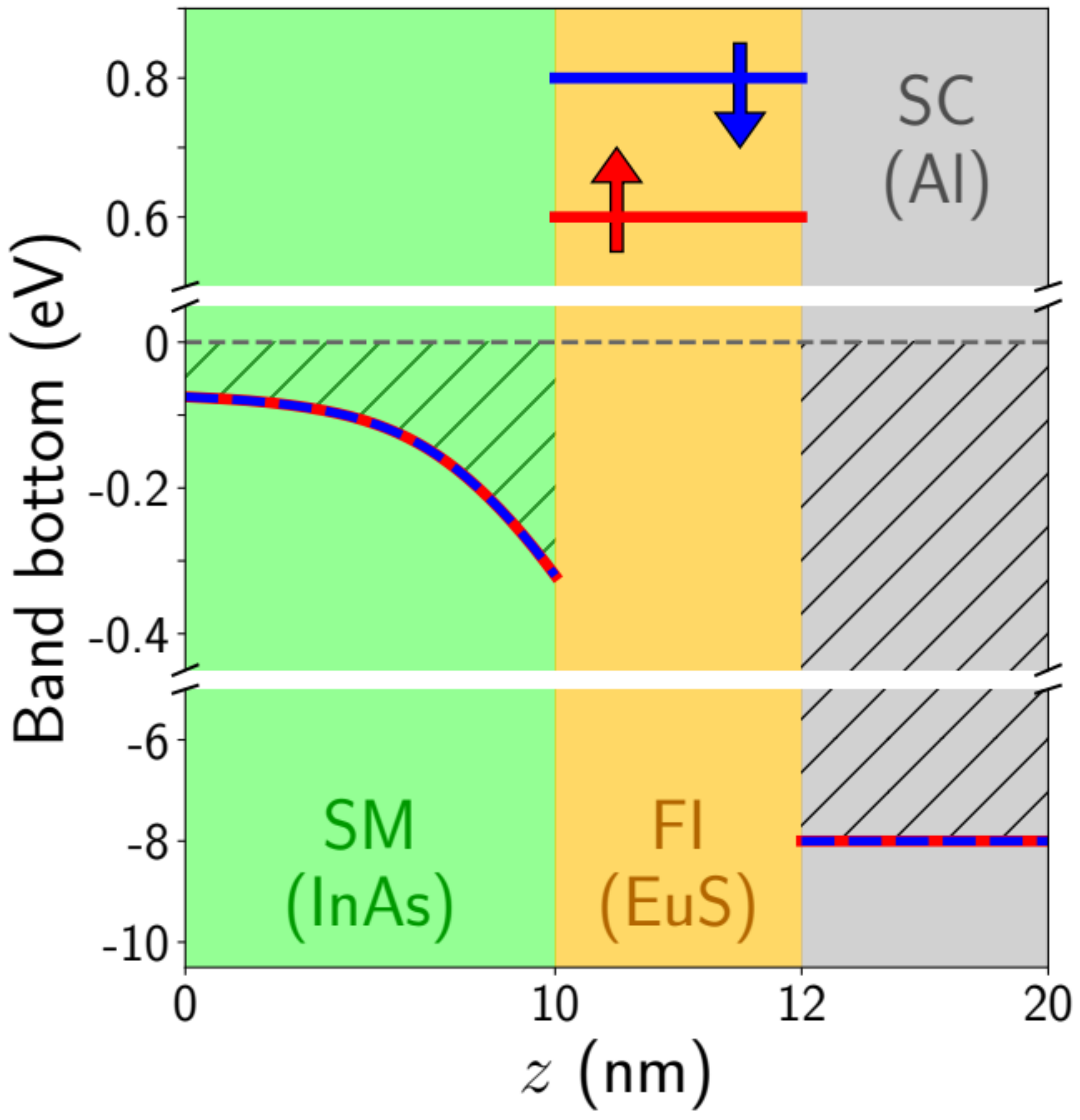




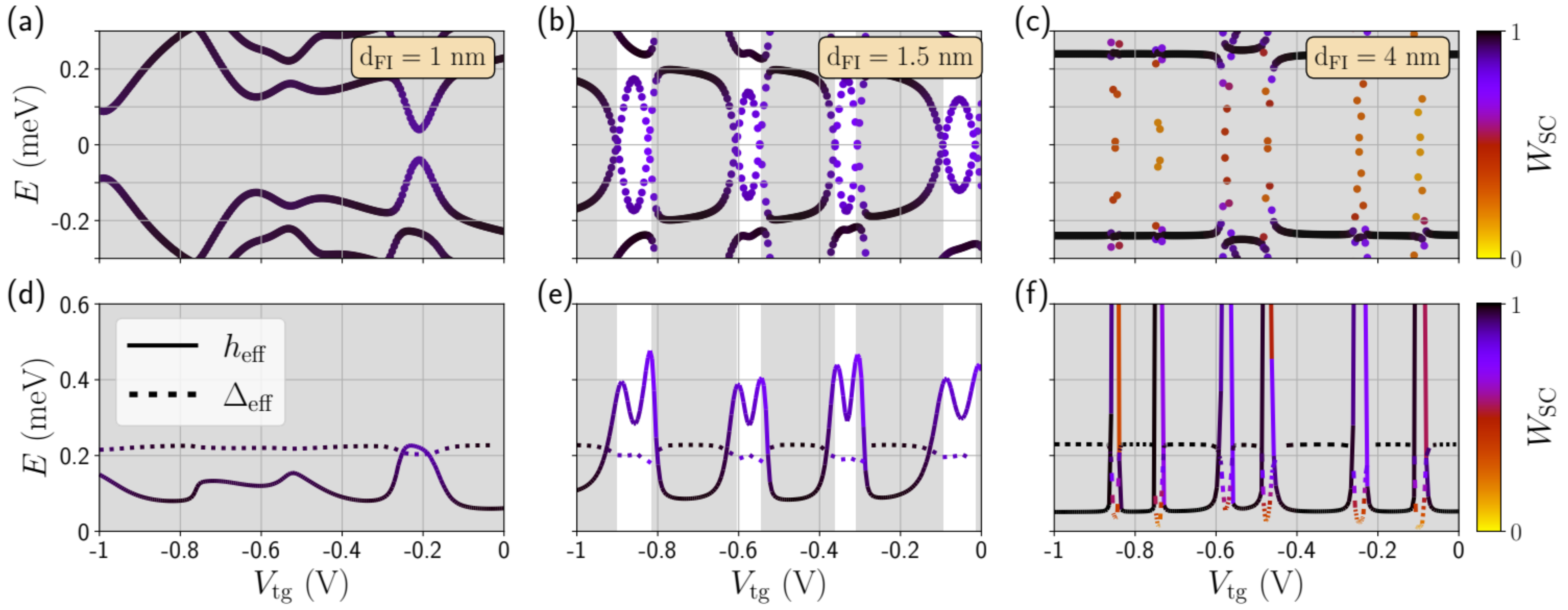
$$H = \left[\vec{k}^T \frac{\hbar^2}{2m^*(\vec{r})} \vec{k} + E_{\rm F}(\vec{r}) - e\phi(\vec{r}) + h_x(\vec{r})\sigma_x \right] \tau_z$$
$$+ \frac{1}{2} \left[\vec{\alpha}_R(\vec{r}) \cdot \left(\vec{\sigma} \times \vec{k} \right) + \left(\vec{\sigma} \times \vec{k} \right) \cdot \vec{\alpha}_R(\vec{r}) \right] \tau_z$$
$$+ \Delta(\vec{r}) \sigma_y \tau_y$$

$$\vec{\nabla} \cdot \left(\epsilon(\vec{r}) \vec{\nabla} \phi(\vec{r}) \right) = -\rho(\vec{r})$$

We solve the Schrodinger-Poisson equation self-consistently with realistic parameters

SM-SC-FI planar wires

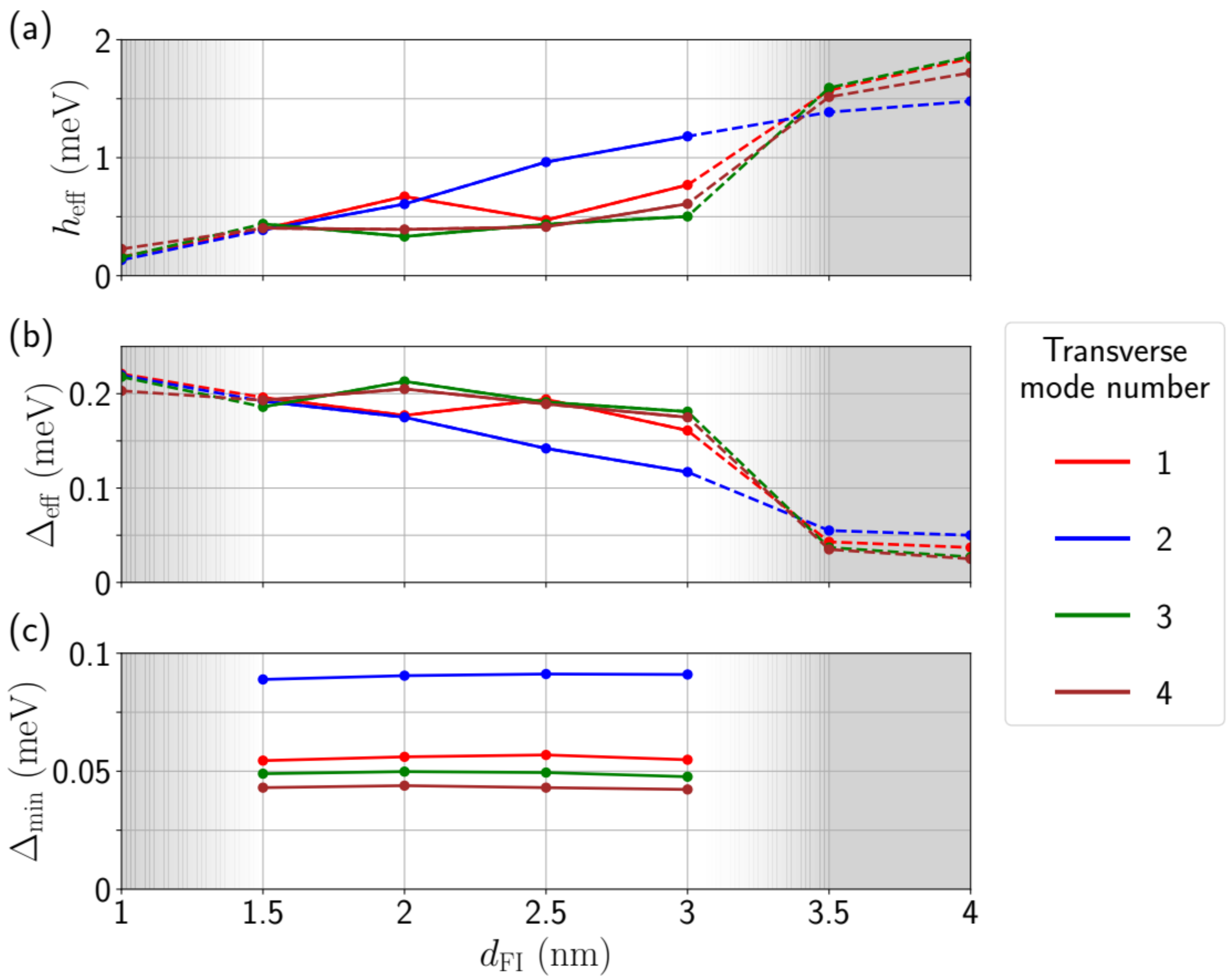
Spectrum (at k_x=0) for different FI thicknesses



SM-SC-FI planar wires

We analyze the evolution of different subbands for different FI thicknesses

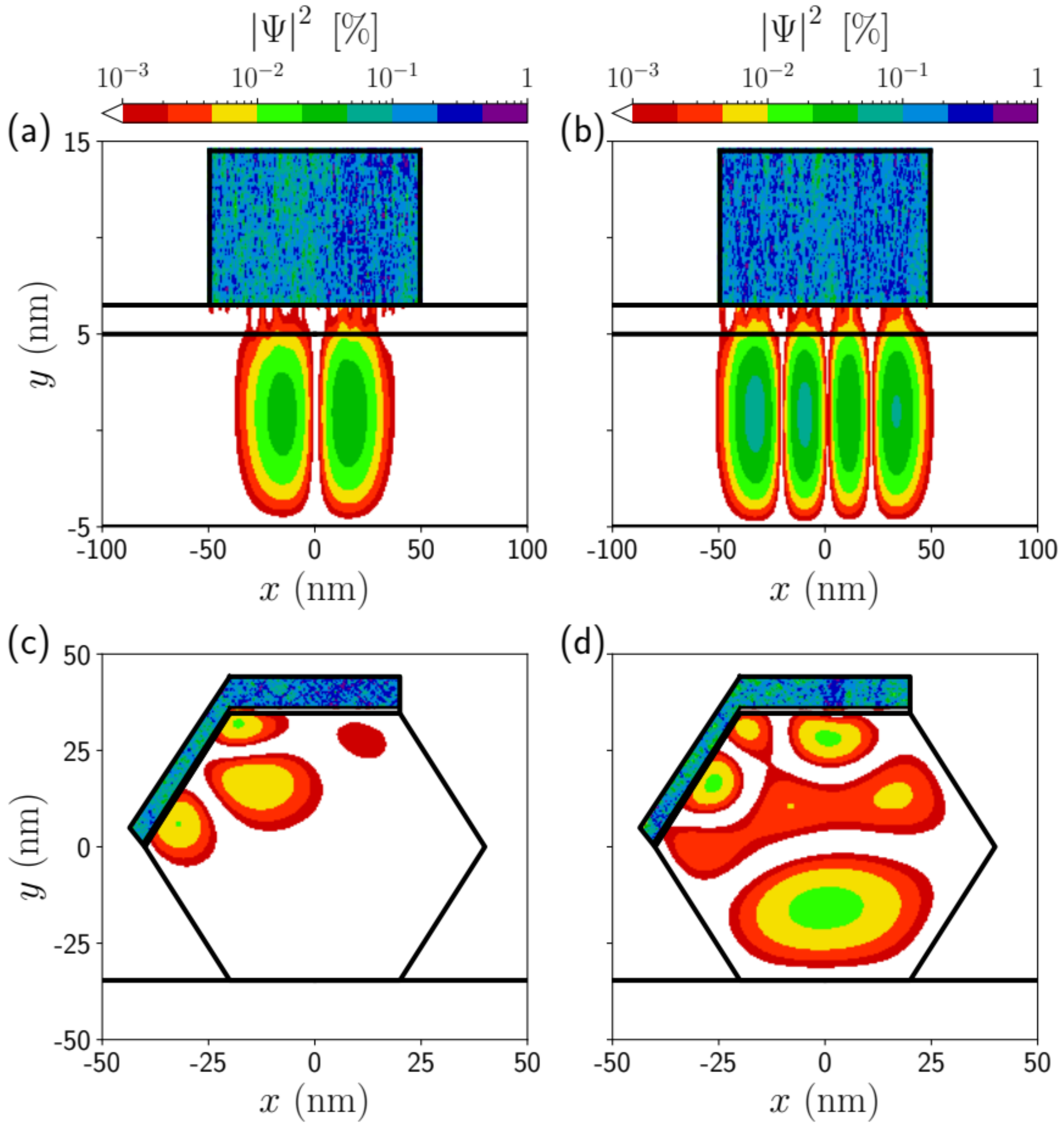
We find that around 1.5 to 3 nm, InAs-EuS-Al heterostructures can support a topological superconducting phase



SM-SC-FI planar wires

Planar-based heterostructures show stronger confinement (compared to nanowires), leading to:

- Stronger proximity effects
- More regular and larger topological phases (predictability)
- Larger minigaps



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