# Effects of the electrostatic environment on superlattice Majorana nanowires

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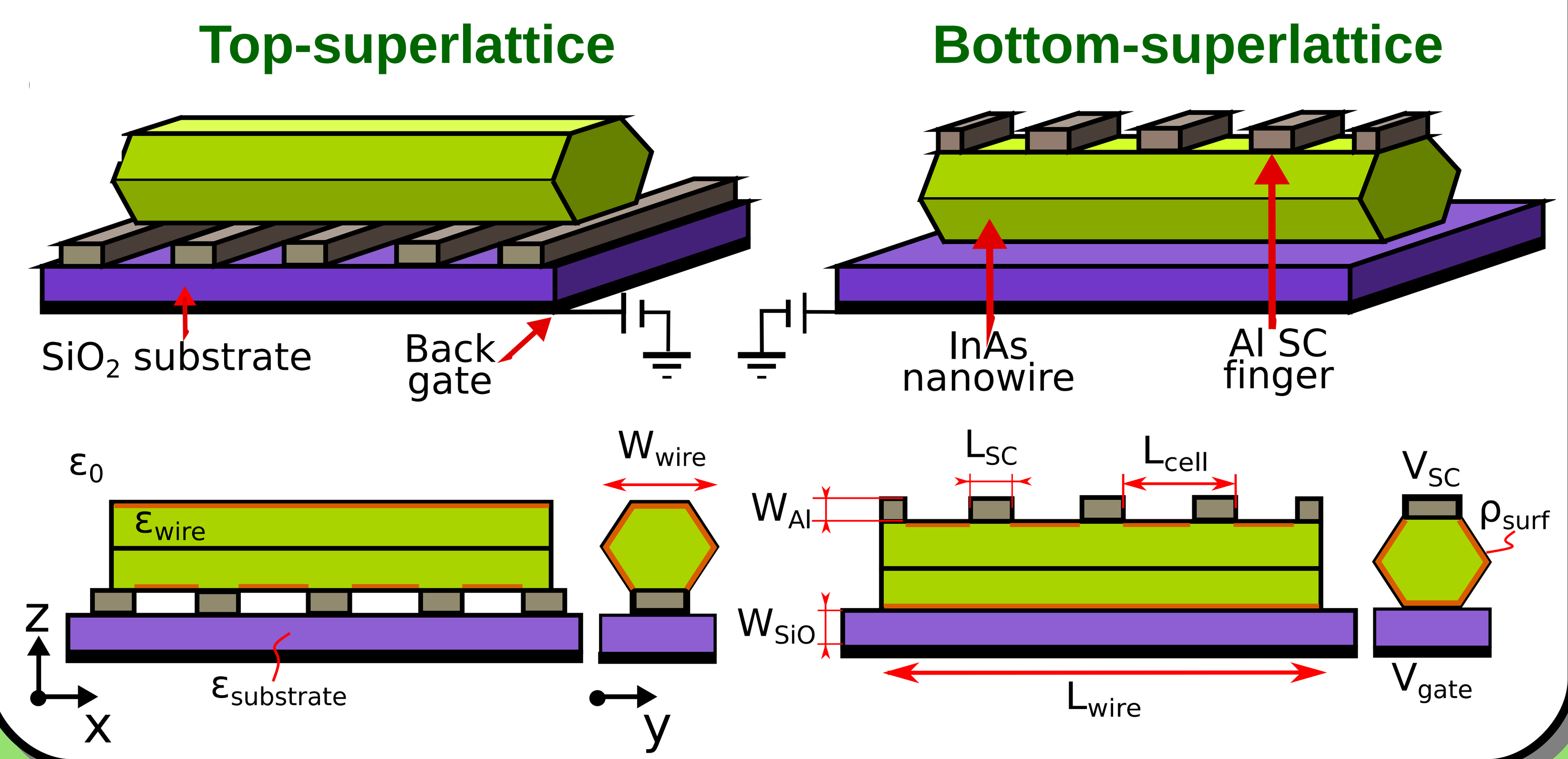
**ABSTRACT:** Finding ways of creating, measuring and manipulating Majorana bound states (MBSs) in superconducting-semiconducting nanowires is a highly pursued goal in condensed matter physics. It was recently proposed [1] that a periodic covering of the semiconducting nanowire with superconductor (SC) fingers would allow both gating and tuning the system into a topological phase while leaving room for a local detection of the MBS wavefunction. Here we perform a detailed, self-consistent numerical study of a 3D model for a finite length nanowire with a SC superlattice including the effect of the surrounding electrostatic environment. We find that the analysis of the electrostatic potential, the low energy spectrum and the formation of MBSs reveals a rich phenomenology that depends on the nanowire parameters as well as on the superlattice dimensions and the external back gate potential.

## 1. Superlattice setups




## 2. Methods

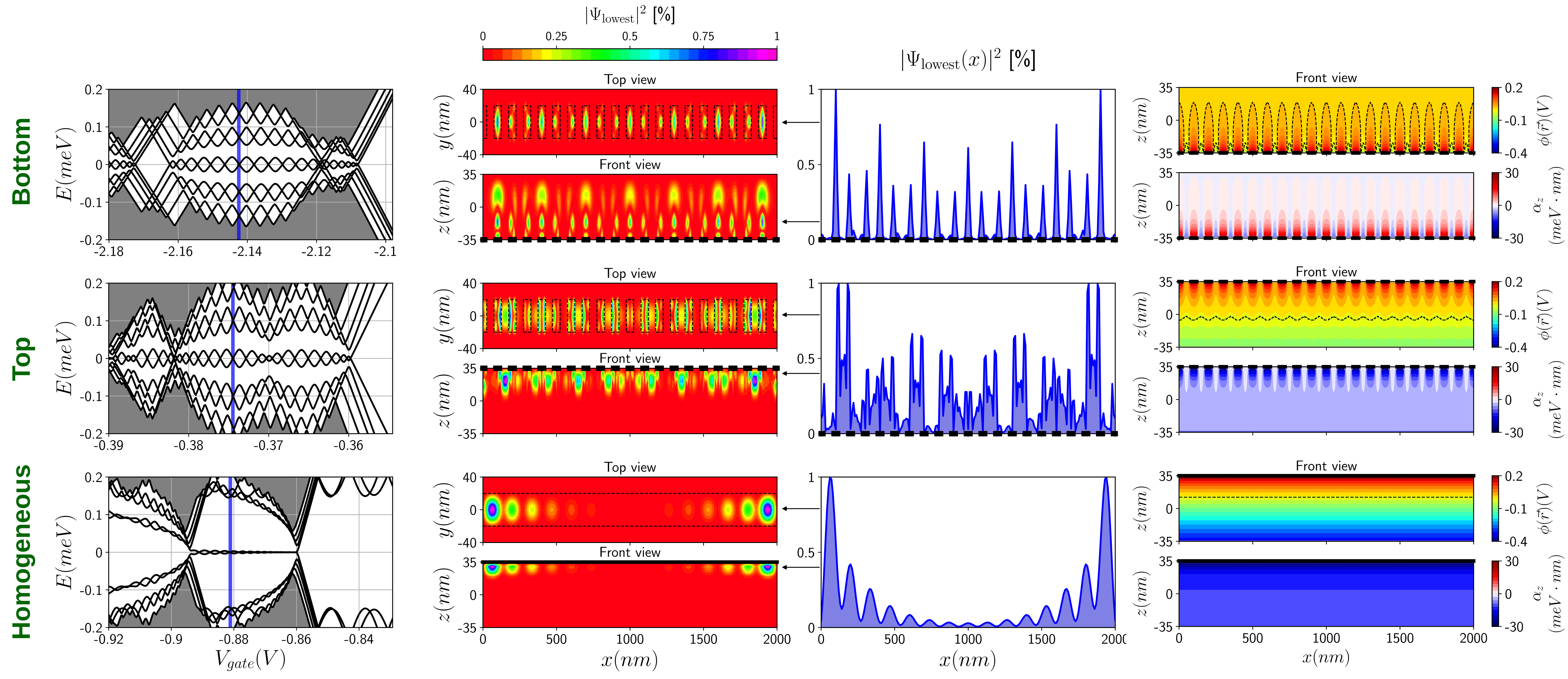
We solve self-consistently the 3D Schrödinger-Poisson equation in the Thomas-Fermi approximation,

$$\hat{H}(\vec{r}) = \left[\frac{\hbar^2 k^2}{2m^*} - e\phi(\vec{r}) - E_{\rm F}\right]\hat{\sigma}_0\hat{\tau}_z - \frac{i}{2}\hat{\vec{\sigma}}\cdot\left(\vec{\alpha}_{\rm R}(\vec{r})\times\vec{k}\right)\hat{\tau}_z + V_{\rm Z}\hat{\sigma}_x\hat{\tau}_z - i\Delta(\vec{r})\hat{\sigma}_y\hat{\tau}_y,$$

where the three inhomogeneous parameters are given by,

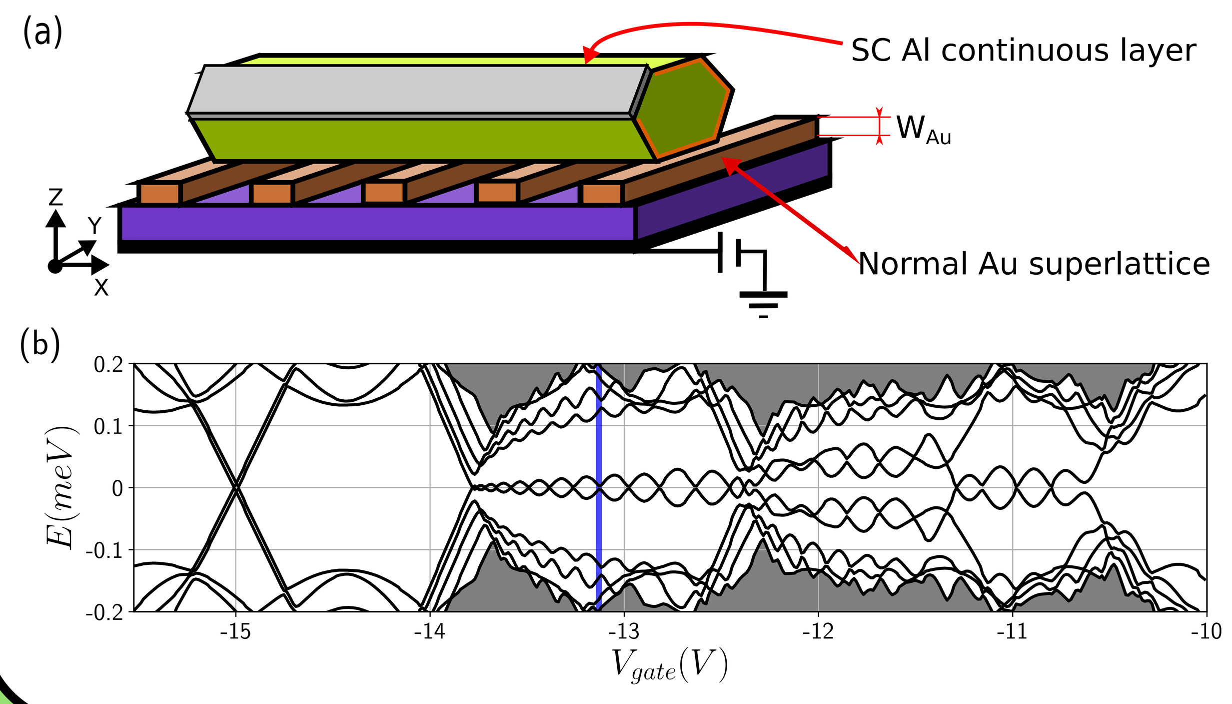
- The Poisson equation: $\vec{\nabla}(\epsilon(\vec{r})\cdot\vec{\nabla}\phi(\vec{r})) = \rho_{\rm e}^{\rm (TF)}[\phi(\vec{r})] + \rho_{\rm surf}$
- An 8-band k·p model: $\vec{\alpha}(\vec{r}) = \vec{\alpha}_{\rm int} + \frac{eP^2}{3}\left[\frac{1}{E_{\rm cv}^2} - \frac{1}{(E_{\rm cv}+E_{\rm vv})^2}\right]\vec{\nabla}\phi(\vec{r})$
- A rigid boundary condition: $\Delta(\vec{r}) = \begin{cases} \Delta_0 & \text{if } \vec{r}\in\Omega_{\rm SC} \\ 0 & \text{else}\end{cases}$

## 3. Results

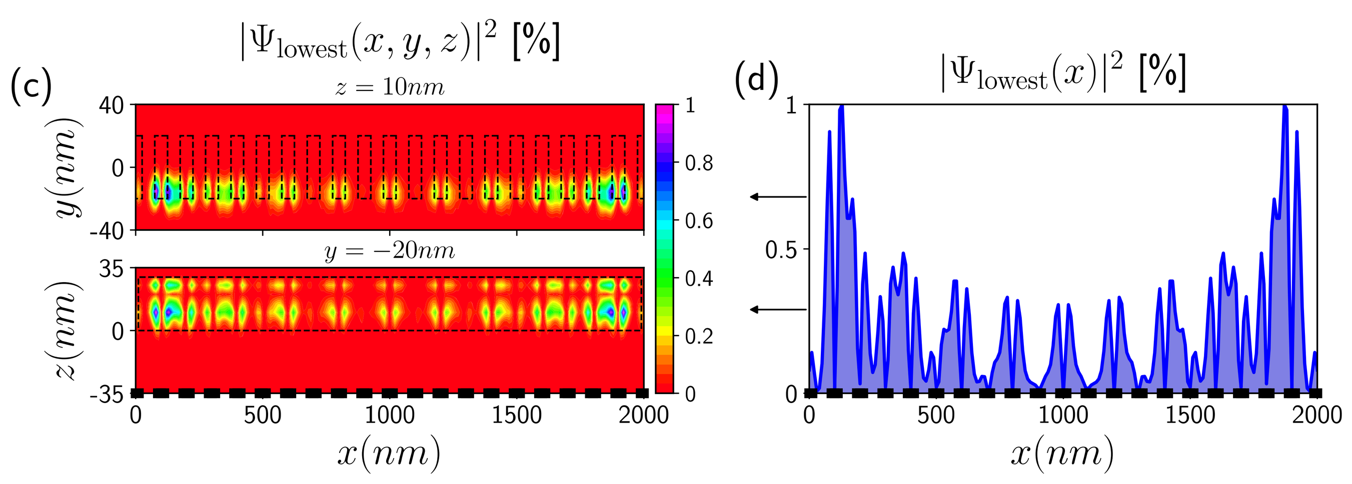



- In comparison to the homogeneous case, the energy spectra of the superlattice devices show: emergence of **localized states** which interact with the MBSs, **longitudinal minibands** (not shown here), and a **smaller minigap**.
- The lowest-energy modes of the superlattice setups exhibit a Majorana-like profile. However, (1) they have **additional** (faster) **oscillations**, (2) they **overlap more** (are more extended), (3) they are not as much localized close to the SC as in the homogeneous case.
- The **electrostatic potential exhibits oscillations** (larger in the Bottom device) that leads to the creation of localized states.
- This **oscillations creates a larger unit cell**, which leads to the folding of the bands, creating the longitudinal subbands.
- The **Rashba coupling varies along and the wire length**. Since **on average is smaller**, so does the topological protection.

## 4. Alternative configuration




- When one lateral facet is covered by a SC continuous layer in the bottom-superlattice, we find a comparable topological protection to the homogeneous one.




***Further details.-*** arXiv:1904.10289 (2019)

***Parameters.-*** L=2μm, W=80nm, $W_{Al}$=8nm, $W_{SiO}$=20nm, $L_{cell}$=100nm, $L_{SC}$=50nm, $V_{Al}$=0.2eV, $V_Z$=0.7meV, $\rho_{surf}=2\cdot10^{-4}$ e·nm$^{-3}$.

***References.-*** [1] Yoav Levine, Arbel Haim, and Yuval Oreg, *Phys. Rev. B* **96**, 165147 (2017).