Effects of the electrostatic environment on superlattice **Majorana nanowires**



¹<u>Samuel D. Escribano</u>, ²Alfredo Levy Yeyati, ³Yuval Oreg and ¹Elsa Prada ¹Departamento de Física de la Materia Condensada and ²Departamento de Física Teórica de la Materia

Condensada, IFIMAC and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, E-28049 Madrid, Spain ³Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, Israel 7610

ABSTRACT: Finding ways of creating, measuring and manipulating Majorana bound states (MBSs) in superconductingsemiconducting 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

Bottom-superlattice

Top-superlattice

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

3. Results



• In comparison to the homogeneous case, the energy spectra of the superlattice devices show: localized emergence states of with the which interact MBSs, longitudinal minibands (not shown here), and a **smaller minigap**.

• The lowest-energy modes the Of superlattice setups exhibit a Majoranalike 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.- (soon in PRB) arXiv:1904.10289 (2019)

Parameters.- L=2µm, W=80nm, W_{AI} =8nm, W_{SiO} =20nm, L_{cell} =100nm, L_{sc} =50nm, V_{Al} =0.2eV, V_{7} =0.6meV, $\rho_{surf} = 2 \cdot 10^{-4} \, e \cdot nm^{-3}$.

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