Interplay of excitonic correlation with Quantum Spin Hall effect and Superconductivity

Tania Paul[1], Victor F Becerra[1], Dmitry Pikulin[2,3], Timo Hyart[1,4]
[1]International Research Center, MagTop, IFPAN, Warsaw, Poland
[2]Microsoft Quantum, Station Q, University of California, Santa Barbara, California, USA
[3]Microsoft Station, Redmond, Washington, USA
[4]Department of Applied Physics,Aalto University, Aalto, Espoo, Finland
tpaul@magtop.ifpan.edu.pl

European Union
European Regional Development Fund
Fundacja na rzecz Nauki Polskiej
European Funds Smart Growth

INTRODUCTION:

It has been proposed that in band-inverted electron-hole bilayers the excitonic correlations arising due to **Coulomb interactions** lead to phase transitions from a trivial insulator phase to an insulating phase with spontaneously broken Time-Reversal Symmetry (TRS) and finally to a nontrivial quantum spin Hall insulator phase as a function of increasing electron and hole densities[1].

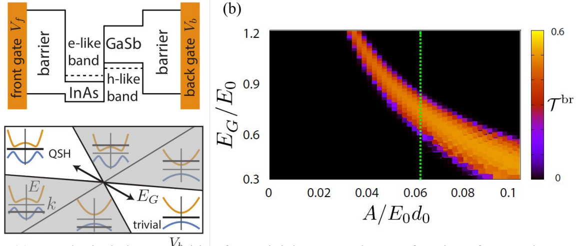


Fig 1. (a) Topological phase transition from trivial to QSH phase as function of gate voltage (b) Emergence of time-reversal broken phase as a result of **Coulomb interaction** induced excitonic correlations in InAs/GaSb.

$\hat H = \hat H_0 + \hat H_I$

$\hat H_0$: single particle Hamiltonian

$$\hat H_I = \frac{1}{2}\sum_{a,a',s,s'}\sum_{\mathbf{k},\mathbf{k}',\mathbf{q}} V^{aa'}(q)\, c^\dagger_{\mathbf{k}sa} c^\dagger_{\mathbf{k}'s'a'} c_{\mathbf{k}'+\mathbf{q}s'a'} c_{\mathbf{k}-\mathbf{q}sa}$$

$$\hat H_{mf} = \sum_{\mathbf{k}} \psi^\dagger_{\mathbf{k}} \hat H(\mathbf{k}) \psi_{\mathbf{k}}$$

$$H(\mathbf{k}) = \begin{bmatrix} H_{11}(k) & H_{12}(k) \\ H^\dagger_{12}(k) & H_{22}(k) \end{bmatrix}$$

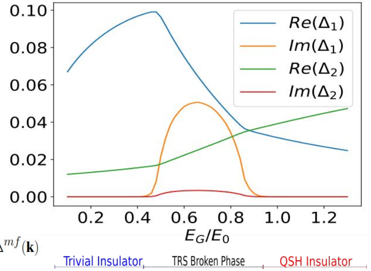
$$H_{11}(\mathbf{k}) = \left[\frac{\hbar^2 k^2}{2m_e} - E_G\right]\sigma_0$$

$$H_{22}(\mathbf{k}) = \left[E_G - \frac{\hbar^2 k^2}{2m_h}\right]\sigma_0$$

$$H_{12}(\mathbf{k}) = A(k_x\sigma_3 + ik_y\sigma_0) - i\Delta_z\sigma_2 - \Delta^{mf}(\mathbf{k})$$

$$\Delta^{mf} = i\Delta_1\sigma_2 - \Delta_2(k_x\sigma_3 + ik_y\sigma_0)$$

Fig 2. Real and Imaginary parts of Δ_1 and Δ_2 vs E_G



REALIZATION OF MAJORANA ZERO MODES:

We show that it is possible to realize **Majorana Zero Modes(MZMs)** in the TRS broken phase in the presence of proximity induced superconductivity in the absence of magnetic field.

Fig 3. Schematic figure of the device setup to realize **MZMs** (depicted as red/purple circles).

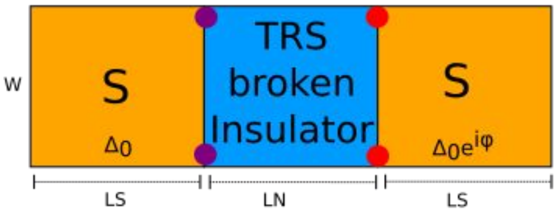
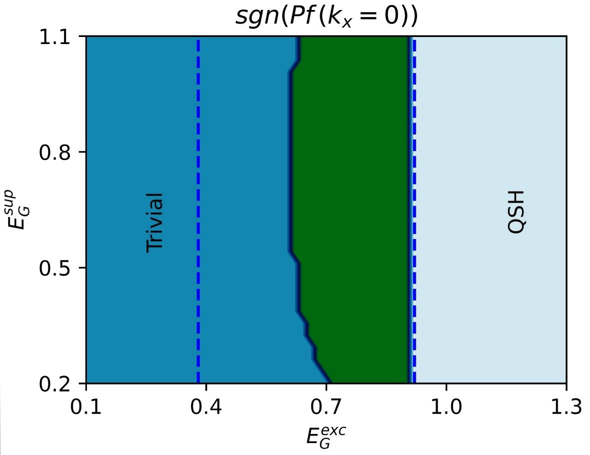


Fig 4. Contour plot of Pfaffian as a function of E_G in the superconductors and in the normal region, where the non-trivial green area mark the existence of **MZMs**.



DETECTION OF MAJORANAS:

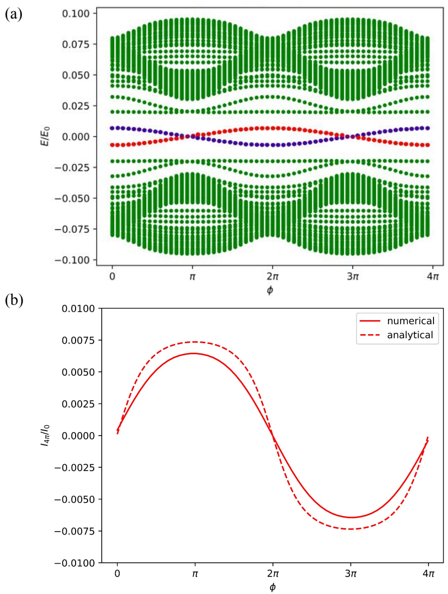


Fig 5. (a) Energy eigenvalues as a function of phase difference between the superconductors, for a TRS broken phase. The states around zero energy show π crossing characteristic of MZMs (b) 4π periodic current of the corresponding low energy states, also compared with the analytical current obtained from our effective low energy theory in the presence of TRS broken parameter. Numerical calculations performed using Kwant[2] and Hybrid Kernel Polynomial Method[3].

OUTLOOK: Controlling Majorana Zero Modes with excitons

REFERENCES:

[1] D.I. Pikulin and T.Hyart, Phys. Rev. Lett 112, 176403 (2014)
[2]C.W.Groth et al, New Journal of Physics, 16, 063065, (2014)
[3]M.Irfan et al, arxiv:1909.09649