Electric field induced edge-state oscillations in InAs/GaSb quantum wells

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The promises of applications in spintronics and quantum-computing have leveraged the research towards the understanding and the synthesis of systems that present topologically protected states. Among these promising systems are those that are characterized as quantum spin Hall insulator (QSHI), which can be thought as two-dimensional versions of 3D topological insulators.

Broken-gap InAs/GaSb asymmetric quantum wells have been predicted to behave as QSHI [1]. More importantly, 8-band $\mathbf{k} \cdot \mathbf{p}$ calculations have suggested that the topological transition (i.e., gap inversion) can be controlled by applying an external electric field along the growth direction [2] through a potential difference between front- and back-gates.

Recently, such electric-field driven topological phase transitions was characterized in InAs/GaSb quantum wells [3] and thin films of 3D topological insulators [4]. However, finding quantized conductance plateaus in these systems is a challenging task, as the actual conductance values can vary from sample to sample and in different experiments, and as the edge state transport has been detected in the *trivial* phase of InAs/GaSb quantum wells as well.

By studying a realistic model for InAs/GaSb quantum wells in the presence of an applied electric field, we show that the inter-edge coupling of edge states in narrow samples can lead to oscillations as a function of the field. Such oscillations occur only in the topological phase and can be directly linked to the presence of helical edge states, and thereby, signal the onset of QSHI behavior.

We also show that the electric field controls not only the topological transition but also increases the exponential localization of the edge states, similarly to the role played by the magnetic field in regular quantum Hall edge states. In this sense, the situation is analogous to the energy oscillations seen in other contexts such as Majorana systems [5, 6] and zeroth Landau level oscillations in nodal semimetals [7].

The results achieved in this work can serve as a guide for the search of additional experimental signatures of the presence of topologically-protected helical edge states in InAs/GaSb systems.

[1] C. Liu, T. L. Hughes, X.-L. Qi, K. Wang, and S.-C. Zhang, Quantum spin hall effect in inverted type-ii semiconductors, Phys. Rev. Lett. **100**, 236601 (2008).

[2] L.-H. Hu, C.-X. Liu, D.-H. Xu, F.-C. Zhang, and Y. Zhou, Electric control of inverted gap and hybridization gap in type-ii inas/gasb quantum wells, Phys. Rev. B **94**, 045317 (2016).

[3] K. Suzuki, Y. Harada, K. Onomitsu, and K. Muraki, Edge channel transport in the inas/gasb topological insulating phase, Phys. Rev. B **87**, 235311 (2013).

[4] M. Kim, C. H. Kim, H.-S. Kim, and J. Ihm, Topological quantum phase transitions driven by external electric fields in sb2te3 thin films, PNAS **109**, 671 (2012).

[5] S. Das Sarma, J. D. Sau, and T. D. Stanescu, Splitting of the zero-bias conductance peak as smoking gun evidence for the existence of the majorana mode in a superconductor-semiconductor nanowire, Phys. Rev. B **86**, 220506(R) (2012).

[6] C.-K. Chiu, J. D. Sau, and S. Das Sarma, Conductance of a superconducting coulomb-blockaded majorana nanowire, Phys. Rev. B **96**, 054504 (2017).

[7] T. Devakul, Y. H. Kwan, S. L. Sondhi, and S. A. Parameswaran, Quantum oscillations in the zeroth landau level and the serpentine landau fan, arXiv:2101.05294 (2021), arXiv:2101.05294 [cond-mat.mes-hall].