Topological Flat Bands in Strained Graphene: Optical Control and Robust Edge States

Md. Tareq Mahmud[1,2], Dawei Zhai[1,3], Adel Belayadi[4] and Nancy Sandler[1]

[1] *Department of Physics and Astronomy, and Nanoscale and Quantum Phenomena Institute, Ohio University, Athens, OH, USA*

[2] *Department of Physics, University of Dakha, Dakha 1000, Bangladesh*

[3] *Department of Physics, The University of Hong Kong, and HKU-UCAS Joint Institute of Theoretical and Computational Physics at Hong Kong, Hong Kong, China*

[4] *Department of Physics, University of Science and Technology Houari Boumediene, Bab-Ezzouar, Algeria*

sandler@ohio.edu

The discovery of correlated phases in twisted moiré superlattices motivated the search for low-dimensional materials showcasing extraordinary properties [1]. A novel avenue involves leveraging engineered substrates to introduce specific periodic strain profiles into materials, offering a promising alternative to producing large periodic patterns [2]. Nonetheless, the design of substrates tailored for specific properties encounters challenges due to the incomplete understanding of the relationship between the substrate shapes and the resulting electronic properties of the deposited materials. Through a thorough analysis employing effective models of graphene subjected to periodic deformations with various crystalline profiles, we identify strong C_{2z} symmetry breaking as the pivotal geometric feature of substrates required to induce energy gaps and quasi-flat bands. We demonstrate that continuous strain profiles, giving rise to connected pseudo-magnetic field landscapes, play a decisive role in triggering specific band topologies leading to the emergence of edge states in finite samples [3]. Interestingly, the band structures for finite geometries with zigzag terminations consistently resemble those for nanoribbons in an external periodic magnetic field, provided the ribbon's termination conserves the valley pseudospin. Despite lacking topological protection due to a vanishing total Chern number [3], these edge states exhibit remarkable ubiquity, persisting against variations in ribbon width, strain period, and intensity while weakly affected by realistic disorder potentials. We analyzed the effects of an out-of-plane electric field mirroring the periodicity of an hBN-engineered substrate to explore their potential in straintronics devices. Manipulating the field profile at the edges of the sample reveals the feasibility of controlling the existence and quantity of edge states, thereby imparting a typical semiconductor behavior to the material. Building upon these findings, we propose specific electric field (gate) profiles capable of effectively separating the system into different sections, leading to various junction configurations. By properly designing gate geometries, we show the emergence of genuine topological edge states at these interfaces positionable anywhere within the sample [4]. Finally, all these resultant electronic and topological properties can be finely tuned with circularly polarized light, offering distinctive signatures for discerning the band topology imprinted by strain.

References

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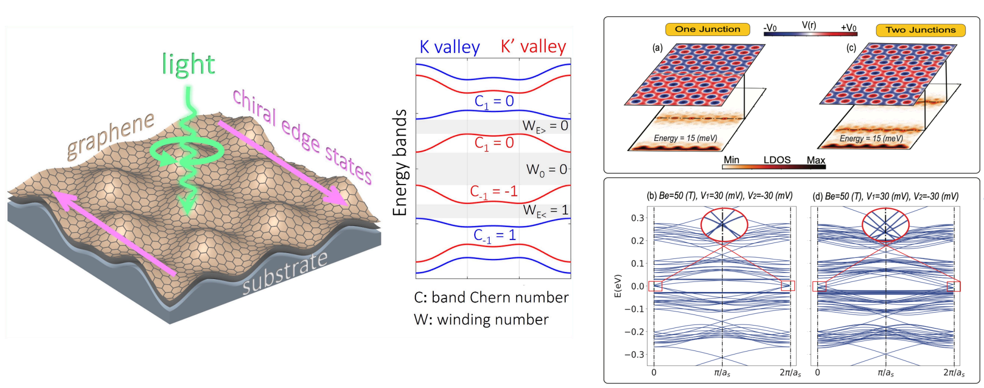

Fig. 1. Left: Graphene on hBN engineered substrate with periodic modulations under circularly polarized light (CPL) irradiation inducing staggered potentials $\delta\sigma_z$ and $\pm\Delta\sigma$ respectively. Band structure and corresponding valley Chern numbers. Right: junctions with topological and non-topological edge states and corresponding band structures.