Anomalous Bloch Oscillation and Electrical Switching of Edge Magnetization in Bilayer Graphene Nanoribbon

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Abstract

SSH(Su-Schrieffer-Heeger) chain is one of the most famous examples of one dimensional (1D) topological insulator. The system has two distinct phases, characterized by distinct topological invariant winding number W. The appearance of edge states, i.e. a state localized at the chain's edge when it is cut finite, is closely related with W.

Meanwhile, Graphene is a kind of 2D material. When it is cut finite, i.e. into graphene nanoribbon, it would also possess edge states under certain scenarios. The application of such edge states are wide and interesting, for example, edge magnetization in Graphene nanoribbon.

This project is an extension of our previous work, we study bilayer graphene nanoribbon with hybridized edge, which exhibits interesting potential for anomalous Bloch Oscillation and electrical switching of edge magnetization

Introduction

- **Chiral Symmetry and Winding Number**

For 1D infinite system with wave vector k, Hamiltonian H(k) is called chiral symmetric if there is an operator S, $S^2 = I$, such that

$$SH(k)S = -H(k)$$

under which scenario we can define a topological invariant called winding number W

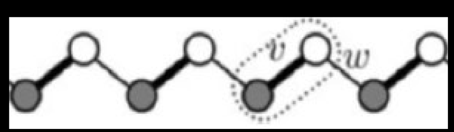
$$W = \frac{-i}{4\pi}\int_{-\pi}^{\pi} dk Tr[SQ\partial_k Q]$$

$$Q \equiv I - 2\sum_{N_-} |u_{N_-}\rangle\langle u_{N_-}|$$

Winding number will not change as long as the change is adiabatic, i.e. the system's bulk gap do not close.

- **SSH chain**

Right figure is the SSH chain. When it is infinite, it has the following chiral symmetric bulk Hamiltonian



$$H(k) = \begin{pmatrix} 0 & v + w exp(-ik) \\ v + w exp(ik) & 0 \end{pmatrix}$$

$$S = \sigma_z$$

We present in Fig. 1 the winding number W of H(k) under different parameter range. When v<w, W=1, the chain possesses a pair of edge states when it is cut finite. When v>w, W=0, the chain has no edge states. Corresponding energy levels and wave function is shown in Fig.2. These two scenarios are termed topological and trivial. The system can only evolve from one to the other by closing the bulk gap of H(k).

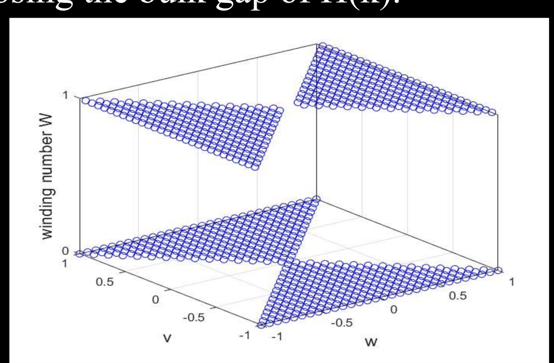
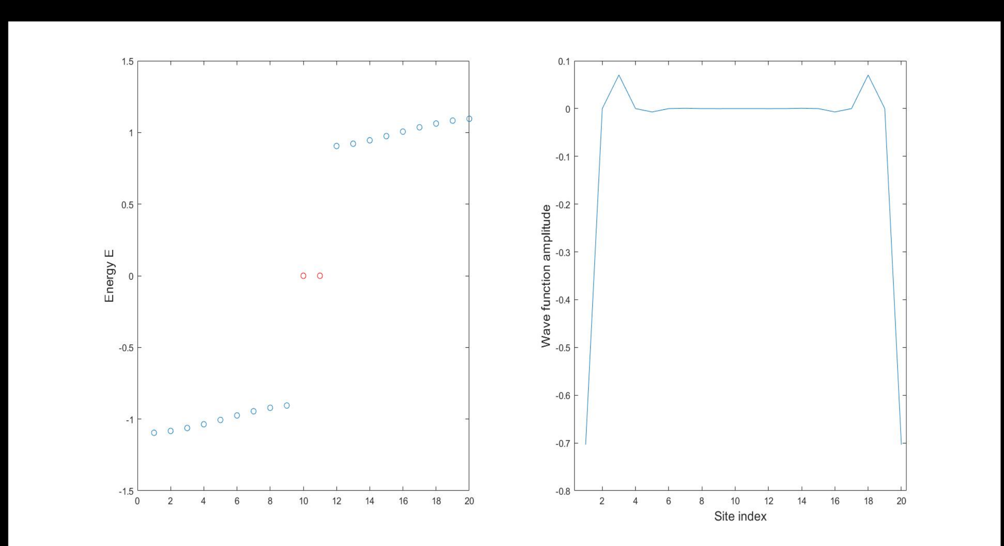


Fig.1: Winding number of SSH chain with different parameter



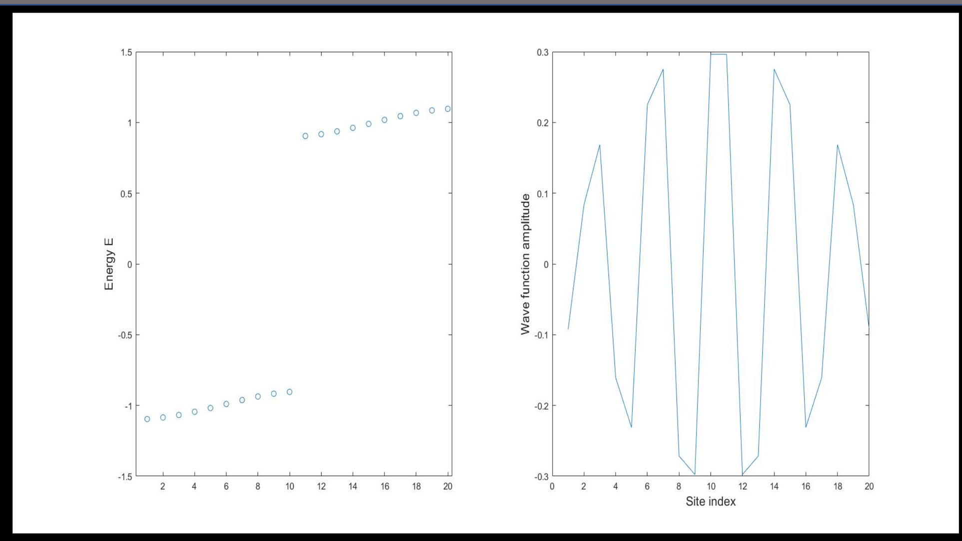
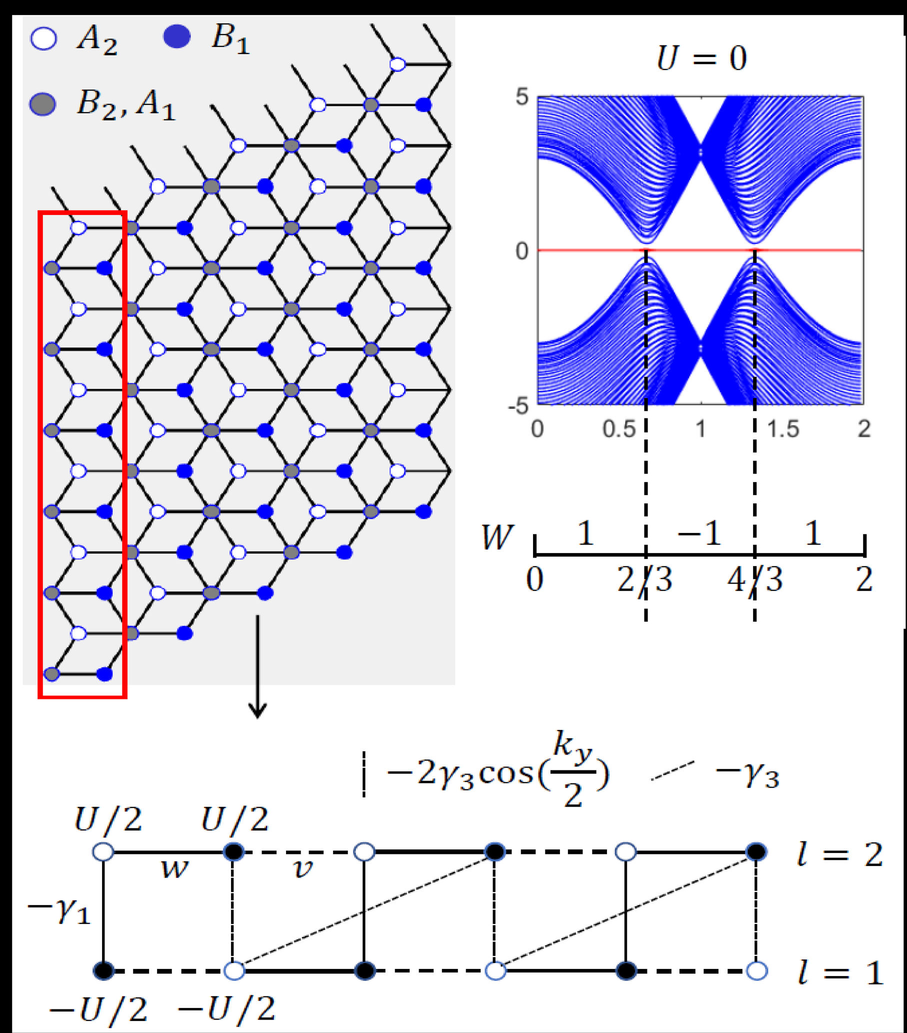


Fig.2 Energy levels and wave function of the finite chain with 20 sites. The first panel is plotted with v=0.1, w=1. The red circles denote the edge states, and its corresponding wave function amplitude is plotted, which is localized at the two end of the chain. The second panel is plotted with v=1, w=0.1. There are no edge states, and a typical wave function is plotted, which shows no localization

Selected Results

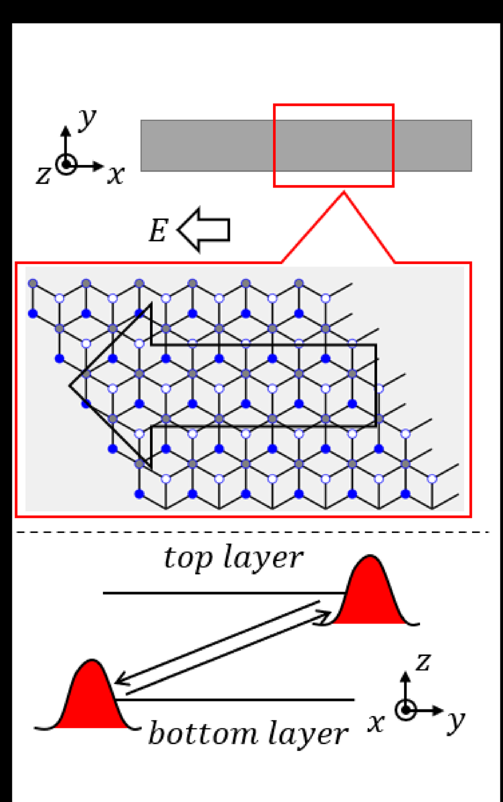
- **Bilayer Graphene with Hybrid Edge**



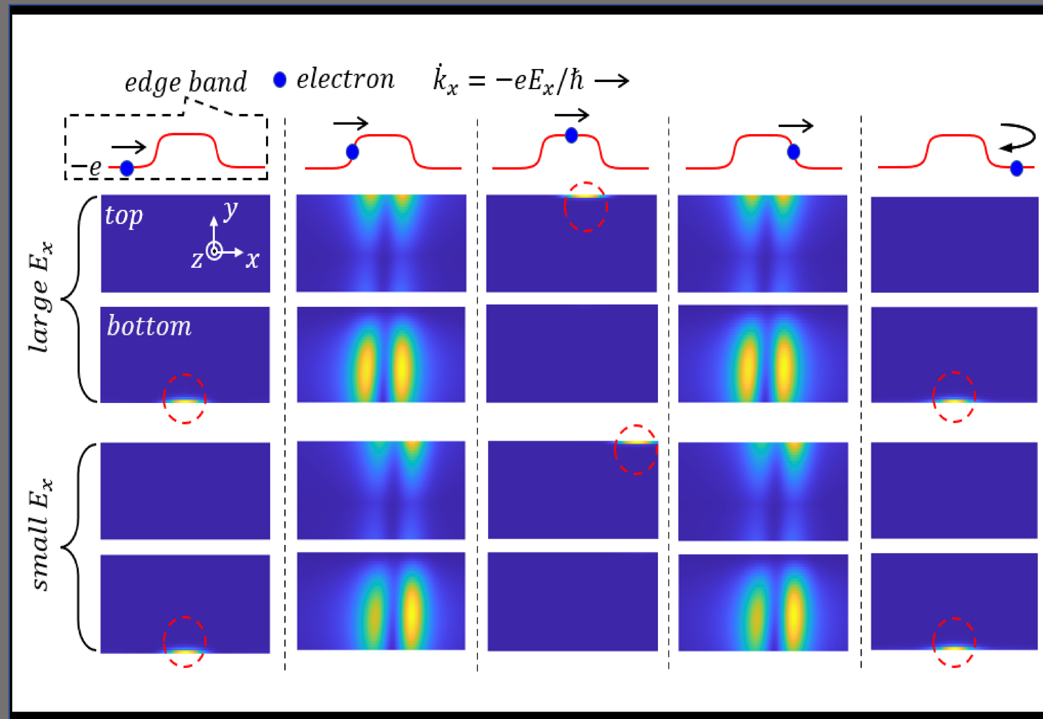
We consider an AB-stacked bilayer graphene nanoribbon with hybrid edges, i.e. bearded edge on one layer and zigzag on the other. The corresponding atomic structure and edge configuration is shown at the top left, which is equivalent to a coupled SSH chain system shown at the bottom. We include γ_1, the interlayer nearest neighbor coupling, and γ_3, the interlayer next nearest neighbor coupling, in our calculation. Both quantities preserve the chiral symmetry of the system. The corresponding band structure and winding number are shown on the top right. It is observed that a phase transition from W=-1 to W=1 happens when crossing the Dirac point.

- **Semi Classical equation of motion and Bloch Oscillation**

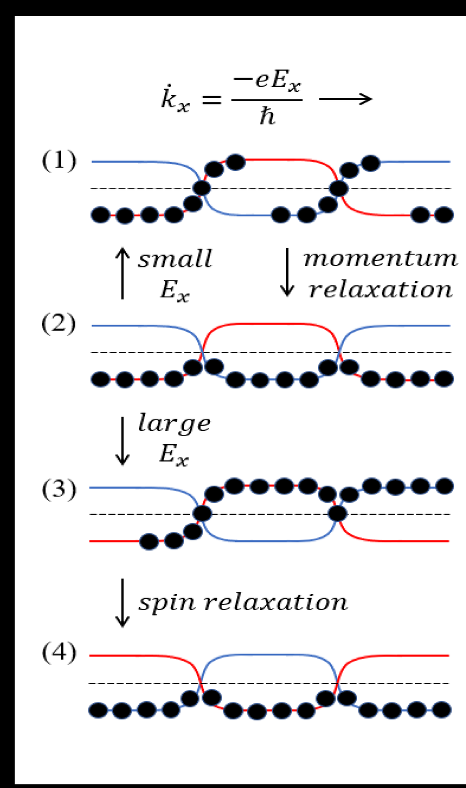
$$\dot{k} = -\frac{qE}{\hbar} \qquad \dot{r} = \frac{\partial \epsilon}{\partial k}$$



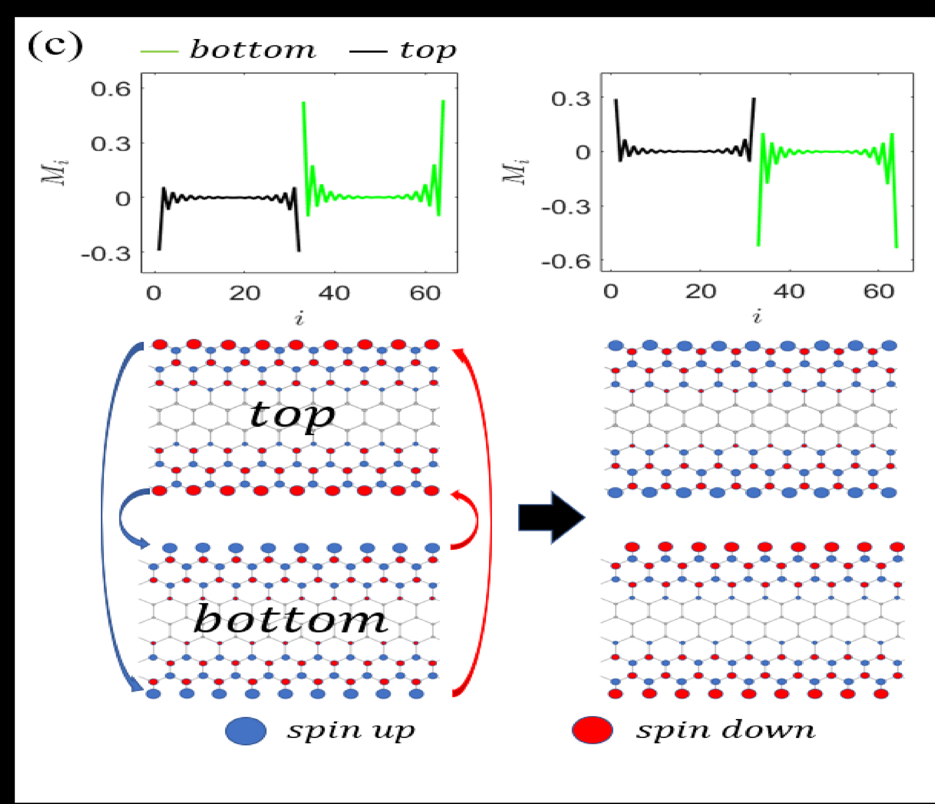
Set up: A ribbon is placed along the x direction while an electric field is also applied along this direction. As demonstrated, the electron wave packet would experience oscillation along the transverse direction



- **Edge Magnetization and Electrical Switching**



Left: Schematic illustration of the effect of electrical field in the momentum space. Bottom: Initial and final state of the electrical switching



Conclusion

We demonstrated the connection between graphene nanoribbon with parametrized SSH chain system. We showed the existence of edge states in graphene nanoribbon can be predicted by the bulk topological invariant, namely winding number, of the parametrized chains.

We further extend the project to explore what the experimental consequences of the novel edge states are. We demonstrated two of these experimental implications: anomalous Bloch oscillation and electrical control of the edge magnetization.

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