Topology, Dispersion and Localization in SSH, Graphene and Bilayer Graphene

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Master's Project in English

→ What is this work about?

In this project we will study the dispersion, localization and topological properties of the SSH, graphene and bilayer graphene lattices using theoretical approximations and computational methods.

→ Methodology:

The project is theoretical and computational, from the tight-binding approach and via Bloch waves we find theoretically the energy spectrum from which we can study the dispersion and localization properties. From the computational part we corroborate the theoretical results.

The project is divided in three parts for the student to get familiarized with the analytical and computational methods in simple models before apply them on complex models.

→ Context:

The Su–Schrieffer–Heeger (SSH) model shown in Fig.1(a), is the simplest lattice that exhibits a topological transition [1]. The sites are connected with hoppings t_1 and t_2 and we can define a control parameter $\delta = t_1/t_2$. Via stacking SSH chains we produce a graphene lattice as is shown in Fig.1(a). From the SSH energy spectrum in Fig.1(b), we observe that as we change the control parameter two states appear in the middle of the gap when $\delta < 1$, those states are related to the topological transition. In the case of graphene also mid-gap states appear as is shown in Fig.1(c). Those states are edge states as is shown for SSH in Fig.1(d). The Fig.1(e) shows one edge state of the graphene with 3 layers of SSH, and we observe that the edge states of the graphene are similar to the edge states of the SSH lattices. Depending on the shape of the graphene edge and the hoppings there are different edge states associated to topological transitions [2]. Also, we stack two graphene lattices to study the bilayer graphene as shown in Fig.1(f). The bilayer of graphene has acquired a lot of relevance since it was discovered that it is a superconductor in a magic angle [3]. Therefore, we expect to study how the change in the angle changes the topological properties.

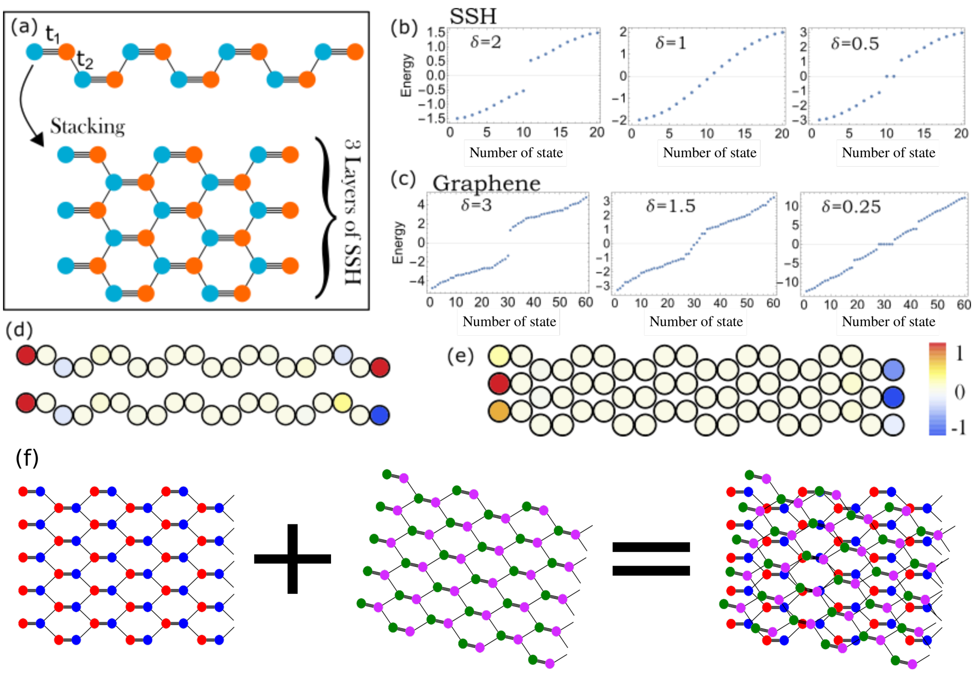

Fig. 1 (a) The top image is a schematic of the SSH lattice and the bottom image is a schematic of the graphene lattice with three stacked SSH lattices. (b) The eigenvalues of the SSH lattice in the trivial regime at $\delta = 2.0$ (left), in the transition at $\delta = 1$ (middle) and in the topological regime at $\delta = 0.5$ (right). (c) The eigenvalues of the graphene with 3 stacked SSH lattices in the trivial regime at $\delta = 3.0$ (left), during the transition at $\delta = 1.5$ (middle) and in the topological regime at $\delta = 0.25$ (right). (d) The two edge states of the SSH lattice. (e) One of the edge states of the graphene lattice. (f) Bilayer graphene.

References

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[2] P. Delplace, and D. Ullmo, and G. Montambaux, "Zak phase and the existence of edge states in graphene", Phys. Rev. B 84, 195452 (2011).
[3] Cao, Y., Fatemi, V., Fang, S. et al., "Unconventional superconductivity in magic-angle graphene superlattices", Nature 556, 43–50 (2018).