Magnetic edge anisotropy in graphene-like honeycomb crystals

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Abstract

The independent predictions of edge ferro-magnetism and the Quantum Spin Hall phase in graphene have inspired the quest of other two dimensional honeycomb systems, such as silicene, germanene, stanene, iridiates, and organometallic lattices, as well as artificial super-lattices, all of them with electronic properties analogous to those of graphene, but much larger spin orbit coupling. Here we study the interplay of ferromagnetic order and spin orbit interactions at the zigzag edges of these graphene-like systems.

We show that the spin orbit coupling (SOC) introduces an anisotropy in the magnetic edge states of zigzag ribbons. The consequence of such anisotropy is radical: whereas both the nonmagnetic QSH and the ferromagnetic non SOC ribbon show gap-less edge states, the combination of both phenomena leads to a in-plane magnetization without any gap-less edge state. On the other hand, an off-plane magnetic solution retains the gap-less edge states. Since the anisotropy can be overwhelmed by a strong local magnetic field, the control of the local field at the edges makes possible the development of a device which can be driven between two regimes: a spin filtered edge state and an insulating edge state, only by acting on the edge of the system. We suggest that the most promising material which will exhibit the most observable behavior would be a two dimensional sheet of buckled honeycomb germanium, the so called germanene. Other possible materials that could show such unusual phenomena would be silicene, organometallic lattices or iridate multi-layers.

Regarding the technical details. We determine that the interplay between interaction driven edge magnetism in zigzag ribbons and the SOC yield a magnetic edge anisotropy. The easy axis is located in the plane of the ribbon (with a SO(2) degree of freedom), whereas the hard axis corresponds to the off-plane axis. Associated with this anisotropy, the system shows two different regimens, both characterized for a topological Z_2 bulk invariant and broken time reversal symmetry at the edge. Since the gap-less edge states are no longer protected by the local broken symmetry, the off-plane magnetic solution retain the gap-less states, whereas in the in-plane the states became gapped. This last behavior should result in a giant anisotropic magneto-resistance, which in the zero temperature limit will lead to an infinite magneto-resistance. In comparison with conventional anisotropic systems,, the changing of the direction of the magnetization from the easy axis to the hard axis can completely destroy the magnetization.

The calculations were performed using a Hubbard model with the Kane-Mele tight binding Hamiltonian in a one dimensional zigzag stripe, solved in a mean field approximation by self-consistency. We explored the parametric space of spin-orbit coupling, Hubbard interaction and direction of the magnetization. We determine the importance of the trade-off between the triggering of the anisotropy by the SOC and the quenching that produces on the magnetic moment, which leads to a maximum of the anisotropy at a certain value of the SOC, and in general, a strong dependence of the anisotropy on the SOC. In comparison, the anisotropy is highly dependent at low values of the on-site interaction, but shows a small dependence at the intermediate regime, even until the anti-ferromagnetic phase transition is reached.

References

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Figures

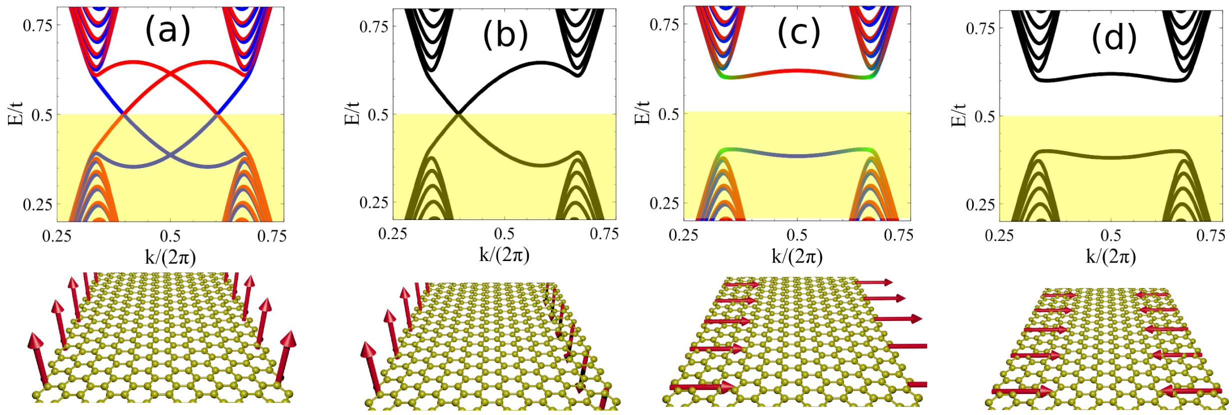

Figure 1: Self-consistent band structures obtained by the mean field Kane-Mele-Hubbard model at half filling in a honeycomb lattice in several magnetic configurations as shown in the ribbons. (a) and (b) correspond to ferromagnetic edge solutions whereas (b) and (d) to anti-ferromagnetic solutions. As can be checked in the band structures, the transport properties depend strongly on the direction of the magnetization, leading to a spin filtered quantized edge conductance for the off-plane solution, and an insulating phase in the in-plane solution. The mean field calculation shows that the lowest energy state corresponds to the in-plane solution, being the ground state of the system insulating. Upon an application of a strong magnetic field localized in the edges, the system could be driven between the two regimes, leading to a theoretically infinite magnet-resistance at zero temperature.

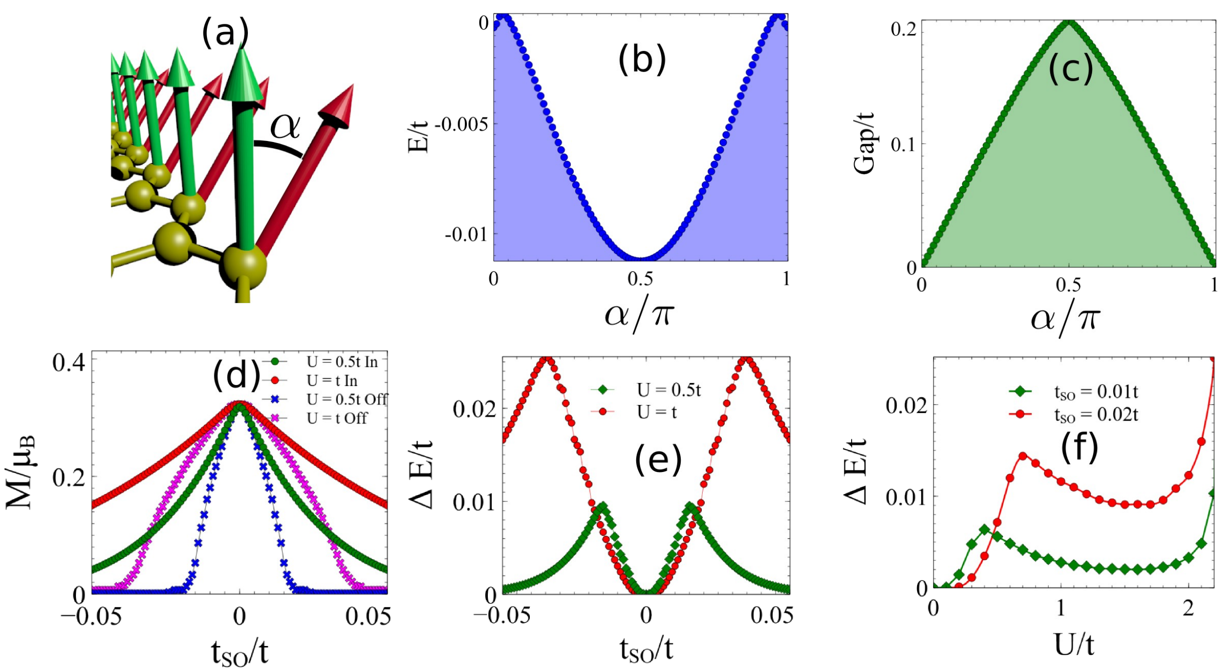

Figure 2: Evolution of energies, magnetizations and gaps with several parameters. Ground state energy and magnetization with the angle (b,c), magnetization with the SOC (d), anisotropy energy with the SOC (e) and on-site interaction (f). (a) shows the scheme of how is measured the angle in (b) and (c). These behaviors show that the ground state is an in-plane magnetic and insulating state, and highlights the strong dependence of the magnetization on the SOC and the angle.