Highlights

Innovative materials with strong interplay of spin orbital charge and topological degrees of freedom - 2018

A topological quantum pump in serpentine-shaped semiconducting narrow channels

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In a charge pump, periodic perturbations induce a dc current without an external bias. Very recently, topological quantum pumps, where the induced current is quantized and topologically protected, have been realized in ultracold atomic systems through the creation of dynamically controlled optical superlattices. In one-dimensional (1D) electronic systems, the creation of a dynamical superlattice potential critically relies on the presence and control of superimposed oscillating local voltages, and this severely hampers the possibility to bring topological charge pumping within reach in condensed matter experiments.
Within this framework we propose and validate theoretically a solid-state system in which topological quantum pumping can be achieved even in the complete absence of superimposed voltage leads. The system consists of a Rashba spin-orbit coupled semiconducting narrow channel with a serpentine shape at the mesoscopic scale (Fig. 1(a)), which can be obtained either by processing a semiconducting quantum well lithographically, or by creating a “zigzag” nanowire network of crystalline quality. To operate, the device makes use of an auxiliary external planar rotating magnetic field, which serves as the periodic (ac) perturbation driving the charge pumping (Fig. 1(b)). As the strength of the rotating magnetic field is increased, the system undergoes a topological phase transition from an insulating phase with a nontrivial Chern number $C=-2$ to a completely trivial $C=0$ insulating phase (Fig. 1(c)). The time-dependent Zeeman interaction due to the planar rotation of the magnetic field cooperates with the spin-orbit coupling, which is effectively inhomogeneous because of the geometric curvature of the nanostructure, in such a way to render a sliding superlattice potential acting on the electronic charges. As a consequence, in the topological non trivial phase, an even integer number of electronic charges is transported in each rotation period of the magnetic field (Fig.1(d)). This effect ultimately yields a quantized dc current which realizes the topological pumping protocol, originally introduced by Thouless, in a completely novel fashion. The precise pumping of electric charges in our mesoscopic quantum device can be relevant for quantum metrology purposes.

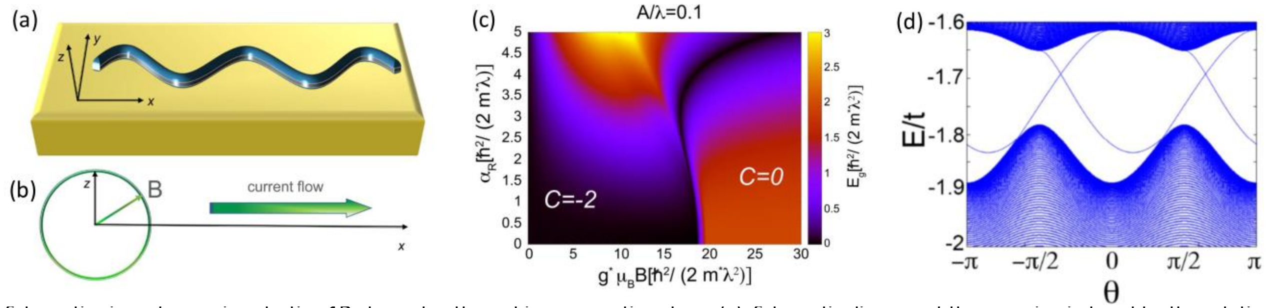

Fig. 1: Schematic view of a semiconducting 1D channel patterned in a serpentine shape (a). Schematic diagram of the pumping induced by the rotation of the magnetic field (b). Map of the gap between the second and third minibands of an undulating 1D channel subject to rotating magnetic fields, in the continuum limit. A topological phase transition separates the topologically non trivial region (with C=−2) from the topologically trivial one (C=0) (c). The energy spectrum of a finite size system with open boundary conditions in the topological non trivial phase displays two chiral edge states within the one quarter-filling gap (d).