Theory of adiabatic charge pump with a topological insulator nanowire device

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Charge pumping can be realised in "almost open" unbiased confined nanostructures by applying two or more slowly varying, periodic potentials. Differently from previous quantum dot-based devices that rely on strong Coulomb blockade interaction, adiabatic charge pumping is applied to non-interacting electronic systems and exploits the constructive interference of the scattering states. The presence of Dirac-like states, which are protected from non-magnetic disorder, at the surface of 3D topological insulators (TIs), makes this material an optimal candidate for the design of improved charge pump devices.

In this work we show how quantised adiabatic charge pumping can be achieved in a confined nanostructure based on a topological insulator nanowire. Differently from two-dimensional TIs, the bulk electronic transport of TI nanowires is highly suppressed. Therefore, the exploitation of these low-dimensional structures can be found beneficial in devices that use their protected surface states. The theoretical study presented here focuses on a recently proposed device where the charge confinement is achieved via a radius variation along the nanowire [1]. The pumping mechanism is studied within the Landauer-Büttiker formalism and involves the use of only electrostatic gates applied to the restricted radius regions (see Figure), avoiding the use of strong local magnetic fields, experimentally difficult to work with. Limitations and possible extensions of the protocol are also presented.

Figures

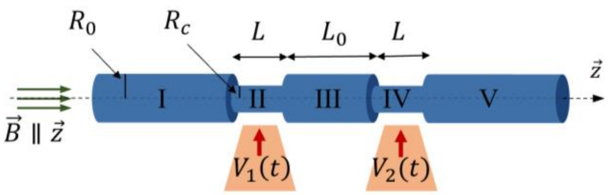

Figure: Schematic of the proposed device: a TI nanowire of radius R_0 is etched in regions II and IV, of length L and reduced radius $R_C < R_0$, leaving region III of length L_0 in between. Regions I and V are assumed of infinite length. To implement adiabatic quantum pumping, two oscillating electrostatic gates with a nonzero phase difference, $V_1(t)$ and $V_2(t)$, are applied to regions II and IV respectively.

References

[1] R. Saxena et al, Phys. Rev. B 106, 035407 (2022)