Theory for non-equilibrium carrier dynamics in two-dimensional topological insulators

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ABSTRACT

Topological insulator materials have been extensively studied in the field of condensed matter physics because the surfaces of the topological insulators show a new class of states with a novel Dirac dispersion [1]. This characteristic could be understood based on a consideration on the bulk-edge correspondence, where the exotic surface states are derived from the nontrivial wavefunctions of Bloch electrons. Thus, the nontrivial wavefunctions are qualitatively different from those of the ordinary semiconductors, and therefore, the anomalous optical responses to the external ac electric fields should be expected when focusing on the topological insulators. To understand this unusual characteristic, it is essential to develop a theoretical framework for the topological insulators involving both transport and excitation processes of Bloch electrons. Based on this consideration, we develop a theory of carrier dynamics in the two-dimensional topological insulators and investigate the differences between the topological insulators and the normal insulators.

Our theoretical framework is on the basis of Kane-Mele model [2] which includes the spin-orbit interaction in the honeycomb lattice of graphene. Utilizing a tight-binding basis, the Hamiltonian for the light-matter interaction could be introduced as well as the single-particle Hamiltonian in the Kane-Mele model. The transformation from the lattice picture to the band-structure picture can be performed by diagonalization of the single-particle Hamiltonian. Through the use of this transformation, we can derive the electron-hole Hamiltonian involving the light-matter interaction where the transport and excitation processes of Bloch electrons should be included. To investigate the carrier dynamics, we suppose the carrier-densities and polarization functions and derive the closed-form coupled equations for these quantities. In this theoretical framework, tuning of the spin-orbit interaction can cause a transition from normal insulators to topological insulators. Using this formalism, we perform a numerical calculation and discuss the differences of carrier dynamics between the topological insulators and normal insulators.

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