Dissipation and Geometric Effects in Bloch-Zener Oscillations

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Field-induced phenomena of quantum materials have much attention with the developments of laser technology. Strong laser fields trigger intriguing nonlinear responses, such as nonreciprocal responses and high-harmonic generation. The Landau-Zener transition (LZT) [1], which is a key process of the nonperturbative phenomenon caused by such a strong electric field, has been studied in various contexts, including atomic physics and quantum information. From a topological point of view, the geometric effects (Berry phase) associated with LZT [2] are of interest. In nonreciprocal systems such as ferroelectrics, the tunneling probability depends strongly on the direction of the electric field E due to broken inversion symmetry [3,4]. Experimentally, the nonreciprocal LZT has been observed as the transition between different spin states in a Diamond [5]. Theoretically, the nonreciprocal current in the Rice-Mele model (1D topological insulator) has been studied by the nonequilibrium Green's function approach [6]. However, it is not so clear how the periodic energy structure of lattice systems affects the nonreciprocal transport with the geometric origin. We have recently developed an efficient method for theoretical analysis of non-perturbative currents using the quantum master equation, called dynamical phase approximation (DPA) [7]. The advantage of this method is that it does not require much computation time and can be straightforwardly applied to lattice models.

Here, we analyze the Rice-Mele model and the Su-Schrieffer-Heeger model in detail using the DPA method. In particular, we focus on the Bloch-Zener oscillation (Fig. 2), which is the interference effects of periodically repeated LZT due to the Bloch oscillation specific to lattice systems. We find that the periodic structure and the peak position of the Bloch-Zener oscillation are independent of the strength of dissipation, and also the nonreciprocity of the electric current is enhanced in the high field due to the Bloch-Zener oscillation.

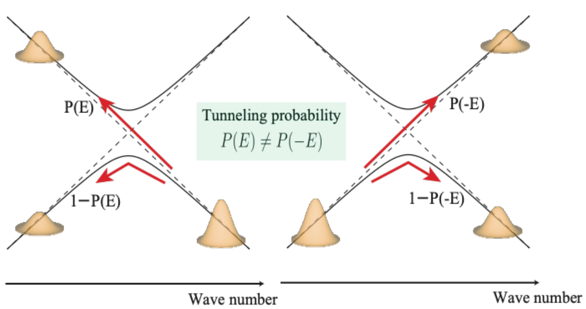

Figure 1 : Schematic picture of the nonreciprocal LZT. *P(E)* is a tunneling probability at an electric field *E*.

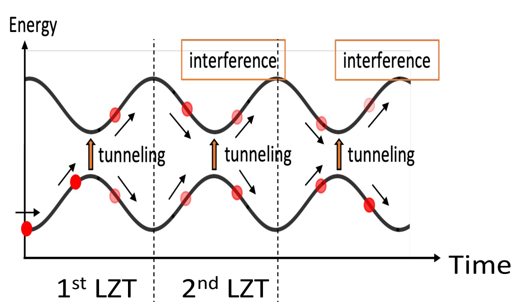

Figure 2 : Schematic picture of the Bloch-Zener oscillation.

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