Abstract

We theoretically study the electromagnetic responses of low-dimensional lattice models, focusing on bosons in optical lattices and fermions in deformed honeycomb lattices. The non-interacting bosonic model exhibits distinct particle currents for localized and delocalized phases in the presence of incommensurate superlattice potentials. Specifically, the current in the delocalized phase displays odd harmonics, whereas both even and odd harmonics are observed in the localized phase. The amplitudes of these harmonics can be tuned by varying the pulse frequency and the number of pulse cycles. When repulsive onsite interactions are introduced, distinct harmonic spectra emerge between disorder- and interaction-driven phases. The inclusion of nearest-neighbour interaction, in the absence of incommensurate superlattice potentials, further enriches the phase diagram of the bosonic system due to long-range correlations. Particularly, a few additional phases, namely the Haldane insulating (HI) and the density wave (DW) phase appear. The DW phase features nearly flat excitation spectra and demonstrates optimal conditions for amplifying specific harmonic orders. We identify resonance-induced amplification (RIA) as a mechanism to selectively enhance nonlinear harmonic responses in the DW phase. This approach allows the precise selection of incident pulse frequencies to amplify specific harmonic orders, revealing an optimal field strength necessary for achieving significant enhancements.

For fermions in deformed honeycomb lattices, we investigate the electromagnetic responses of low-energy Dirac quasi-particles. Specifically, we address whether the van Hove singularity (VHS) in the density of states (DOS), originating from the stationary point (saddle) of the energy dispersion, can be identified by the light field. Near such a saddle point, the response of a quantum system under a weak light pulse is found to differ compared to the response away from the saddle point. Using density matrix formalism, we find persistent and oscillatory particle currents even after the end of the applied pulse. Interestingly, away from the saddle point, the post-pulse oscillatory particle current diminishes. This unique behaviour in the particle current is attributed to the interband coherent transitions near the saddle point. Consequently, this feature can serve as a diagnostic tool to probe topological Lifshitz transitions.