URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Characteristics of the propagation of Dirac-type waves for arbitrary temporal variations of various parameters

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We investigate the influence of the temporal variations of various medium parameters on the propagation of Dirac-type waves in materials where quasiparticles are described by a generalized version of the pseudospin-1/2 Dirac equation. Our considerations include the propagation of electromagnetic waves in metamaterials with the Dirac-type dispersion as well as various types of quantum Dirac materials. We consider arbitrary continuous and discontinuous temporal variations of the scalar and vector potentials, mass, Fermi velocity, and tilt velocity describing the Dirac cone tilt. For the simplest cases such as the single temporal interfaces and slabs, we derive the scattering coefficients analytically and find that the temporal scattering in the backward direction is caused by the variations of the mass, Fermi velocity, and vector potential, but does not arise in the variations of the scalar potential and tilt velocity. Using the analytical expressions for the temporal transmittances and the interband transition rates, we obtain the explicit conditions for which the temporal total transmission and the temporal total reflection occur. We also derive the expressions for the change of the total wave energy. We consider bilayer temporal Dirac crystals where the medium parameters alternate between two different sets of values periodically in time and prove that momentum gaps never appear in such systems in sharp contrast to classical waves such as electromagnetic and elastic waves. For the temporal variations of an arbitrary form, we derive the invariant imbedding equations which describes the temporal evolution of the scattering coefficients and the field profiles. We solve them numerically and analyze the characteristics of wave propagation in the presence of periodic and quasiperiodic temporal variations of finite duration. We discuss the experimental feasibility for observing the temporal scattering effects for Dirac-type waves.