Quantum Field Modelling of Nonlinear Optical Response in Graphene

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Graphene is a monolayer of carbon atoms sitting in a hexagonal lattice. Owing to the special symmetries of the crystalline structure, the band structure of graphene differs substantially from the other condensed matter systems. The effective Hamiltonian describes quasirelativistic massless Dirac fermions. The Dirac fermions introduced by the low energy Hamiltonian are dominantly chiral [1]. Moreover, the band structure of graphene is scale-invariant in the low energy limit [2]. It has been shown that the chirality of the charged carrier leads to several unconventional transport properties such as minimum conductiovity, Klein paradox and Zitterbewegung [1]. The impact of the chirality on the optical response of graphene has not been investigated so far.

We have shown that the chiral nature of the charged carriers in conjunction with the scale invariance of the band structure results in a strong nonlinear optical response. The time evolution of the quasiparticles in the presence of the electromagnetic field can be decomposed into the quasicalssical intraband transport and interband time evolution. Employing Semiconductor Bloch Equations (SBEs) [3] for graphene, we have decoupled the qusicalssical and quantum dynamics. Based on SBEs, the dynamics is goverend by a classical theory with quantum flactuations superimposed. The principle advantage of SBEs is twofold: first they provide a convenient mathematical scheme leading to analytical expressions for arbitrary order of interaction. Secondly, SBEs encode the topological properties of band structure in an effective dipole appearing in the equations. As a matter of fact, the geometrical properties of the band structures affect the intraband contribution of the optical response and interband transitions are influenced by the special topological aspects of the band. We exploit the band renormalizations such as spin-orbit coupling to calculate the nonlinear optical response. We have shown that the nonlinear response function can be expressed as the summation three different contributions: pure-intraband, pure-interband and combination of the both.

References

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