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Nonequilibrium Electrical Transport in Materials with Localized Electronic States

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A broad range of disordered materials contain electronic states that are spatially well localized. In this work we studied the electrical response of such materials to external terahertz electromagnetic field [1]. We obtained expressions for nonequilibrium terahertz conductivity of a material with localized electronic states and weak electron-phonon or electron-impurity interaction. The expression is valid for any nonequilibrium state of the electronic subsystem prior to the action of external field. It gives nonequilibrium optical conductivity in terms of microscopic material parameters and contains both coherences and populations of the initial electronic subsystem's density matrix. Particularly, in the case of incoherent nonequilibrium state of the electronic subsystem, the optical conductivity is entirely expressed in terms of the positions of electronic states, their nonequilibrium populations, and Fermi's golden rule transition probabilities between the states. The same mathematical form of the expression is valid both in the case of electron-phonon and electron-impurity interaction. Moreover, our result for the nonequilibrium optical conductivity has the same form as the expressions previously obtained for the case of equilibrium. Our results are expected to be valid at sufficiently high frequencies, such that the period of the external field is much smaller than the carrier relaxation time. We apply the derived expressions to two model systems, a simple one-dimensional Gaussian disorder model and the model of a realistic three-dimensional organic polymer material obtained using previously developed multiscale methodology [2]. We note that the simple one-dimensional model captures the essential features of the mobility spectrum of a more realistic system. Furthermore, our simulations of the polymer material yield the same order of magnitude of the terahertz mobility as previously reported in experiments.

[1] V. Janković and N. Vukmirović, Phys. Rev. B 90, 224201 (2014).

[2] N. Vukmirović and L.-W. Wang, Nano Lett. 9, 3996 (2009).