Ultrafast quantum kinetics of photo-excited carriers in semiconductors in high electric field

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Recently it became possible to observe the dynamics of the photo-excited carriers by means of femtosecond pulse laser technology. The coherent phenomena in semiconductors observed within sub-picosecond time-domain gather our attraction. We have theoretically investigated the ultrafast quantum kinetics of carriers in semiconductors in high electric field. We have considered the electron-hole system in two-band semiconductors described by the effective mass theory to investigate the band-edge dynamics of carriers. The effects of high electric field have been included by the method of the Airy basis. We have formulated the system together with longitudinal (LO) phonons in the framework of the density matrix method. A set of effective Bloch equations in high electric field has been derived. The simulations have been done with computer programs based on the Runge-Kutta-Verner method, which have been developed to analyze the dynamics of the carriers.

We have first concentrated on the coherent generation of carrier with ultrashort pulse laser. We have simulated the dynamics of carriers up to one picosecond. Besides the peak associated with the energy of the excitation laser, the distribution function of carriers excited in high electric field exhibits the Franz-Keldysh-like oscillatory structure as a function of energy. This oscillation is interpreted as the result of quantum interference with interband polarization and laser field. The components of the interband polarization that fulfills resonant excitation condition contribute to the carrier distribution significantly. The profile of the oscillatory structure is determined by the field dependence of this condition for the interband polarization. The field-assisted generation is also seen in the excitation process. The peak centered on the excitation energy is shifted toward the lower energy side proportional to the strength of the field.

We have then considered the process including the carrier-LO phonon interaction. The incoherent process via carrier-LO phonon interaction brings relaxation to the carrier. The relaxation of the peak associated with the excitation energy is seen in the distribution function of electron. The relaxation is significant especially within first several hundreds femtosecond. The oscillatory structure generated under the influence of the high electric field is strongly modified through the incoherent process. Instead of the phonon replica structure observed in the absence of a high electric field, growing peaks are observed in the low energy side of the distribution function of electron. These peaks shift toward lower energy as time evolves. This phenomenon is result of the overlap between the generation of the oscillatory structure, i.e. electron, and the relaxation of it in the time-domain. The generations of the oscillatory structure and the phonon replica take place competitively and form new structure. This can be thought as one of the characteristics coherent phenomena in semiconductors in high electric field. On the other hand, the hole is scarcely relaxed since the provided energy for it is smaller than the phonon energy.