Relaxation properties of the quantum kinetics of carrier-LO-phonon interaction in quantum wells

P. Gartner and F. Jahnke
Institute for Theoretical Physics, University of Bremen
28334 Bremen, Germany

LO-phonon collisions are the dominant dephasing and scattering mechanism in semiconductors at low carrier densities. Nevertheless, due to the dispersionless spectrum of such phonons, it was a matter of debate whether they can provide efficient relaxation. This is illustrated for instance by the 'phonon bottleneck' controversy in the quantum dot literature, in the case when there is a mismatch between the carrier energy spacing and the LO-phonon energy. On the other hand, the Boltzmann-like, energy-conserving picture, based on the Markov limit of the quantum kinetics is expected to fail if the carrier-phonon coupling is not small. As it was shown in [1], one has to take into account in such cases both polaronic and quantum-kinetic (memory) effects.

As encouraging as such results are, the more general problem of the correct relaxation behaviour of the solutions of quantum kinetic equations remains an open one. More specifically two questions are relevant here: (a) whether the solutions reach a steady state at large times and (b) if they do, are these steady states describing thermal equilibrium?

We investigate numerically this problem for a two-band semiconductor quantum well, following the carrier evolution after a short optical pulse excitation deep in the band. We consider the selfconsistent RPA carrier-phonon scattering both in the two-time Green’s function (GF) formalism and in the one-time approximation provided by the generalized Kadanoff-Baym ansatz. The criterion for reaching a thermal equilibrium distribution is the fulfillment of the Kubo-Martin-Schwinger (KMS) condition [2], expressing the lesser and greater GFs in terms of the spectral GF and the Fermi function. We consider both low (GaAs) and intermediate (CdTe) coupling regimes.

The results show that a steady state is reached in all these cases. For low couplings these states obey fairly well the KMS condition. For higher couplings the one-time solution remains unthermalized while the two-time one is again in good agreement with the KMS condition.