A Space Dependent Wigner Equation Including Phonon Interaction

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The quantum transport in far from equilibrium conditions is determined not only by the nanostructure potential, but also by dissipative processes due to interaction with phonons. Of interest is the reduced Wigner function $f_w(\mathbf{r},\mathbf{p},t)$, which is obtained by taking the trace over the phonon coordinates.

We present an equation for the reduced Wigner function which is obtained after a hierarchy of approximations. The equation treats the coherent part of the transport imposed by the nanostructure potential at a rigorous quantum level. It is general enough to account for the quantum effects in the interaction with phonons. The relevant quantum effects are collision broadening associated with the lack of energy conservation in the scattering process, collision retardation due to the memory character of the equation and the intra-collisional field effect, the action of the field during the collision process.

The approximations for this equation will be presented in a systematic way. They include a weak scattering limit in the phonon interaction, assumption of an equilibrium phonon system, mean phonon number approximation, and an effective field in the scattering-Wigner potential correlation. The thereby obtained equation becomes nonlocal in the real space and is a generalization of the Levinson equation [1].

An analysis of the equation reveals a novel quantum effect which is due to the correlation between the interaction process and the space component of the Wigner path. The interaction process has a finite duration responsible for the memory character of the interaction. During a scattering process with a duration τ, the path is shifted in the real space by $\frac{\hbar\mathbf{q}/2}{m}\tau$ where $\mathbf{q}$ is the phonon mode and m is the effective mass of the electron.

The femtosecond relaxation of optically excited electrons in presence of a homogeneous electric field is studied. For this case the equation reduces to the Levinson equation. Simulation results for *GaAs* material with a PO phonon with constant energy $\hbar\omega$ are obtained by a backward Monte Carlo method. A choice of a very low temperature allows to study the quantum effects. Fig. 1 and Fig. 2 demonstrate the intra-collisional field effect. Depending on the field direction one can observe an effective change of the phonon energy.

[1] J. Rammer, Reviews of Modern Physics **63**, 781 (1991).

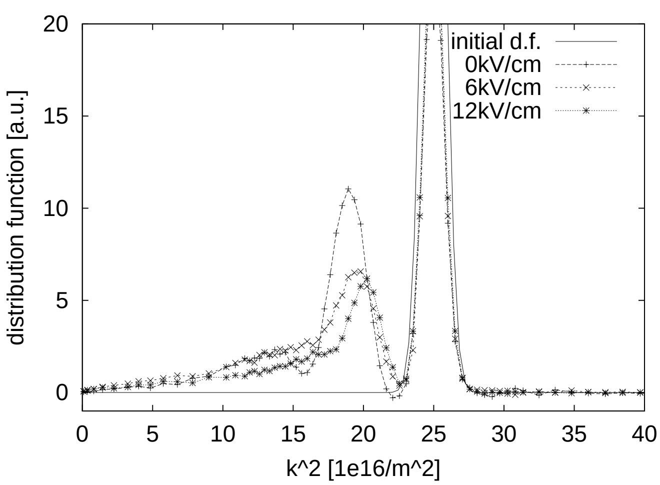

Figure 1: 200 fs solutions along the field direction for different field values. The field shifts the first replica to the right leading to an effective decrease of the phonon energy.

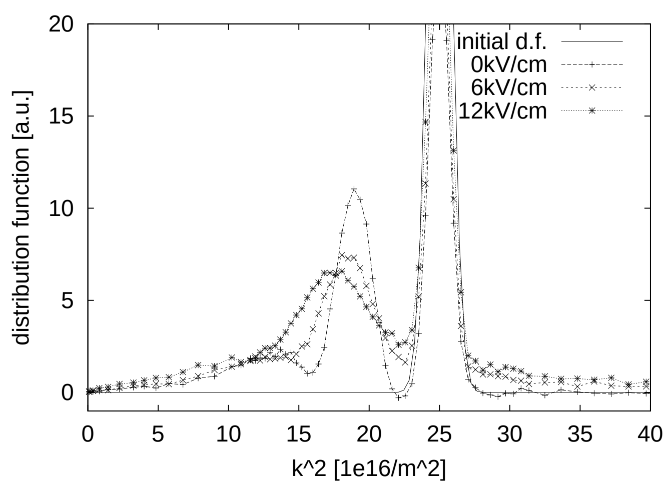

Figure 2: 200 fs solutions opposite to the field direction for different field values. The field shifts the first replica to the left leading to an effective increase of the phonon energy.

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