Electronic and phonon coherence in n-GaAs studied using ultrafast quantum path interferometry with attosecond controlled near-infrared pulses

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Coherence is one of the most important issues in recent quantum information technologies. It is very hard to define the coherence time of free electrons in bulk solids because it disappears very quickly. We determine the electron and phonon coherence time (femtosecond time range) in n-type GaAs by using the quantum path interferometry with relative phase-locked optical pulses. The results indicate that electronic decoherence mainly due to the electron-electron scattering.

We measure transient reflectivity of a GaAs crystal by using a pump-probe technique with a pair of relative-phase locked femtosecond pump pulses.[1, 2] The pulse width and center wavelength of the pulse is approximately 60 fs and 800 nm. The polarization angle between the pump 1 and 2 is set to be 0 or $\pi/4$. A delay (t_{12}) between the pump pulses are controlled with a step of 300 attoseconds. The sample used is a n-type GaAs (100) crystal and set in a refrigerator (10-290 K). At a fixed pump-pump delay, a change in transient reflectivity as a function of a pump-probe delay (t_{13}) shows a coherent oscillation due to longitudinal optical (LO) phonons (8.8 THz) and LO-phonon-plasmon coupled mode (7.8 THz). The coherence time of LO phonons is estimated to be approximately 2 ps at 10 K. The amplitude of the coherent LO phonons as a function of t_{12} shows interference fringes due to an electronic coherence (2.7-fs interval) and phonon coherence (115-fs interval). This indicates that the electronic coherence in GaAs keeps after the laser-pulse irradiation.

The interference pattern is analyzed using quantum-model calculations with a simple system Hamiltonian for the electron-phonon composite system and the Lindblad-type quantum master equation [2, 3]. The retention time of coherence (decoherence time) between the free electron-hole is estimated to be 27.8 ± 0.5, 23.0 ± 0.3, and 12.9 ± 0.3 fs at 10, 90 and 290 K, respectively.[2] Temperature dependence of the decoherence time is well reproduced by the equation:

$$\tau^{-1}(T) = \tau_0^{-1}(T) + v(T)[n_d(T) + n_e(T)]^{1/3}, \tag{1}$$

where $\tau_0(T)$ is the momentum relaxation time of electron-phonon and electron-impurity scattering, $v(T)$ is the group velocity of electrons, $n_d(T)$ is the dopant induced electron density and $n_e(T)$ is the photo-excited electron density. Electron decoherence is mainly dominated by electron-electron scattering, and collision frequency seems to be more in effect than momentum relaxation.

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References

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