Microscopic theory of ultrafast dynamics of carriers photoexcited by THz and near-infrared linearly-polarized laser pulses in graphene

B. Y. Sun and M. W. Wu*

Hefei National Laboratory for Physical Sciences at Microscale and Department of Physics, University of Science and Technology of China, Hefei, Anhui, 230026, China
Email: mwwu@ustc.edu.cn

We investigate the dynamics of photoexcited carriers and nonequilibrium phonons in graphene by solving the microscopic kinetic Bloch equations with the relevant scatterings (including the Coulomb scattering with dynamic screening) explicitly included. Under the gauge invariant approach, both the drift and pump terms are included naturally. We look into the dynamics of carriers photoexcited by the linear polarized laser pulses with the pump-photon energy in both near-infrared and THz regimes. When the pump-photon energy is high enough, the influence of the drift term is shown to be negligible. Moreover, the anisotropic photoexcited electrons tend to be isotropic under the scattering and an isotropic hot-electron Fermi distribution is established before the end of the pulse investigated here. However, in the case with low pump-phonon energy, the drift term is important and leads to a net momentum transfer from the electric field to electrons. Together with the dominant Coulomb scattering, a drifted Fermi distribution different from the one established under static electric field is found to be established in several hundred femtoseconds. Besides, we also show that the temporal evolution of the differential transmission (DT) measured by Hale et al. [1] can be well fitted with our microscopic calculation. We further show that the Auger process investigated in the literature which involves only the diagonal terms of density matrices, is forbidden by the dynamic screening. However, we propose an Auger process involving the interband coherence and show that it contributes to the dynamics of carriers when the pump-photon energy is low. In contrast, it is shown that the rotation-wave approximation widely accepted in semiconductor optics fails when the pump energy is low. The negative DT is further studied by fitting the temporal evolution of DT measured by Sun et al. [2]. Our results support their suggestion that their negative DT comes from the weakening of the Pauli blocking due to the heating of the electrons by the pump pulse. In addition, the anisotropical momentum-resolved hot-phonon temperatures due to the linearly polarized light are also investigated, with the underlying physics revealed.

[1] P. J. Hale, S. M. Hornett, J. Moger, D. W. Horsell, and E. Hendry, Phys. Rev. B **83**, 121404(R) (2011).
[2] D. Sun, Z.-K. Wu, C. Divin, X. Li, C. Berger, W. A. de Heer, P. N. First, and T. B. Norris, Phys. Rev. Lett. **101**, 157402 (2008).
[3] B. Y. Sun, Y. Zhou, and M. W. Wu, Phys. Rev. B **85**, 125413 (2012).
[4] B. Y. Sun and M. W. Wu, arXiv:1302.3677.