Ultrafast electron kinetics in graphene

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Graphene is an ideal structure to study the efficiency of different carrier relaxation channels in a two-dimensional system: Its linear energy dispersion and the vanishing bandgap allow scattering processes, which are suppressed in conventional semiconductors (cp. Fig.1a).

Here, we present self-consistent calculations of the coupled carrier and phonon dynamics based on a second order Born-approximation [1]. This approach allows to track the way of optically excited carriers toward equilibrium - resolved in time-, momentum-, and angle - in theory and corresponding experiments (Helmholtz-Zentrum Dresden-Rossendorf; RWTH Aachen).

After optical pulse excitation, a highly anisotropic non-equilibrium carrier population (cp. Fig. 1b) is created [2]. The efficient intraband carrier-carrier scattering leads to a redistribution of carriers to energetically lower states already within the first 10 fs. Preferably, the scattering occurs along the Dirac cone conserving the anisotropy. In contrast, the phonon-induced relaxation processes bring carriers across the Dirac cone, which leads to an isotropic distribution already after 50 fs (cp. Fig. 1c-d).

The calculations also predict a significant contribution stemming from Auger processes. Inverse Auger recombination leads to a considerable carrier multiplication - in spite of the directly competing phonon-induced processes [3]. After about 100 fs, the carriers are completely thermalized resulting in a spectrally broad Fermi distribution. Unique signatures of Auger processes can be identified in pump-probe experiments on graphene in a magnetic field [4].

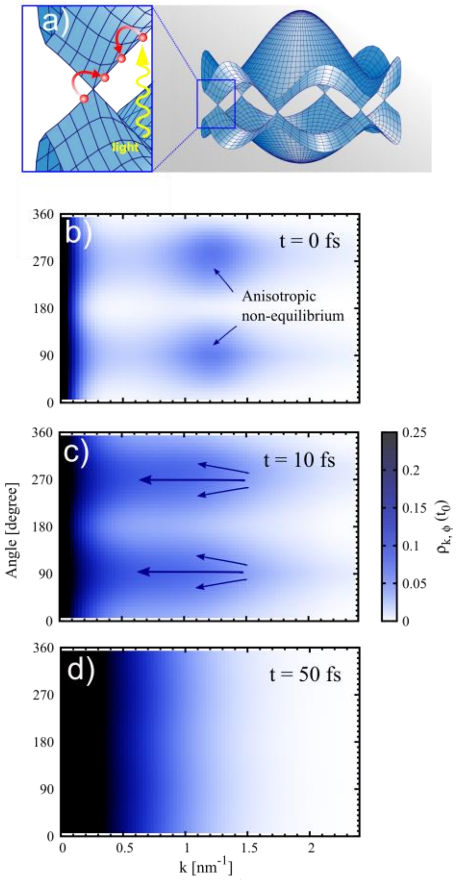

Fig. 1: a) Bandstructure of graphene. b)-d) Carrier occupation probability as a function of the momentum and angle around the Dirac point. It illustrates the carrier relaxation dynamics after optically generating a non-equilibrium distribution.

In summary, the presented microscopic study provides insight into the ultrafast relaxation dynamics of optically excited carriers in graphene, in particular in anisotropic relaxation and Auger processes.

References

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[3] Nano Lett. 10, 4839 (2010); Nano Lett. 14, 5371 (2014).

[4] Nature Comm. 5, 3703 (2014); Nature Phys.11, 75 (2015).