The ultrafast dynamics and conductivity of photo-excited graphene

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Graphene is a particularly promising material for optoelectronic applications, such as photodetection and data communication, owing to its ability to absorb light of any color, and to generate a carrier-heat-induced photoresponse on an ultrafast timescale after absorbing light. In order to realize such applications, it is essential to properly understand carrier heating and the conductivity of photo-excited graphene.

Here, we present a unified and intuitive physical picture of the ultrafast photo-induced dynamics and the conductivity of substrate-supported graphene, which is exclusively based on electronic effects [1]. In particular, we show optical pump – terahertz probe studies, where the terahertz probe is sensitive to graphene's conductivity directly after photoexcitation, while varying the Fermi energy. We compare the results with numerical calculations using the Boltzmann equation.

Regarding the ultrafast carrier heating dynamics, we identify two regimes:

1) For E_F < 0.1 eV, the carrier distribution broadens directly (within tens of femtoseconds) after light absorption, where it involves interband transitions from the valence to the conduction band – *interband heating*. In this regime, carrier multiplication can occur [2].

2) For E_F > 0.15 eV, the carrier distribution also directly broadens, however now this only involves intraband transitions within the conduction band – *intraband heating*. In this regime hot-carrier multiplication can occur [3, 4].

Interestingly, in both cases carrier heating is efficient, with only a small fraction of the absorbed energy from light going to the phonon system (during the first ~100 femtoseconds), while the largest fraction remains in the electronic system.

We also report a surprising correlation, which is that the conductivity directly after photoexcitation *increases* in the *interband heating* regime (regime 1), whereas it *decreases* in the *intraband heating* regime (regime 2). This correlation prompted us to find an explanation for the conductivity of photoexcited graphene based solely on electronic effects (rather than invoking *e.g.* increased phonon scattering).

Our numerical calculations show that, in regime 1, the ultrafast increase in conductivity comes (partially) from the additional free carriers created by *interband heating*. In regime 2, the decrease in conductivity comes from the reduced screening of charged impurities, leading to increased momentum scattering.

We thus find that we can explain many experimental results using this simple and intuitive physical picture that is based solely on electronic effects.

References

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