Light-field-driven currents in graphene

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Ultrafast electron dynamics inside of solids under strong optical fields has recently found particular attention. In dielectrics and semiconductors light-field driven effects like high-harmonic generation and sub-optical-cycle interband population transfer have been reported. However, much less is known about strong field phenomena in conducting materials. Graphene is an ideal playground for studying strong-field phenomena in a conductor because of its excellent carrier mobility, much weaker screening due to a low carrier concentration compared with conventional metals and its ultrafast and broadband optical response.

Here we show that one can control a residual conducting current in epitaxially grown graphene by the electric field of few-cycle laser pulses [1]. The electric-field waveform of such an ultrashort pulse is characterized by the carrier-envelope-phase (CEP), which determines where the maximum of the carrier field lies within the pulse envelope. We found a CEP-dependent current in monolayer graphene stripes, excited with linearly polarized laser pulses parallel to the graphene stripe with a peak field up to 3 V/nm. The amplitude of the current scales strongly nonlinearly with field strength. The CEP dependent current changes its sign at around 1.5 V/nm with increasing field strength. The main experimental features, especially the change in current direction as a function of field strength are well reproduced by numerical simulations.

We interpret this change in direction of the current as a result of transition from a weak perturbative nonlinear response to optical-field-driven non-perturbative electron dynamics. In particular, when the influence of the intraband dynamics to the interband transition cannot be neglected, this combined dynamics turns into a novel non-perturbative regime. In this strong-field regime, electron dynamics is governed by electron quantum-path interference that takes place on the 1-femtosecond timescale. The process can be categorized as Landau-Zener-Stückelberg interferometry.

In summary, light-field control of electrons in graphene is demonstrated, and a novel non-perturbative mechanism for conduction current generation is identified.

References

[1] [1] T. Higuchi, C. Heide, K. Ullmann, H. B. Weber, P. Hommelhoff, arXiv:1607.04198 (2016).

Figures

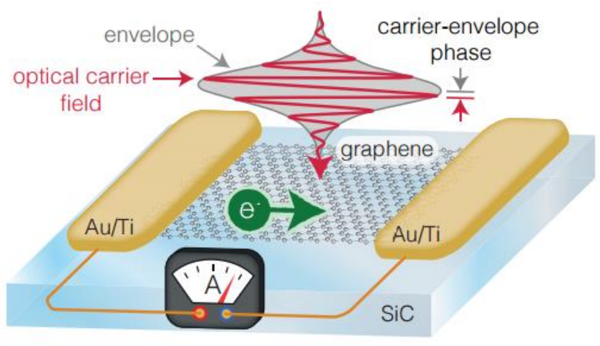

Figure 1: A graphene stripe on a SiC substrate is illuminated with few-cycle carrier-envelope-phase stabilized laser pulses. The laser-induced current flowing through the graphene stripe, contacted with Au/Ti electrodes, is measured.