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Non-Equilibrium Phenomena in Graphene

Submitted by Samuel Martyn Hornett to the University of Exeter as
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Samuel Martyn Hornett
April, 2013

Abstract

Graphene has displayed much promise as an electrical conductor and as a optical material. To date there is a large body of literature dedicated to the equilibrium properties of graphene. In this thesis the properties of graphene out of equilibrium are probed. Through combined optical and transport measurements the behaviour of hot electrons are probed at temperatures over five orders of magnitude from 50mK to 2000K. This wide range of temperatures allows access to the behaviour of quantum corrections at the lowest temperatures to the highest energy phonon modes. From ultrafast femtosecond laser pulses to steady state heating from an electric field the cooling of hot electron populations through coupling to various phonon modes in the graphene and the substrate are explored. Additionally the effect of an electric field on the weak localisation correction to the conductivity was separated from heating effects using applied magnetic fields combined with careful modelling of the heat transport properties of the graphene. Finally the desorption dynamics of oxygen bound to the surface are shown using a combination of transport and two pulse correlation technique using an ultrafast laser. Surprisingly the cooling of hot carriers in graphene at low energies shows substrate surface phonons as an important cooling mechanism, highlighting the importance of substrate choice in future graphene devices. In contrast at the very highest energy scales accessed only by photoexcitation the cooling is shown not to be influenced by the presence of a substrate, but out-of-plane phonon modes increase cooling of the hot optical phonons.

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