Cooling of Hot-Carriers with Landau Levels in Graphene

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Introduction

In recently years graphene has developed tremendous interest in the research community owing to its extraordinary physical properties. One such property is its unique quantum Hall effect with unusual filling factor ±2, ±6, ±8 ··· demonstrated by Geim's and Kim's groups separately in 2005.These experiments establish the massless Dirac fermion properties of electrons in graphene and imply strong electron-electron interactions in graphene at high magnetic fields. However, there have been very limited efforts to directly probe the dynamics of carriers in the quantum Hall regime. Such understanding will provide insights into the many-body physics in graphene complimentary to those studies with traditional electrical transport measurements.

Experimental

Our experiment focuses on the investigation of hot carrier cooling rates and mechanisms in graphene as its continuous bands are broken into discrete Landau Level states restricting the phase space through which photo-excited carriers are able to cool down. To this end we employed ultrafast pump-probe photocurrent spectroscopy where local photo-excitations create hot carriers which can be observed to cool to the lattice temperature through various channels in the graphene device.

We used the 17.5 T superconducting magnet (SCM 3) with optical access in the DC field facility. Staff scientist Zhiqiang Li has provided tremendous help. Working with Zhiqiang Li, a innovative sample mount has been designed incorporating three piezoelectric stages which allow precise *in-situ* positioning of the laser onto the sample. Additionally a low temperature, high magnetic field compatible objective lens has been installed to allow for near diffraction limited focusing of the laser light. With this setup we were able to focus a 2 µm laser spot onto the sample and maintain is precise positioning as the sample was cooled down and the magnetic field ramped up to the needed fields.

Results and Discussion

With these new improvements we were able to see some initial promising results. In Figure 1 we plot several traces of the normalized photocurrent as a function of the two pulse delay for various magnetic fields. Near delay=0 there is a prominent peak that appears indicating that we are clearly resolving the desired nonlinear signal. This signal then decays quickly to the one pulse value. It is immediately evident that there is a strong dependence of the cooling rate on the applied magnetic field. In Figure 2 we extract a cooling time constant from an exponential fit to the original data and plot this as a function of the magnetic field. The data shows a prominent peak near B=9T and falls off rapidly by 5-10 times in either direction of this peak value.

This sample has a fairly low mobility and lacks a functioning gate, but shows clearly the functionality of the setup we built. This is promising for future experiments.

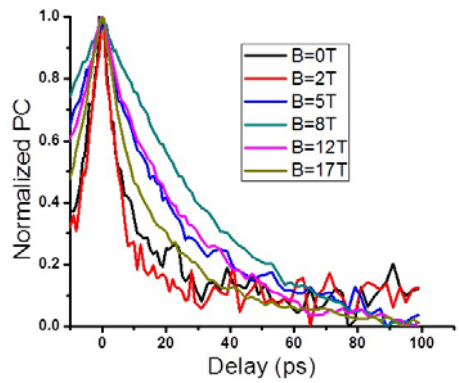

Figure 1: Normalized photocurrent as a function of 2-pulse delay for different magnetic fields.

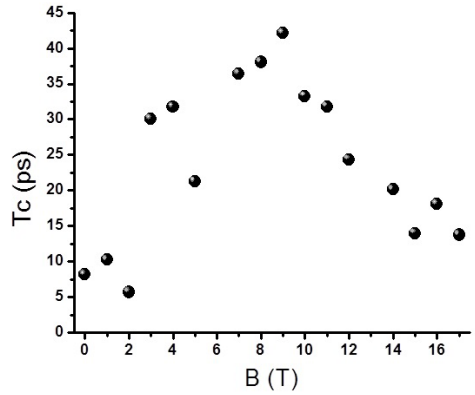

Figure 2: Hot carrier cooling time constant as a function of magnetic field.

Conclusions

The highly improved optical spectroscopy system will enable us to investigate hot-carrier cooling pathways with Landau levels in graphene. We will fabricate high mobility devices for our next visit and should be able to see the desire effect with enhanced clarity.

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