# Gate Controlled Magnetophonon Resonance in Graphene

J. M. Poumirol, J. Ludwig, D. Smirnov (NHMFL); K. Myhro, C.N. Lau (UC Riverside)

## Introduction

The magneto-phonon resonance (MPR) effect is observed in semiconductors when the optical phonon energy coincides with the separation of two Landau levels (LLs). In graphene, the MPR can be described as a resonant mixing of inter-LL excitations and zone-center $E_{2g}$ phonons into a combined mode, leading to a splitting proportional to the electron-phonon coupling [1,2]. As a result, the Raman G-peak is expected to exhibit a series of filling-factor-dependent, multi-component anti-crossing structures as a function of applied magnetic field. Recently, we performed a polarization-resolved high-field magneto-Raman spectroscopy study of ungated, chemically doped graphene and identified three distinct types of G peak magnetic- field dependencies, providing a comprehensive experimental evidence of the MPR effect in graphene [3].

## Results and Discussion

Here, we report a Raman spectroscopy study of MPR in gated single layer, demonstrating continuous tuning of the MPR lineshape by varying the carrier density [4]. Several NHMFL magnet systems have been used: 14.5T EMR magnet, 17.5T SCM3 and 18T SCM2 systems. Tuning the gate voltage from -70V to 70V at constant magnetic field, we observe the progressive development of the low-field anticrossing branch corresponding to the fundamental MPR with (-1,0) and (0,1) inter-LL transitions, expected at approximately 25-30T. As the Fermi energy crosses the n=0 LL, a complex $E_F$-dependent structure appears in the Raman spectra. This is because a higher (lower) occupancy of the n=0 LL reduces (enhances) the oscillator strength of the (0,1) transition due to the availability of filled and empty states in the involved LLs, whereas the same change in the electron density has the opposite effect on (-1,0) transition.

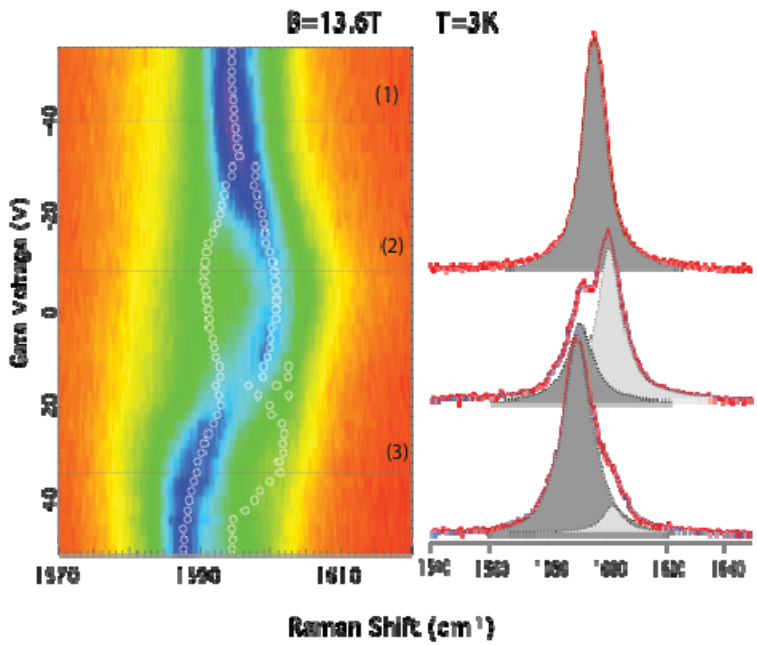


Fig. 1. (Left) Raman intensity map of measured as a function of gate voltage at 13.6T. (Right) Representative Raman scattering spectra taken at -40V, -10V, and 40V.

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