Raman and coherent phonon spectroscopy of nanotube and graphene

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Raman spectroscopy of single wall carbon nanotubes (SWNTs) and graphene has provided symmetry specific Raman spectra depending on laser energy and the Fermi energy [1,2]. In this talk, we overview our recent works on Raman and coherent phonon spectroscopy of carbon nanotubes and graphene. First, we report theoretical analysis of special Raman spectra which characterize the layer number and stacking order of few layers graphene. Especially, we show how to distinguish ABA and ABC stacking of a tri-layer graphene by Raman spectroscopy [3,4] in which weak Raman spectra at 1690-2150cm^{-1} are relevant to out-of-plane vibrations and thus sensitive the stacking order [5]. In order to assign Raman spectra to combination modes of two phonons, Raman measurement as a function of the Fermi energy is useful in which anomalous behavior of phonon frequency and its spectral width for double resonance Raman spectra was observed as a function of the gate voltage in electro-chemical doping [6]. Finally, we would like to discuss Raman spectra of carbon nanotube using C^{13} isotope in which the phonon spectral width is given as a function of C^{13} concentration, suggesting phonon localization due to the C^{13} isotope [7].

The second topic is coherent phonon (CP) spectroscopy. CP spectroscopy is an alternative way to measure the phonon frequencies, in which (1) ultra short pulse of pump laser light excites the photo-excited carriers, then (2) the photo-excited carriers excite phonons in a coherent way by electron-phonon interaction and (3) we measure the vibration of transmission of the probe light whose the Fourier transformation gives the CP spectra as a function of phonon energy. What is a significant point in CP spectroscopy is that we can directly measure the phase of vibration. According to experiment and calculation, radial breathing mode (RBM) of SWNTs starts either by expanding or shrinking diameter depending on *(n,m)* of a SWNT and the optical transition energy E_{ii} [8]. We investigate the tendency of the RBM phase for more than 20 SWNTs and E_{ii}'s. We found that the sign of electron-phonon interaction as a function of the wave vector on the 1D Brillouin zone is essential for determining the initial RBM phases [9]. We will discuss CP spectroscopy of graphene nanoribbon [10].

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