Third and Fourth Optical Transitions in Semiconducting Carbon Nanotubes

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We have studied the optical transition energies of single-wall carbon nanotubes over broad diameter (0.7 to 2.3 nm) and energy (1.26 to 2.71 eV) ranges, using their radial breathing mode Raman spectra. We establish the diameter and chiral angle dependence of the poorly studied third and fourth optical transitions in semiconducting tubes. Comparative analysis between the higher lying transitions and the first and second transitions show two different diameter scalings. Quantum mechanical calculations explain the result showing strongly bound excitons in the first and second transitions and a delocalized electron wave function in the third transition.