Strain dependence of photoluminescence of individual carbon nanotubes.

Pavel N. Nikolaev, Tonya K. Leeuw, Dmitri A. Tsyboulski, Sergei M. Bachilo, R. Bruce Weisman and Sivaram Arepalli

1. ERC Inc and NASA Johnson Space Center, Houston, TX.
2. Rice University, Houston, TX

We have investigated strain dependence of photoluminescence (PL) spectra of single wall carbon nanotubes (SWNT). Nanotubes were sparsely dispersed in a thin PMMA film applied to acrylic bar, and strained in both compression and extension by bending this bar in either direction in a homebuilt four-point bending rig. The average surface strain was measured with high accuracy by a resistive strain gage applied on top of the film. The near – infrared imaging and spectroscopy were performed on the inverted microscope equipped with high numerical aperture reflective objective lens and InGaAs CCD cameras. PL was excited with a diode laser at either 658, 730 or 785 nm, linearly polarized in the direction of the strain. We were able to measure (n,m) types and orientation of individual nanotubes with respect to strain direction and strain dependence of their PL maxima. It was found that PL peak shifts with respect to the values measured in SDS micelles are a sum of three components. First, a small environmental shift due to difference in the dielectric constant of the surrounding media, that is constant and independent of the nanotube type. Second, shift due to isotropic compression of the film during drying. Third, shifts produced by the uniaxial loading of the film in the experiment. Second and third shifts follow expression based on the first-order expansion of the TB hamiltonian. Their magnitude is proportional to the nanotube chiral angle and strain, and direction is determined by the nanotube quantum number. PL strain dependence measured for a number of various nanotube types allows to estimate TB carbon-carbon transfer integral.
Strain dependence of photoluminescence of individual carbon nanotubes.

Pavel N. Nikolaev1, Tonya K. Leeuw2, Dmitri A. Tsyboulski2, Sergei M. Bachilo2, R. Bruce Weisman2 and Sivaram Arepalli1
1. ERC Inc and NASA Johnson Space Center, Houston, TX. 2. Rice University, Houston, TX

PL observations on individual nanotubes.

Origin of the initial PL shifts

Measurements

PL maps of NT dispersions in H2O/SDBS and dry PMMA

Measurements for (8,4) SWNT

-50 100 200

Slope is 320 ± 24 cm⁻¹/%

PL shifts upon cooling from 293K to 16K

Theoretical prediction of the bandgap shift under strain:

Determining C-C transfer integral \( \tau_c \) from experiment

E11 (cm⁻¹)

\( \Delta E_{gap} = \sigma (l + 1) \frac{\nu}{1 + \nu(1 + \nu)} \cos(\theta) \sin(\theta) \)

E11 (cm⁻¹)

E11 FWHM (cm⁻¹)

E11 shift, eV

Inverted microscope

E11 shift, eV

Environmental shift, ~155 cm⁻¹.

Hysterisis indicates some slipping of SWNT in PMMA

-200 -100 -50 0 50 100 150 200

Percent strain

E11 FWHM (cm⁻¹)

Measurements for (11,3) SWNT.

E11 (cm⁻¹)

Environmental shift, ~155 cm⁻¹.

Experimental shift, ~155 cm⁻¹.

InGaAs320×256

InGaAs320×256

Strain direction

E11 (cm⁻¹)

Environmental shift, ~155 cm⁻¹.

InGaAs320×256

Spectral shift (cm⁻¹)

Environmental shift, ~155 cm⁻¹.

SLIPS vs. PMMA vs. PMMA solution in Xylene

Inverted microscope

E11 shift, eV

Increase in the linewidth also indicates that only part of it is slipping.

Environmental shift, ~155 cm⁻¹.

Environmental shift, ~155 cm⁻¹.

Environmental shift, ~155 cm⁻¹.

Environmental shift, ~155 cm⁻¹.

Environmental shift, ~155 cm⁻¹.

Environmental shift, ~155 cm⁻¹.