Probing lattice temperature in current-driven carbon nanotube fibers by Raman spectroscopy

Damien Tristant[1,2], Ahmed Zubair[3], Dmitri E. Tsentalovich[4], Colin C. Young[4], Pascal Puech[2], Iann Gerber[1], Matteo Pasquali[4,5,6], Robert J. Headrick[4,5,6], Junichiro Kono[3,6,7], Jean Leotin[8]

[1]LPCNO-INSA, Université de Toulouse, Toulouse, France
[2]CEMES-CNRS, UPR 8011, Université de Toulouse, Toulouse, France
[3]Department of Electrical and Computer Engineering, Rice University, Houston, Texas, USA
[4]Department of Chemical and Biomolecular Engineering, Rice University, Houston, Texas, USA
[5]Department of Chemistry, Rice University, Houston, Texas, USA
[6]Department of Materials Science and NanoEngineering, Rice University, Houston, Texas, USA
[7]Department of Physics and Astronomy, Rice University, Houston, Texas, USA
[8]LNCMI-CNRS, UPR 3228, Université de Toulouse, Toulouse, France

tristant@insa-toulouse.fr

Abstract

Recently, an effective method has been developed for fabricating carbon nanotube (CNT) fibers with ultrahigh conductivities and current carrying capacities [1,2]. These fibers have high potential in a variety of high-power and high-current electrical applications as they have electrical conductivities close to that of copper. Under high currents, complex situations arise in these fibers, where driven electrons heat the lattice by producing non-equilibrium phonons in a time- and space-dependent manner. Quantitatively understanding such situations is crucial for optimum heat management for desired applications.

Here, we use Raman spectroscopy to quantitatively determine the temperature and doping level of these CNT fibers in the presence of a high current [3]. At low frequencies, we observe radial breathing modes (RBMs), which provide information on the diameters of nanotubes in resonance. Combining the diameter and the excitation energy allows us to determine their type (metallic or semiconductor) through the Kataura plot. At high frequencies, by measuring accurately the position of the G-band as a function of current and temperature, we deduce the temperature of the lattice for both doped and undoped fibers as well as the doping level of the doped fiber.

We thus estimate the temperature of the lattice from the G-band shifts versus applied current and temperature. From these data we extracted a value of 2000°C/A as the current coefficient of heating for an undoped fiber with a diameter of 20.4 µm with temperature increases below 200 K. The variation of the Stokes and Anti-Stokes intensities of different modes (inner RBMs, outer RBMs, G) with current at various exciting wavelengths is fully consistent with homogeneous heating.

Moreover, by analyzing in detail a Raman spectrum for doped fibers versus undoped fibers, we estimated the Fermi level shift, ΔE_F, to be about 0.7 eV. This shift modifies the behavior of the outer tube, activating new conduction channels. Our estimation of the ratio of conduction channels between doped and undoped fibers is about 4, consistent with the value of 4 reported in Ref. [2] when the fiber switches from a doped to undoped state.

References

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