VOLTAGE AND LENGTH-DEPENDENT PHASE DIAGRAM OF THE ELECTRONIC TRANSPORT IN CARBON NANOTUBES

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The electronic transport in carbon nanotubes was the topic of a large number of research works during the last decade. The first studies about the most elemental properties of these fascinating conductors focused on the defect-free nanotubes, however these studies covered only 10% of the measured samples. The reason for that was the not-optimum quality of the nanotubes obtained until then. But, thanks to the development of the CVD (chemical vapour deposition) technique for carbon nanotubes growing on insulator surfaces, it became possible to study defect-free nanotubes.

The electrical resistance of a carbon nanotube, and of any molecular wire, is a consequence of two different contributions:

- the elastic scattering produced by the structural defects/disorder.
- the inelastic scattering produced by the electron-phonon interaction.

In order to address the contribution of the two mechanisms we have done a comparative study of the electronic transport properties of two kind of single wall carbon nanotubes (SWCNTs):

1. the ones grown by arc discharge using HiPco Technique, CVD growth in volume (which contains a certain concentration of defects).
2. the ones grown directly on surface by CVD (with a low concentration of defects).

The electrical characterization of the nanotubes has been done by means of a Conductive Atomic Force Microscope. In this AFM the tip is covered by a metal (AuPd) that is also used as a mobile electrode. This technique allows us to measure the room temperature differential resistance of the nanotubes versus the SWCNT-length (R(L)) [1].

At low bias our data for the first kind of SWCNTs show an exponential dependence of R(L) indicating that the system is in the strong Anderson localization regime (due to the elastic scattering with defects) [2], while for the second kind of SWCNTs, the data reveal a linear dependence of R(L) which corresponds to a quasiballistic regime [3] (due to the low concentration of defects). We can conclude that the electric transport at low bias is governed by the elastic scattering with the structural defects in the nanotube.

As the bias increases the role of the phonons in the electronic transport become more important [4]. At high bias the R(L) for both kind of nanotubes presents a linear behaviour until lengths of 1 μm. Beyond that length, we have no experimental data for HiPco nanotubes (they are too short), but for the CVD-on-surface nanotubes our data show an surprising behaviour: at 1 μm the R(L) first saturates and then even decreases. The acoustic and optical phonons are responsible for that behaviour. At high bias, at short SWCNT-lengths the SWCNT resistance is controlled by the number of optical phonons excited by one electron, while at long lengths, electron scattering with acoustic phonons controls the resistance.

We also present MonteCarlo numerical simulations for the one-dimensional Boltzmann's equation, describing how the electrons propagate along the tube and how they interact with acoustic and optical phonons. Our theoretical results show a remarkable agreement with the experimental differential resistance allowing us to give a detailed description of the electron distribution function and the chemical potential along the nanotube.

Finally, we present experimental results on the transition from Anderson localization at low bias to high diffusive regime at high bias in defected SWCNTs. This result is combined with those of defect-free SWCNTs to present a general landscape of the electronic transport in carbon nanotubes.

References:

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Figures:

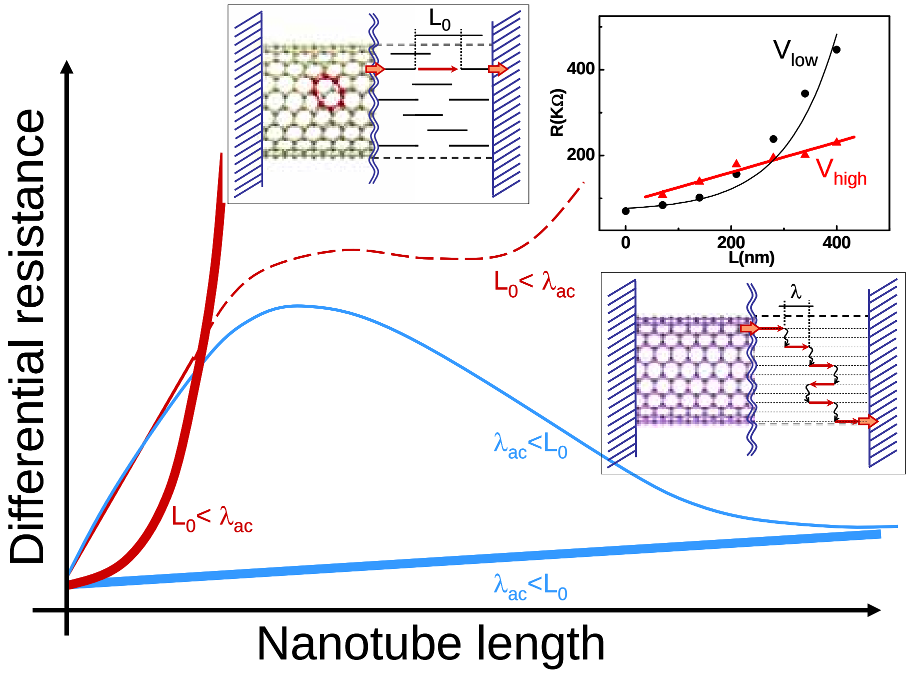

Figure 1. This figure summarizes the different electron transport regimes for SWCNTs with and without defects as a function of the bias voltage and length. The thick lines apply to the low bias voltage. The thin lines apply for the high bias voltage. The blue curves are for defect-free SWCNTs (lower inset) and the red ones for defected SWCNTs (upper left inset). The upper right inset shows experimental R(L) at low and high bias voltages for a defected SWCNT.