Novel SWCNT hybrids with tailored properties combining different doping methods

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In modern world single-walled carbon nanotubes are an object of constant interest. Due to their unique properties. They are one of the very few materials that can show both metallic and semiconducting types of conductivity depending on their structure. One can find many applications for SWCNTs in various fields such as nanoelectronics, solar cells, sensors, batteries etc. However to use such a promising material as SWCNT one should have a full control on its properties.

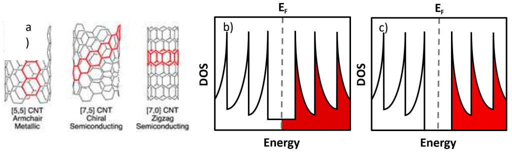


Figure 1. a) Different types of single-walled carbon nanotubes and their types of conductivity; b) density of states for metallic SWCNTs; c) density of states for semiconducting SWCNTs

One can divide nanotubes modification in four large groups, shown on the picture above. Modification of the SWCNTs has been a hot topic since their discovery. Numerous attempts were made to control their electronic and physical properties through different ways of modification. The number of methods is calculated in tens, depending on requirements.
Our research is mainly focused on electrochemistry of fullerene filled metallicity sorted nanotubes (c and d on Figure.2) with further conversion to double-walled nanotubes and carbon chains inside DWCNT.

One of the main novelties of this work is the use of ionic liquid as an electrolyte for electrochemical gating. This substance can be described as room temperature melt of a salt. The main advantage of such electrolyte is the decrease of electrochemical reactions almost to zero as compared to classic electrolytes. Furthermore the charge is going to be applied indirectly to a sample of carbon nanotubes.

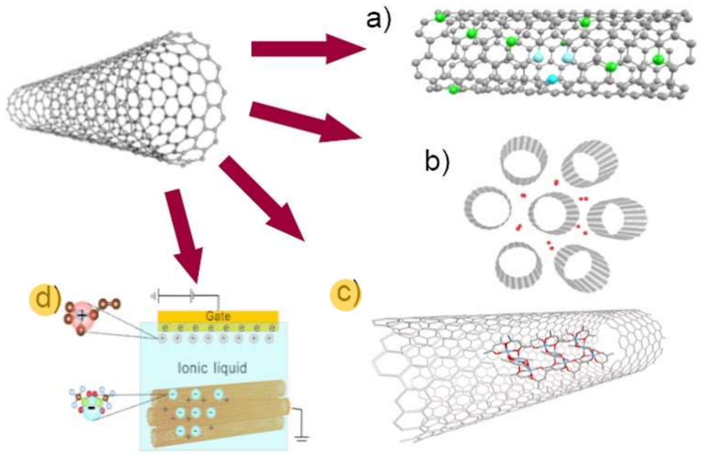
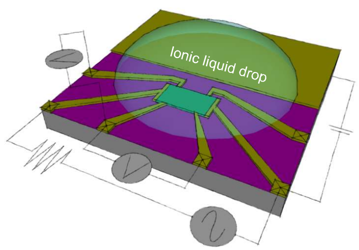


Figure 2. Different approaches of SWCNT modification: a) substitution of carbon atoms; b) intercalation of different substances in the void between nanotubes in the bundle; c) filling of the nanotube channel (e.g. organometallics); d) electrochemical doping.

m-/s-SWCNT	C_{60}@*m-/s*-SWCNT	DWCNT	CC@SWCNT

The whole synthetic process is described on the table above. To study the changes in electronic structure of modified nanotubes we will use a combination of SWCNT doping methods such as filling and ionic liquid gating. High purity metallicity sorted SWCNTs (99,5%) will be studied using electrochemical charging with *in-situ* Raman spectroscopy and Optical absorption spectroscopy. In the end it is planned to use X-ray photoelectron spectroscopy with *in-situ* ionic liquid gating.



Electrochemical setup for ionic liquid gating. A thin film of carbon nanotubes (~100nm) or modified carbon nanotubes is deposited on Si/sapphire surface with further gold contact deposition. Ionic liquid, a superior electrolyte, is deposited as a droplet on top of the cell.

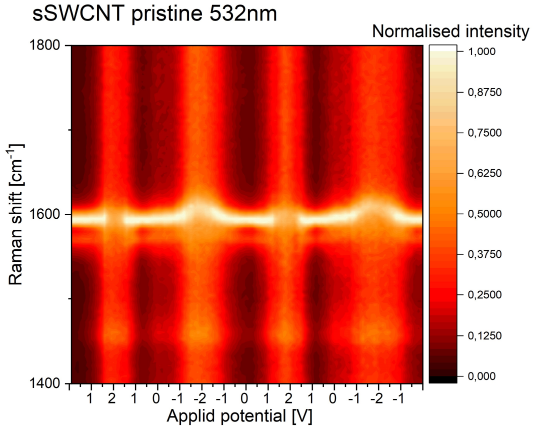


Figure 3. Raman map of pristine s-SWCNT ionic liquid gating.

One can observe directly how does the electronic properties of SWCNTs and modified nanotubes changes upon ionic liquid gating via Raman spectroscopy. From Figure 3 it is obvious that the highest changes occur at around -2V of applied potential. The G-line, located at ~1590 cm^{-1} and responsible for latitudal and tangential vibrations of carbon nanotube, almost dissolves. Which corresponds to a high charge transfer. The G-line returns to its normal position and intensity when the charge is removed. Not only the applied charge changes the vibrational bands of carbon nanotubes, but also filling with fullerenes with further conversion to double-walled carbon nanotubes . In Figure 4 one an observe a more accurate representation of what happens to the G-line of SWCNT, C_{60}@SWCNT and DWCNT at 0V applied potential, and ±2V.

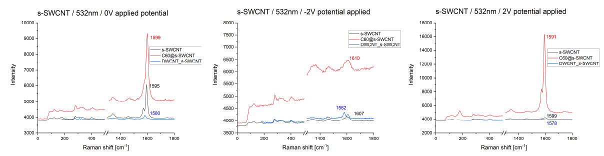


Figure 4. RBM region and G-line of SWCNTs and their modifications upon ionic liquid gating