GAS SENSING WITH CARBON NANOTUBES: EFFECTS OF CONTAMINANTS and ENVIRONMENTAL MONITORING

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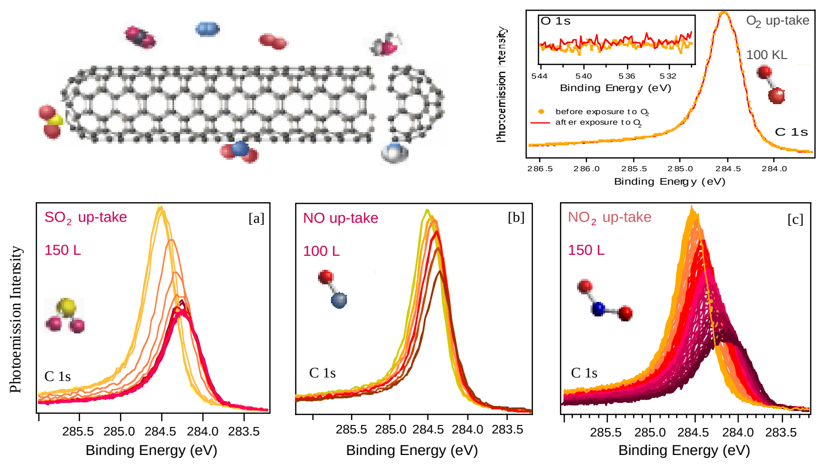
The recent experimental [1] and theoretical [2] indication that the transport and electronic properties of single-walled carbon nanotubes (SWCNTs) might severely change upon exposure to gas such as O_2, NO_2 and NH_3, has important consequences in practical applications. From one side this could bring to the development of better gas sensors (nano-nose), but on the other side it suggests that the performances of novel nanotube-based electronic devices may be dependent on the atmospheric environment. The gas molecules could affect directly the SWCNT properties *via* physisorption (interaction through van der Waals forces) or chemisorption (formation of chemical bonds). They could also indirectly affect the SWCNT properties by interacting with already present donors and/or acceptor centers due to contaminants bonded to the nanotube.

Using photoemission spectroscopy we show that the presence of contaminants in purified SWCNT bundles, mainly chemical residues of the purification, dispersion and filtration processes, is responsible for a strong sensitivity to oxygen. After complete removal of these contaminants the core level spectra of SWCNTs are insensitive to O_2, CO, H_2O and N_2, while a strong sensitivity to NH_3, NO, NO_2 and SO_2 is observed. Our experimental results confirm that SWCNTs could find use as powerful chemical gas sensors capable of measuring environmentally significant levels of toxic gases, but likewise indicate that many supposedly intrinsic properties measured on as-prepared or mildly annealed in vacuum purified nanotubes may be severely compromised by the presence of catalyst particles and contaminants coming from the purification procedure. In particular, we observe that gas molecules present in air (e.g. O_2, H_2O and N_2) interact weakly with clean SWCNT bundles, through dispersion forces only and not by the formation of chemical bonds. The electronic structure, as reflected in the photoemission spectra, (and likely the transport properties) of clean SWCNTs at 150 K is not influenced by the exposure to these molecules. This conclusion, for instance, is very important for future applications of SWCNTs in electronics since it suggests that the performances of nanotube-based devices should not be influenced by the air exposure. On the other hand, the data reported here also demonstrate a strong catalytic activity of purified SWCNTs to remove/trap nitrogen and sulfur oxide species. This is extremely important in environmental pollution catalysis since the NOx and SOx species released into the atmosphere are responsible for the acid rain that corrodes monuments and kills vegetables.

Finally, we will show two examples of selective growth of oriented single-walled and multi-walled carbon nanotubes without catalyst particles, that may be exploited for the construction of sensing devices.

[1] P.G. Collins *et al.*, *Science* **287**, 1801 (2000); J. Kong *et al.*, *Science* **287**, 622 (2000); X.P. Tang *et al.*, *Science* **288**, 492 (2000); G.U. Sumanasekera *et al.*, Phys. Rev. Lett. **85**, 1096 (2000).
[2] S.-H. Jhi, S.G. Louie and M.L. Cohen, Phys. Rev. Lett. **85**, 1710 (2000); Z. Zhu et al., Phys. Rev. Lett. 85, 2757 (2000); S. Peng and K. Cho, Nanothecnology **11**, 57 (2000); H. Chang et *al.*, Appl. Phys. Lett. **79**, 3863 (2001); J. Zhao et *al.*, Nanothecnology **13**, 195 (2002); D.C. Sorescu, K.D. Jordan and P. Avouris, J. Phys. Chem. B **105**, 11227 (2001).


O 1s
544 540 536 532
Binding Energy (eV)
O_2 up-take
100 KL
before exposure to O_2
after exposure to O_2
Photoemission Intensity
C 1s
286.5 286.0 285.5 285.0 284.5 284.0
Binding Energy (eV)
SO_2 up-take
150 L
[a]
C 1s
NO up-take
100 L
[b]
C 1s
NO_2 up-take
150 L
[c]
C 1s
Photoemission Intensity
285.5 285.0 284.5 284.0 283.5
Binding Energy (eV)