

## Functionalization of carbon nanotubes investigated by spatial-resolved EELS

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Functionalized carbon nanotubes (C-NT) have a huge interest due to their very promising optoelectronic properties [1-2]. However, local (sub-nanometer/atomic level) studies are still challenging. In particular, chemical detailed analyses of these hybrid systems are lacking, even if they are crucial for improving the understanding of such materials. Spatially-resolved EELS is a very powerful technique for providing rich information at the local scale on complex hybrid nanostructures [1-6]. In this contribution, we will present a detailed and direct investigation at the atomic level, of non-covalent functionalized ( $\pi$ -stacked and endohedral) single-walled (SW) C-NTs.

Fig. 1 shows some of these results, in particular the case of endohedral functionalization: iron-phthalocyanine (Fe-Pc) moieties in C-SWNTs. Fig. 1(a) corresponds to an atomic-sketch showing the supramolecular order of the Fe-Pc within a SWNT and in inset of Fig. 1(e), an atomic-sketch of one of these Fe-Pc molecules is displayed (a Fe atom is surrounded by 4 pyrrolic-like subunits). The HRTEM image of Fig. 1(b) displays one of these individual filled C-SWNTs. These NTs tend to be organized in bundles. Fig. 1(c)&(d), which correspond to of STEM (BF and HAADF) micrographs, show one these bundles of C-SWNTs. A 24x12 EELS spectrum-image (SPIM) has been recorded, under cryo conditions (-170C), in the green marked area on one of these NT. (e) EEL spectra extracted from the squared regions marked in Fig. 1(d). They correspond to four EEL spectra each of them. C-K, N-K and Fe-L<sub>2,3</sub> edges are clearly seen. From these spectra, nitrogen and iron elemental maps can be obtained, see Fig. 1(f). These studies confirm the supramolecular organization of the organic moieties [6]. In summary, these works provide very rich information about these hybrid and complex nanomaterials, opening fascinating perspectives for optoelectronic applications of such nanosystems.

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[7] This work was supported by the MINECO (MAT2016-70776-P) and the EU (G. A. 642742 & 696656).

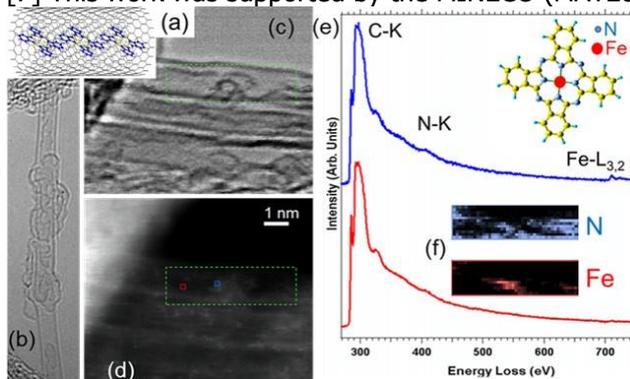


Figure 1. (a) Atomic-sketch showing the supramolecular order of the iron-phthalocyanine (Fe-Pc) moieties within a SW-NT. (b) HRTEM micrograph of a filled SWNT. (c)-(d) BF- and HAADF-STEM images of a bundle of filled SWNT. A SPIM-EELS has been recorded in the green marked area. (e) EEL spectra extracted from the squared regions marked in Fig. 1(d). They correspond to 4 EEL spectra each of them. C-K, N-K and Fe-L<sub>2,3</sub> edges are clearly seen. (f) N and Fe elemental maps. Inset, atomic-sketch of a Fe-Pc. [6]