Individual atom spectroscopy: challenges, reality and perspectives

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This talk focuses on challenges and recent results in STEM-EELS spectro-microscopy of single atoms. The quest to capture the signature of an individual atom under an electron beam started with the pioneering work of Crewe et al. [1] who showed as early as 1970 the first images of heavy atoms moving on thin amorphous carbon foils. Thanks to many instrumental developments (C_s corrector focusing lens delivering atomic resolution at lower primary voltages, EELS and EDX detector improvements,...), the latest generation of STEM microscopes now offers the ability to track in a spectrum-image mode, several signals generated simultaneously by individual atoms [2,3,4].

A number of practical situations, ranging from "test" cases to material science issues, are discussed to illustrate the present reality in individual atom spectroscopy. For these studies, a Nion UltraSTEM microscope (USTEM200) equipped with a C_s corrector and with a home-made fast EELS detector, has been used. In the first case, the recording of characteristic EELS signals from heavy (Tb, Th) atoms in rapid motion on a thin carbon layer is demonstrated. The second one addresses the challenge of identifying the electronic structure of highly beam-sensitive point defects in nitrogen-doped, single-walled carbon nanotubes (Fig 1 [5]), which imposes a compromise between time acquisition and detection limit. Finally, the position of Sm interstitial/substitutional dopants in ceria nanoparticles (Fig 2 [6]) is determined, together with their valence changes in accordance with the variation of the ferromagnetic properties measured as a function of the nominal doping level.

This contribution emphasizes the possibilities currently offered by a tiny electron probe and a suitable efficient detector strategy. However there is still plenty of room for future developments on the instrumental and methodological fronts, as well as for the broadening of the application fields. A few of them (monochromators, time-resolved and/or *in situ* measurements) will briefly be discussed.

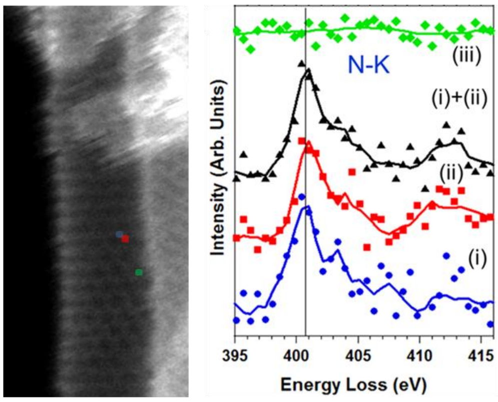

Fig. 1 HAADF image of a single-walled carbon nanotube with a single subsitutional nitrogen identified by EELS [5].

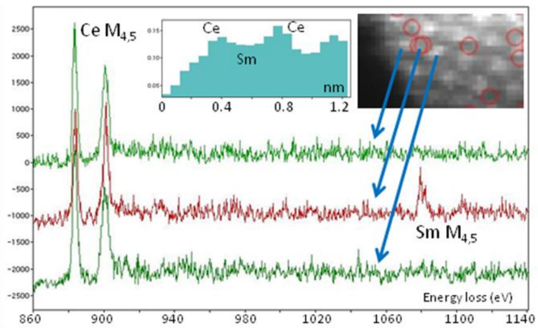

Fig. 2 STEM-EELS spectra (3ms/spectrum, 0.06 nm/pixel) on Sm doped CeO_2 nanoparticles (3%) at the top of two Ce columns and at the position in-between [6].

References

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