XVII School on Synchrotron Radiation
"Gilberto Vlaic":
Fundamentals, Methods and Applications
Muggia (Trieste), Italy / 16-26 September 2024

Watching nanomaterials with X-ray eyes: from nanoparticles to real devices

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Nowadays several novel nanomaterials, obtained by physical or by chemical synthesis routes, are attracting the attention of researchers. These nanoscale materials show distinct and tunable properties (electronic, magnetic, catalytic, etc.) with respect to the corresponding bulk, allowing for additional degrees of freedom to improve the desired applications [1]. Moreover, even more exciting possibilities are offered by the integration of different low-dimensional systems to obtain hierarchical nanostructures.
These complex systems represent a challenge for the characterization, requiring structural and morphological studies across multiple length scales, from the building blocks to the whole architecture. This contribution will show how X-ray-based techniques can significantly help to solve these issues, providing crucial information to improve material engineering at the nanoscale. In particular, on the one hand, X-ray diffraction/scattering techniques allow investigating the structure of complex nanosystems at different levels from atomic to mesoscale [2]. On the other hand, X-ray spectroscopies (both in absorption and in emission) provide insights on the electronic levels and on the local atomic environment, coupling chemical selectivity and high resolution at the short distance scale. These peculiar features of X-ray spectroscopies are extremely useful in the characterization of nanomaterials which may be made up of a very low number of atoms, often embedded in a hosting matrix, which can dominate the response of any non-atomic selective characterization technique [3]. The complementary of the two approaches will be discussed through different examples at increasing levels of material complexity, from size and shape analysis of single nanoparticles for green energy applications to real devices [4]. The importance of *in situ* studies to understand the dynamic behavior of nanomaterials under working conditions will be also highlighted [5].

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