Challenges for exploring dynamic/transient behaviour of complex nano-objects and new opportunities opened by ultra-bright hard x-rays

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The specific advantages of ultrabright hard x-rays, low absorption, atomic resolution and extended *Q*-range are ideally suited for monitoring at atomic level spatiotemporal changes of complex materials in their native environments. They open new opportunities for dynamic spectroscopic and structural characterization with nanometric spatial resolution by complementing time scales from ps to min, using the last generation synchrotron sources, with snap shots on a time scale that is only limited by the fs pulse length of Free Electron Lasers.

Using exemplary systems the talk will address some selected topics that are still a scientific and technical challenge. It will be focused on dynamic behaviour of nano-objects in response to the chemical ambient, temperature, electric fields and radiation. The size and morphology effects on the physicochemical properties, e.g. melting temperature, thermal conductivity, thermal expansion, intercalation and transport phenomena, magnetic and electronic properties etc of inorganic (metal, metal compound) nanoparticles (NPs) and in particular embedded and core-shell NPs are still far from being understood, controlled and predicted. Size-controlled intercalation mechanisms in NP-based electrodes in batteries and fuel cells compared to macroscopic materials, the related dynamic changes in electronic and atomic structure and the modifications by encapsulation in core material are key issues to be addressed. The relation between photo-induced structural phase transitions and those due to thermal excitation, as well as the correlation between the atomic-magnetic-electronic structure, are another hot topics to be explored. For example, an important breakthrough result will be detecting differences between the temporal evolution after pumping with x-rays (using FEL pulse also as a pump-source) below and above K (L)-edge, selectively exciting electron levels of the core or shell matter of the NPs. The deposited energy will result in electron emission followed by specific de-excitation emission, and using different pump pulse fluences and wavelengths will open opportunities for monitoring new exotic transient states.

To follow the evolution of NPs exposed to different environments requires monitoring the changes in dimensions, morphology, lateral distribution, geometric and electronic structure of elemental constituents at ps (diffusion) to ms scales, whereas for exploring photo-induced transient states (structural, electronic, magnetic etc) the time-scales become shorter than a ps. Among the best relevant experimental methods are the hard x-ray cross correlation techniques, such as nano-XRD, dispersive nano-XAS, X-ray scattering and coherent diffraction imaging with sufficient temporal resolution and signal-to-noise ratio. Probing fast dynamic processes as a function of delay between an optical or x-ray pump and x-ray probe pulse by resonant CDI will shed light on transient states differentiating the evolution of different parts of the particles and correlating them with local dimensions and composition.