X-ray imaging and tomography: recent advances and challenges

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1. INTRODUCTION

State of the art X-ray imaging and tomography techniques provide access to the study of heterogeneous, complex systems with high elemental and structural sensitivity in a non-invasive way. During recent years the significant progress of instrumentation (focusing optics, sample positioning, sample cooling, and detector technology) and X-ray imaging methodologies (e.g. coherent imaging, reconstruction softwares) are triggering experimental approaches with deca-nanometer spatial resolution. The current state of the art of X-ray computer tomography (CT) transforms it from a qualitative diagnostic tool to a quantitative one [1]. Trace metals play important roles both in biology (e.g. normal and in disease-causing biological functions) and in material sciences (e.g. dopants, impurities and their effects on material properties and device functioning). Scanning X-ray fluorescence microscopy reveals trace elements with improved sensitivity relative to electron probes, while crucial additional information can be obtained about the density, chemical state, and the crystalline structure of the sample by collecting various complementary x-ray signals emerging from the sample [2].

The large penetration depth of hard X-rays makes the study of tissue sections, whole cells, layered/buried structures possible within several tens of µm thick samples also in *in situ* and *in operando* conditions. Complex sample environments (temperature, pressure, controlled atmosphere/vacuum, chemical environment) are possible to implement. One of the important issues in modern X-ray microscopy development is the combination of high resolution with imaging in three dimensions, since the 3D nanostructure of a specimen has basic influence on its biological, chemical and physical properties.

This presentation aims to provide a brief overview of the recent advances and challenges of X-ray imaging techniques through some recent examples from the fields of biology and materials sciences. For example, cutting-edge quantitative elemental imaging determining local trace metal changes in subcellular compartments of single cells may open the way towards trace metal studies throughout entire biological processes [3]. In material science investigations, the combination of high resolution imaging and chemical fingerprinting, offered by X-ray absorption techniques, can be used for *in operando* studies to reveal complex heterogeneous chemical processes at different length-scales e.g. [4]. By the combination of complementary techniques, simultaneous information can be obtained on the crystalline structure, stress and strain, electrical and optical properties of the studied samples, devices, or nano-structures [5].

2. OUTLOOK

The development of state of the art X-ray microscopy techniques opens a way towards non-invasive sample characterization at deca-nanometer spatial resolutions with high elemental and chemical sensitivity also in three dimensions. Moreover, a strong need is evolving for the combination of more than one technique in order to exploit their complementarities e.g. for combining high spatial resolution (e.g. by TEM, SEM, scanning probe microscopes) with high elemental sensitivity (by X-ray Fluorescence microscopy). Such synergy of multiple microscopes together with the development of new approaches to their combined applications [6], allows obtaining more complete picture about nanoscale sample regions. This then permits to link structure, composition, and chemical characteristics to specific biological entities or functions, or to the electrical and/or optical properties of materials and devices.

An emerging challenge of X-ray microscopies is to perform statistically meaningful investigations in order to make meaningful conclusions on the effect of nano-sized characteristics on that of the bulk sample bridging the gap between nano-characteristics and bulk properties, functionalities, and processes. Consequently, structural and compositional characterization at various hierarchical length scales from cm-size down to the nanoscale is of fundamental interest [7,8]. High flux to be provided by diffraction limited synchrotron sources and the related high intensity nano-beamlines will contribute to this in a significant way [9].

Handling, combination, and interpretation of large volumes of data (big data) originating from fast, multimodal, and "multi-microscopy" measurements is a real challenge where on-line data visualization and fast data pre-treatment is becoming crucial for the success of an experiment. The utilization of multivariate data analysis is becoming more and more demanded for the interpretation of such data-sets.

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