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Correlative, Multi-scale, Lab-based X-ray Tomography: From Millimeters to Nanometers

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X-ray Computed Tomography has proven to be a crucial method to properly characterize and understand a huge variety of materials applications. Due to the non-destructive 3D imaging capabilities, this imaging methodology provides unique insight into material properties with comparatively minimal sample processing. One limitation however has been resolution capabilities. Previously, X-ray tomography imaging has utilized the principle of geometric magnification to obtain resolution. This has several limitations, the main impact being the realistic resolution achievable. Recently, the application of using a photon-converting scintillator and objective lenses has enabled much higher resolution imaging [1]. A unique ability of this system architecture is to enable non-destructive, multi-length scale visualization; with an imaging field of view range from tens of millimeters down to tens of micrometers, and resolution capabilities reaching 500 nm in instruments such as the ZEISS Xradia Versa, see Figure 1. Alternatively, another X-ray imaging method is to use X-ray lenses such as Fresnel Zone Plates that can achieve resolutions down to 50 nm and less, utilizing a quasi-monochromatic lab-based X-ray source in instruments such as the ZEISS Xradia Ultra. This system also employs an inline phase ring that enables Zernike phase contrast imaging which can greatly improve imaging contrast [2].

Due to the restrictions of lab-based equipment, each imaging solution requires its own imaging system. Often, this results in non-correlative imaging workflows – where a similar but different sample or region is imaged in each system to the maximum system resolution capabilities. This poses a number of inherent limitations in obtaining the full understanding of the sample in question: What does the sample look like as a whole and how representative is this region to another? Are there microscale properties that correlate to macroscale features? Additionally, knowing the exact resolution limit required to properly characterize a sample is an important question that can be difficult to answer without observing enhanced resolution of the exact same feature. Combining systems that can achieve different resolutions in a correlative workflow of the same sample also allows for advanced analysis, such as applying properties obtained from high resolution imaging to a large volume obtained from lower resolution imaging. For example, intra- and inter-particle porosity that is not resolved could inherently change simulation results without proper characterization [3].

We present here results combining two X-ray tomography systems, the Zeiss Xradia Versa and Zeiss Xradia Ultra instruments, into a correlative, multi-length scale analysis workflow through the use of specifically designed hardware and software tools. We demonstrate several applications using this combined approach to enable non-destructive, massively multiscale 3D imaging with minimal sample preparation. Specific examples ranging from biological science to material science are discussed.

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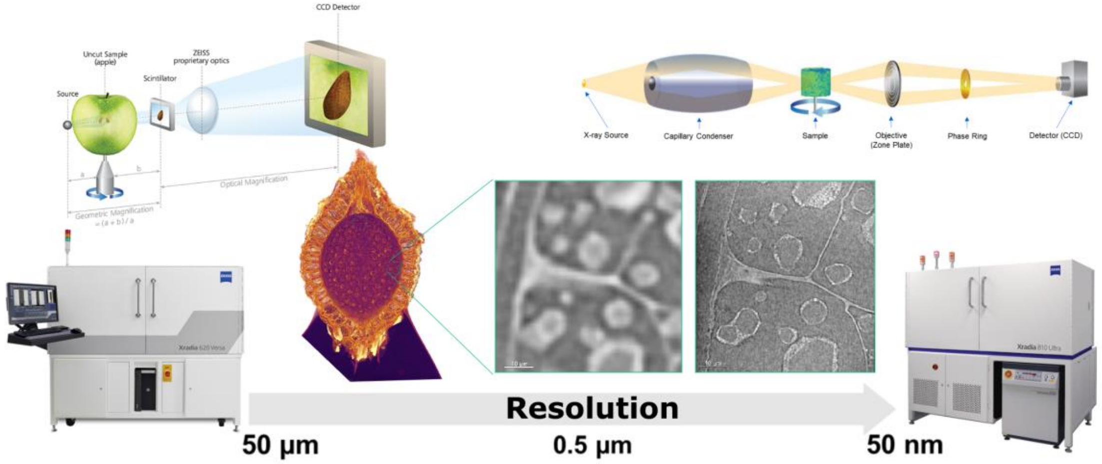

Figure 1. Optics and resolution capabilities of each system used in this demonstrated correlative workflow. Cyclanthus bipartitus seed virtually cross-sectioned and visualized at 1.3 µm / pixel using the Zeiss Xradia Versa. The exact same sample and location is imaged with 64 nm / pixel using the Zeiss Xradia Ultra. Visualization performed using Dragonfly Pro software.

References

1. ZEISS Xradia Versa Product Information. https://www.zeiss.com/microscopy/us/products/x-ray-microscopy/zeiss-xradia-610-and-620-versa.html, accessed 23 January, 2020

2. Holzner, C., Feser, M., Vogt, S., Hornberger, B., Baines, S. B., & Jacobsen, C. (2010). Zernike phase contrast in scanning microscopy with X-rays. *Nature Physics*, *6*(11), 883–887

3. Usseglio-viretta, F.L.E., Smith, K (2017) Quantitative Microstructure Characterization of a NMC Electrode. *ECS Transactions*, 77(11), 1095-1118