Rapid, non Destructive, muti-length scale characterization of biomaterials with novel micro and nano-CTs

S H Lau[1], Andrei Tkachuk[1], Fred Druewer[1], Hauyee Chang[1], Michael Feser[1], Wenbing Yun[1], Sunita Ho[2], Andrew Peele[3]
[1]Xradia Inc, Concord, CA, [2]Department of Preventive and Restorative Dental Sciences, UCSF; [3] Department of Physics, La Trobe University, Australia

Statement of Purpose: One of the current challenges in characterizing biomaterials using conventional imaging tools such as optical microscopy and electron microscopy is that tedious sample preparation is required in order to visualize their internal 3D arrays and structures. Sample preparation can be difficult and can introduce artifacts , especially when these materials are hard, brittle, soft, moist or elastic. Optical and confocal microscopy suffers from diffraction limits due to the wavelength of visible light. Spatial resolution is generally no better than 200 nm in the best case. To obtain higher imaging resolution, scanning or transmission electron microscopy (SEM or TEM) is employed. Electron microscopy can achieve spatial resolution in the nm with lengthscale on the order of angstroms, however, sample preparation for these techniques can be very elaborate, including the need to be compatible with high vacuum and be electrically conductive . We describe a series of novel micro and nano x-ray computer tomography (CT) systems for rapid non destructive multi-length scale characterization of internal structures of biomaterials, from mm to sub 30 nm spatial resolution.

Methods: Computer tomography (CT) has been used for several years in the medical community for non invasive x-ray imaging of the human anatomy. While conventional microCTs are used for a number of bio-medical, material, industrial research and microelectronic pcb and package inspections, the reported spatial resolution typically ranges from several microns to tens of microns [1], which are insufficient to observe feature of interest in biomaterials smaller than a few microns.

Contrast in transmission x-ray imaging is predominantly based on absorption differences or attenuation length differences of material, within the sample. As biomaterials are often in a matrix of mostly low Z materials, attenuation length differences between materials can be very small, resulting in little or no contrast in the image.

We describe a series of novel CTs capable of rapidly characterizing buried 3D features non destructively, down to sub micron (Xradia's MicroXCT) or sub 30 nm with the Xradia's nanoXCT. The key to this technology lies in proprietary x-ray optics, including Fresnel Zone plates and high resolution detectors fabricated by Xradia. High contrast is obtained even for low Z biological cells, tissue, bio-composites, polymers or high Z medical implants and electronic components.

Results/Discussion:
Figure 1 and 2 show a rat molar tooth in 3D and a high resolution CT slice showing ligaments within the periodontal ligament space. When the root dentin structure is imaged with the nanoXCT using Zenike phase contrast mode at sub 60 nm, additional details not apparent with normal absorption x-ray imaging can be seen.. Agarose beads, a low Z material derived from seaweeds, is imaged at 1 micron resolution (Figure 5) while Figure 6 show the texture of the polymer/drug coating on a heart stent .

Figure 1: 3D Rendered Image of Rat Molar: MicroXCT

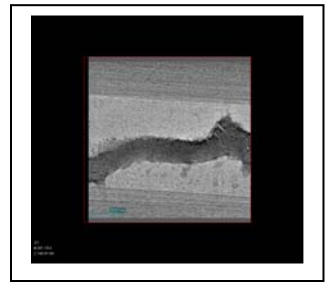

Figure 2: CT slice at high resolution showing ligaments in periodontal ligament space: MicroXCT

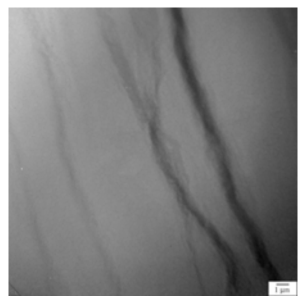

Figure 3: CT slice of ultra high resolution of Dentin, at 60 nm resolution, Absorption contrast: nanoXCT

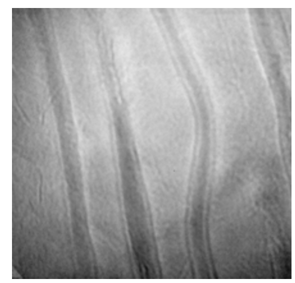

Figure 4: Zenike phase contrast at 60 nm, showing additional fine fine features : nanoXCT

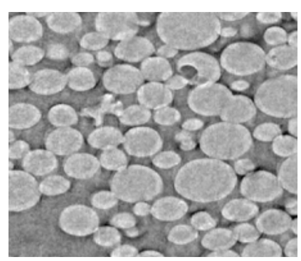

Figure 5: CT slice of Agarose, a low Z polysaccharide at 1 um resolution, MicroXCT

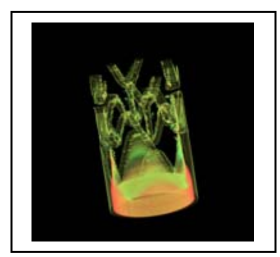

Figure 6: Heart stent with drug coating: MicroXCT

Conclusions: Rapid and non invasive characterization of a variety of biomaterials can be characterized at multilength scales down to sub-30 nm and at high contrast with such novel 3D x-ray tomography systems.

References: [1] Bentz, D.P, et al., 2000: Microstructure and transport properties of porous building materials, II: 3D x-ray tomographic studies, *Materials and Structures*, 33(227),147-153