X-Ray Optics for Biomedical Imaging Applications at the Canadian Light Source

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Abstract

The synchrotron provides an ideal environment to develop new approaches to x-ray imaging. At the Canadian Light Source (CLS) there are a number of activities on the Biomedical Imaging and Therapy (BMIT) beamlines directed to advancing the x-ray optics used for imaging. These optics have been used to improve existing methods as well as provide new capabilities not possible before.

K-Edge Subtraction (KES) is a powerful synchrotron imaging method that allows the quantifiable determination of a contrast element (i.e. iodine) and matrix material (usually represented as water) in both projection imaging and computed tomography [1]. With living systems, a bent Laue monochromator is typically employed to prepare imaging beams above and below the contrast element K-edge which focus at the subject location and subsequently diverge onto a detector [2]. Conventional KES prepares the two beams by utilizing a splitter that blocks approximately 1/3 of the vertical beam size to prevent “edge crossing” energies beyond the monochromator [3].

A bent Laue monochromator has been developed that has very good focal [4] and also, good energy dispersive properties for KES. With a 5mm vertical incident beam from CLS BMIT bend magnet beamline, the vertical splitter size that blocks the edge crossing energies is less than 200 microns at the monochromator location. This makes the design and mounting of a splitter impractical from a mechanical and thermal loading perspective. Since approximately 4% of the vertical beam profile is involved in “edge crossing” energies, no splitter is employed. Also, the beam can be narrowed vertically allowing a smaller crossover angle than a splitter based system which minimizes crossover artifacts. Some aspects of this system will be presented.

An extension of this system has been applied to x-ray absorption spectroscopy where one wishes to determine the speciation or oxidation state of an element. Obtaining a 3D image of chemical forms of an element within a living system would be insightful for many health research areas. XAS can derive chemical form information, but is challenging to apply to 3D objects [5,6]. Meanwhile, KES can reveal the 3D distribution of an element, but traditionally with no chemical information. We have developed a system to test feasibility of 3D speciation imaging with a bent Laue monochromator and analysis algorithms using Se in a living plant system as a test case. Future studies will apply our methods to other biomedical systems. The initial experience with the system was successful with high flux, good energy dispersion properties and spectral bandwidth around the Se K-edge. Some initial results of this work will be presented.

The drive to improve and expand the amount of information extracted from various imaging modalities has led to the use of multiple x-ray photon energies in computed tomography clinical systems [7]. The interest in multiple energy imaging (MEI) is not only with the use of laboratory x-ray source but also with synchrotron x-ray source [8]. A novel MEI system, which prepares a focused polychromatic x-ray, has been developed which is made up of a cylindrically bent Laue single (5,1,1) silicon crystal monochromator and an area detector. Depending on the horizontal beam width of the filtered synchrotron radiation (20 to 50 keV) and the bent radius of the crystal, the size and spectral range of the focused beam prepared vary. For example, using a bent radius of 95 cm and a 50 mm wide beam, a 0.5 mm wide focused beam of spectral range 27 keV to 43 keV was obtained. This spectral range covers the k-edges of iodine (33.17 keV), xenon (34.56 keV), cesium (35.99 keV), and barium (37.44 keV); some of these elements are used as biomedical and clinical contrast agents. With the developed MEI system, a test subject composed of iodine, xenon, cesium, and barium along with water and bone were imaged and their concentrations successfully extracted. Some results from this effort is presented.

Finally, the small vertical beam size of a synchrotron limits its usability in some applications. Micro-CT imaging requires multiple scans to produce a full projection, and certain dynamic imaging experiments such as dynamic lung imaging [9] simply are not possible; a larger vertical beam is desirable to enable such experiments which can be accomplished with a long beamline. However, at BMIT it was not financially feasible to build a longer beamline. Instead, a beam expander was developed that makes the source appear to originate at distance much farther away. This was accomplished using a double crystal bent Laue monochromator in a non-dispersive divergent geometry. The design and implementation of this beam expander is presented along with results from the micro-CT. Flux (photons/area/time) has been measured and found to be comparable to the existing flat Bragg DCM in use at BMIT-BM [10]. An improved version preserves the phase and coherence properties of the output beam and some results of this effort will also be presented [11].

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