First X-ray fluorescence CT experimental results at the SSRF X-ray imaging beamline*

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Abstract: X-ray fluorescence CT is a non-destructive technique for detecting elemental composition and distribution inside a specimen. In this paper, the first experimental results of X-ray fluorescence CT obtained at the SSRF X-ray imaging beamline (BL13W1) are described. The test samples were investigated and the 2D elemental image was reconstructed using a filtered back-projection algorithm. In the sample the element Cd was observed. Up to now, the X-ray fluorescence CT could be carried out at the SSRF X-ray imaging beamline.

Key words: X-ray fluorescence CT, elemental distribution, synchrotron radiation

PACS: 29.30.Kv, 07.85.Qe **DOI:** 10.1088/1674-1137/35/4/015

1 Introduction

Since X-ray fluorescence CT (XFCT) with synchrotron radiation was first proposed in 1986 by Boisseau [1] as a means of observing the distribution of specific elements inside an object without specific preparation, theoretical consideration of XFCT has been performed by several groups and has made it a powerful tool in several fields. Hogan et al have desribed some reconstruction algorithms for XFCT including the filtered backprojection algorithm (FBP) [2], the maximum likelihood method with expectation maximization [3], the least-squares method using singular value decomposition [4] and the monotonic penalized-likelihood algorithm [5]. Finally, Rust and Weigelt [3] applied the XFCT method using two absorption tomograms at the incident and fluorescent energies to quantitatively image human thyroid glands and related phantoms, with an average error of 20% for an iodine concentration running in the mmol/l range. Several other research efforts have used XFCT, including imaging the distribution of specific elements in biomedical objects with high spatial resolution [6–10], imaging the distribution of heavy metals in roots [11] and imaging human cells labeled with CdSe quantum dots [12], and so on.

XFCT is based on the detection of photons from the fluorescent emission of the elements in the sample. These photons are acquired by an energy dispersive detector, placed at 90 degrees to the incident beam direction. Projections are acquired with constant angular steps using translation-rotation motion of the object over 180 degrees. The XFCT image is then reconstructed by software. Finally, we obtain the distribution of some elements inside the sample.

In this article we present the development of XFCT on the X-ray imaging beamline (BL13W1) at SSRF and describe the first experiment with the methodology using the test samples.

2 XFCT system at the SSRF BL13W1 beamline

The X-ray imaging beamline (BL13W1) at SSRF devotes itself to developing and the applications of dynamic in-line X-ray phase-contrast imaging (IL-

Received 6 July 2010

* Supported by National Natural Science Foundation of China (10805071, 10705020), Major Research Plan of National Natural Science Foundation of China (2010CB834301) and Chinese Academy of Sciences Key Project of International Co-operation (GJHZ09058)

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PCI), Micro-CT and other new X-ray imaging techniques. The light source is a hybrid-type wiggler whose periodic length is 14 cm and the number of the period is 8. The fundamental radiation covers the energy range from 8.0 to 72.5 keV by tuning the gap from 17 mm to 35 mm. A fixed-exit double-crystal cryogenic-cooling monochromator is placed 28 m from the source point. The monochromator crystal is a combination of a Si(111) orientation crystal and a Si(311) orientation crystal. A high precision sample stage, allowing translation along all of the three-space direction to be performed with a resolution better than 1 micron and rotation in all three axes, is used for positioning the sample and rotating the sample axis perpendicular to the beam. Fig. 1 shows the schematic diagram for XFCT.

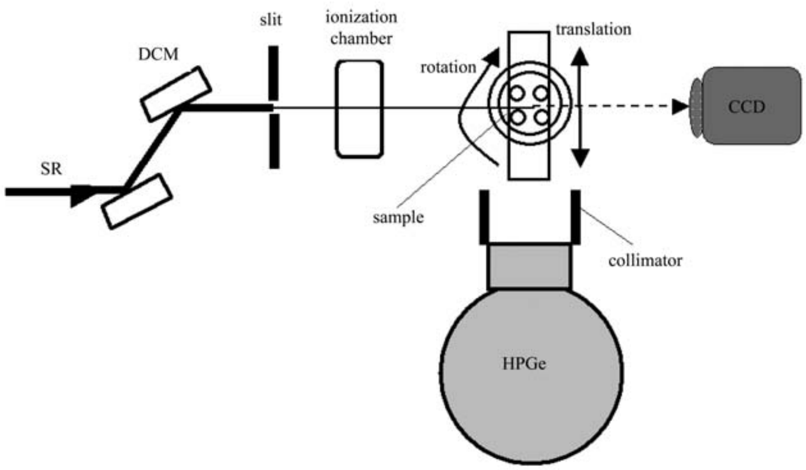

Fig. 1. Schematic diagram of the XFCT.

At the SSRF X-imaging beamline, the XFCT is done using a pencil-beam scanned across the sample. The sample is rotated and translated using a high precision sample stage. The fluorescence photons are detected by a High-purity Germanium (HPGe) detector positioned perpendicular to the incident beam in order to reduce the Compton scattering component in the spectrum. The incident beam is monitored by an ionization chamber and an X-ray charge coupled device (CCD) is used to detect the transmitted radiation.

3 Experiment

The test sample was a 10-mm-diamter polymethyl methacrylate phantom with four 3-mm-diamter holes filled with solutions containing Cd (10^{-6} mol/ml) in two holes. The white X-ray beam was monochromatized at 32 keV using a silicon double-crystal monochromator. The monochromatic beam collimated to a 500 μm × 500 μm beam (horizontal and vertical direction, respectively), with a set of slits used for excitation of the elements within the samples. The sample was placed on a high-precision sample stage and was scanned translationally and rotationally at 500 μm steps and 3° step over 180°, respectively. The data acquisition time was 4 s for each scanned step. The fluorescence photons were collected by an HPGe (Canberra) detector placed perpendicularly to the incident beam and the transmitted radiation was detected by the X-ray CCD (13 μm /pixel, Photonic Science).

4 Results and conclusions

Figure 2(a) shows the typical X-ray spectrum measured from the test sample by the HPGe detector. The X-ray spectrum was then analyzed using the PyMca X-ray Fluorescence Toolkit [13]. The sinogram is the raw data taken by the tomographic setup (Fig. 2(b)). The fluorescence sinogram shown exhibits a sinusoidal shape. This shape is characteristic for a sinogram.

Figure 3 shows the reconstruction results of XFCT and transmission CT for the test sample using the FBP (Filtered Back Projection) algorithm without attenuation [14, 15]. The cross-sectional distributions of Cd within the test sample were clearly imaged by the XFCT.

In the experiment, the X-ray CCD was used to detect the transmitted radiation in the XFCT system at the SSRF X-ray imaging beamline. We can simultaneously obtain a transmission image, which can provide auxiliary data for sample structural in-

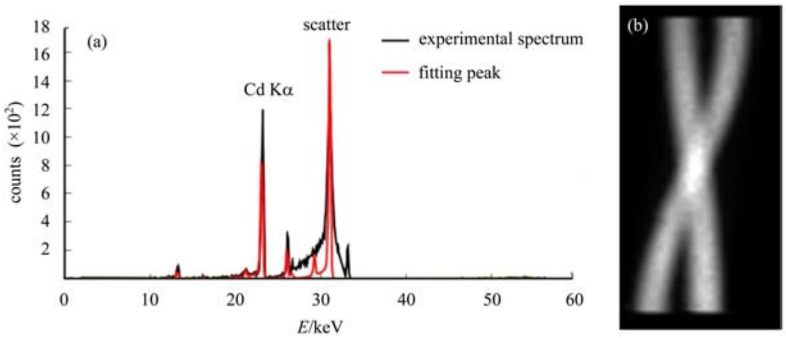

Fig. 2. (a) A typical X-ray spectrum measured from the test sample by the HPGe detector. (color online) (b) Tomographic data (sinogram) from the test sample for Cd Kα ($E_{K\alpha} = 23.17$ keV).

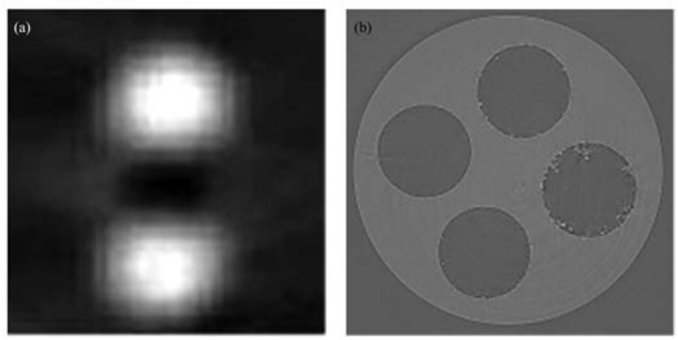

Fig. 3. Reconstruction images for the test sample. (a) Cd distribution (b) Transmission CT.

formation. XFCT is a powerful technique that can be used for imaging the distribution of many biologically relevant elements. Therefore, the XFCT can simultaneously obtain both the morphological and functional information and maybe be used in medical diagnostics.

The XFCT experimental setup at the SSRF X-ray imaging beamline has shown to be very promising. Up to now, XFCT could be carried out at the SSRF X-ray imaging beamline. However, XFCT requires a huge amount of time to obtain a whole set of projections. For instance, the scan of a single slice of the test sample with a 500 μm sampling interval, 3° rotational steps over 180° and 4 s/step dwell time takes about two hours. A helical [16] or parallel data collection method using a sheet beam with an array of detectors [17] may solve the problem of long measurement times. Helical and parallel data collection XFCT will be considered for the next experiment. This technique will be an optional experimental technique at the SSRF X-ray imaging beamline in the future.

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