BL20B2
(Medical and Imaging I)

1. Introduction

BL20B2 is a medium length beamline with a bending magnet source. It is composed of an optics hutch, an upstream experimental hutch 1 (EH 1) located 42 m from the source, and downstream experimental hutches 2 (EH 2) and 3 (EH 3) located 200 m from the source. The EH 2 and EH 3 are located in a medium length beamline facility. A monochromatic X-ray beam from a SPring-8 standard double crystal monochromator is available. BL20B2 is mainly used for X-ray imaging such as X-ray microtomography and projection imaging. In EH 1, high spatial resolution and fast imaging experiments, which require a higher photon flux density, are performed. On the other hand, X-ray imaging experiments with a wide field of view are performed in EH 2 and EH 3 using an X-ray beam with a large cross section. In addition, phase contrast imaging based on a high spatial coherence of the beam generated by a long propagation distance from the source is also performed. As a part of the activities in this beamline, the measurement apparatuses and techniques for X-ray imaging were improved. In FY2018, high-spatial resolution X-ray phase tomography using a grating interferometer was developed.

2. Development of high-spatial resolution X-ray phase tomography

X-ray imaging using phase information can measure weak absorption materials such as biological soft tissues with a much higher image contrast compared with absorption-based imaging. X-ray phase tomography using an X-ray interferometer is a promising technique to visualize small density differences in soft tissues quantitatively, and three-dimensional (3D) density maps can be obtained with a density resolution of around 1 mg/cm^3.

An X-ray grating interferometer is an interferometric technique [1]. It is composed of two transmission gratings. One is a phase grating (G1), and the other is an absorption grating (G2). The moiré fringes generated by two gratings are used for phase measurements. The theoretical spatial resolution achieved in the grating interferometer depends on the grating pitch. Therefore, fine pitch gratings achieve high spatial resolution in phase imaging.

To improve the spatial resolution in X-ray phase tomography, G1 and G2 with grating pitches of 2.4 μm were introduced. G1 is made of nickel with a pattern thickness of 3.53 μm. G1 is designed to generate a π/2 phase shift at an X-ray energy of 20 keV. On the other hand, G2 is made of gold with a pattern thickness of more than 20 μm. The pattern area size exceeds 30 mm × 30 mm in both gratings. G1 and G2 are made on a polyimide substrate and a graphite substrate, respectively. To evaluate the performance of the gratings, the visibility of the moiré fringe was measured at EH 1. In this measurement, the grating was set so that its pattern was parallel to the vertical direction. G2 set on a piezo stage was scanned to obtain the visibility curve. Figure 1 shows the visibility maps measured at third and fifth order fractional Talbot distance. Even in the fifth order fractional Talbot distance, a high uniformity and an average visibility of more than 30% are obtained in an effective field of view of 16.3 mm (H) × 6 mm (V).

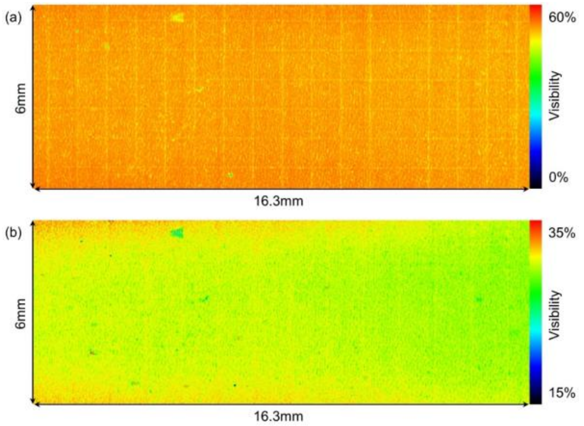

Fig. 1. Visibility map in the effective field of view of 16.3 mm (H) × 6 mm (V) at (a) third and (b) fifth order fractional Talbot distances. X-ray energy is 20 keV.

In addition to the fine pitch gratings, a high-definition CMOS camera was introduced. As a standard X-ray imaging detector, a visible light conversion type X-ray detector was used [2]. The X-ray image onto the scintillator was converted into a visible light image and focused onto the camera device via an optical lens system.

For relatively large field of view imaging with a large numerical aperture, a tandem lens system composed of two camera lenses is usually employed. The magnification factor in the tandem lens system can be easily changed by replacing the lens. The effective pixel size is defined by the magnification factor and the pixel size of the camera used. Since the effective field of view of the X-ray detector is defined by the effective pixel size and the number of pixels in the camera, a high-definition camera serves to keep a wide field of view even for a small effective pixel size.

To combine with new gratings, the effective pixel size of the X-ray detector was set to be almost equal to the grating pitch. The X-ray imaging detector used to evaluate the X-ray phase tomography was composed of beam monitor 4 (AA60; Hamamatsu Photonics) and a high-definition CMOS camera (VCXU-201MR; Baumer). The effective pixel size was 2.43 μm when a camera lens with a focal length of 105 mm was installed just in front of the CMOS camera. In the phase tomographic measurement, the distance from the sample to the detector was set to 600 mm where the grating interferometer operated in the fifth order fractional Talbot distance (232 mm at 20 keV) was installed between the sample and the detector. Figure 2 shows a photograph of the experimental setup using the new gratings and camera.

As a demonstration of high spatial resolution X-ray phase tomography, a formalin-fixed rat brain was measured. The sample was measured in a specially designed container filled with water. The measurement condition in X-ray phase tomography was 900 projections, 5-step fringe scan for phase retrieval, and a 1-s exposure time per image. In this measurement, the offset scanning method was applied to extend the effective field of view. Figure 3 shows the coronal section of the rat brain obtained from X-ray phase tomography. The structure of the hippocampus, small blood vessels, and nerve fibers are clearly observed compared with the previous measurement [3].

3. Summary

X-ray phase tomography was improved by introducing fine-pitch transmission gratings for X-ray interferometer and a high-definition camera in the X-ray imaging detector. Although the high-definition camera used was not a scientific CMOS

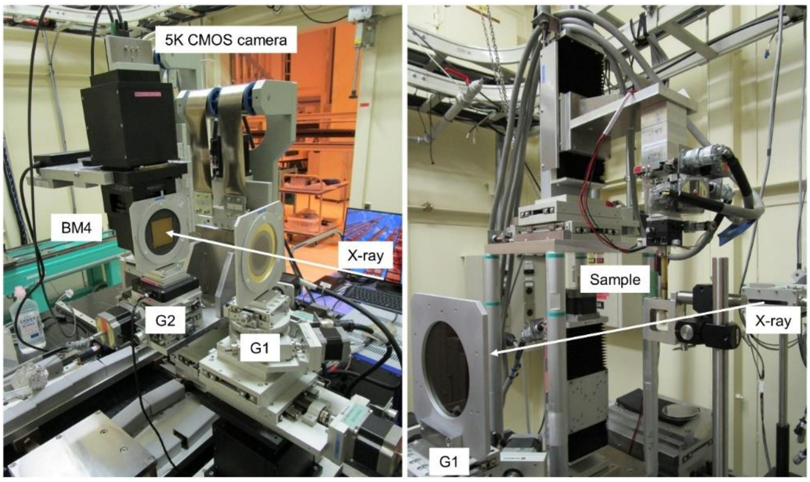

Fig. 2. Photographs of the experimental setup for X-ray phase tomography using new gratings and a CMOS camera at experimental hutch 1.

Fig. 3. Coronal section of a rat brain obtained from X-ray phase tomography with the effective pixel size of 2.43 µm. Image size is 6,601 (H) × 4,393 (V) pixels (cropped from original image size of 10,413 × 10,413 pixels).

camera but a 12-bit CMOS camera, it was adequate for phase tomography with a high-density resolution. This might be due to some kinds of averaging effects in the phase measurement. This is based on the fact that a single-phase image consists of five individual images obtained from scanning G2 as a fringe scan. In the demonstration of X-ray phase tomography shown above, the exposure time for a single image was set to 1 s, which caused a relatively long measurement time.

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[3] SPring-8/SACAL Annual Report FY2014 p.61-62, FY2015 p.55-56.