PHASE-CONTRAST X-RAY IMAGING FOR REAL-TIME OBSERVATION OF LIVING SAMPLES

Phase-contrast X-ray imaging has been the object of recent active study at third-generation synchrotron radiation facilities. At the Hyogo beamline **BL24XU**, the first contract beamline of SPring-8, the real-time phase-contrast X-ray imaging has been performed using a sophisticated optical system consisting of an arrangement of successive horizontal and vertical (+,–) double crystals [1]. As shown in Fig. 1, the incidence beam is expanded to a wide two-dimensional observation area by the use of asymmetric Bragg reflection with a case of a low-incident beam angle in both dimensions. Typical photon energy for the phase-contrast imaging is 15 keV or 25 keV, the 1.5th and 2.5th harmonics of the figure-8 undulator [2], respectively. The incident X-ray beam is monochromatized by a horizontally non-dispersive silicon double-crystal monochromator with 111 symmetric reflection. When the photon energy is 15 keV, the crystal surface and the diffraction plane used are 100 and 511, respectively, with an inclination angle of 15.8 degree from the surface. The asymmetry factor, *b*, is 0.207.

Real-time observation of the motion of a living pill bug (*Armadillidium vulgare*) was performed by using an X-ray camera and recorded on videotape. Its motion could be monitored in real time. Fig. 2(a, b) show examples of phase-contrast images captured from the videotape. For comparison, absorption contrast images were also recorded by placing the same sample immediately in front of the camera (Fig. 2(c, d)). Boundary structures in Fig. 2(a, b) are more clearly observed than those in Fig. 2(c, d) due to higher contrast. For example, the antennae are well observed in Fig. 2(b), whereas they are almost invisible in Fig. 2(d) as indicated by the black arrows. Comparison of these two kinds of images confirms that phase contrast imaging is highly applicable to investigations of samples composed of light elements.

Real-time observation of a living frog was also conducted. In Fig. 3 are shown examples of the captured images. In Fig. 3(a), eyeballs (α) and nostrils (β), and Fig. 3(b), the spine (χ) and cell-like structures inside the lung (δ) are easily observed, with good contrast. White arrows in Fig. 2(a, b) and lung cells in Fig. 3(b) indicate that high contrast is located in regions enclosing air, due to the much

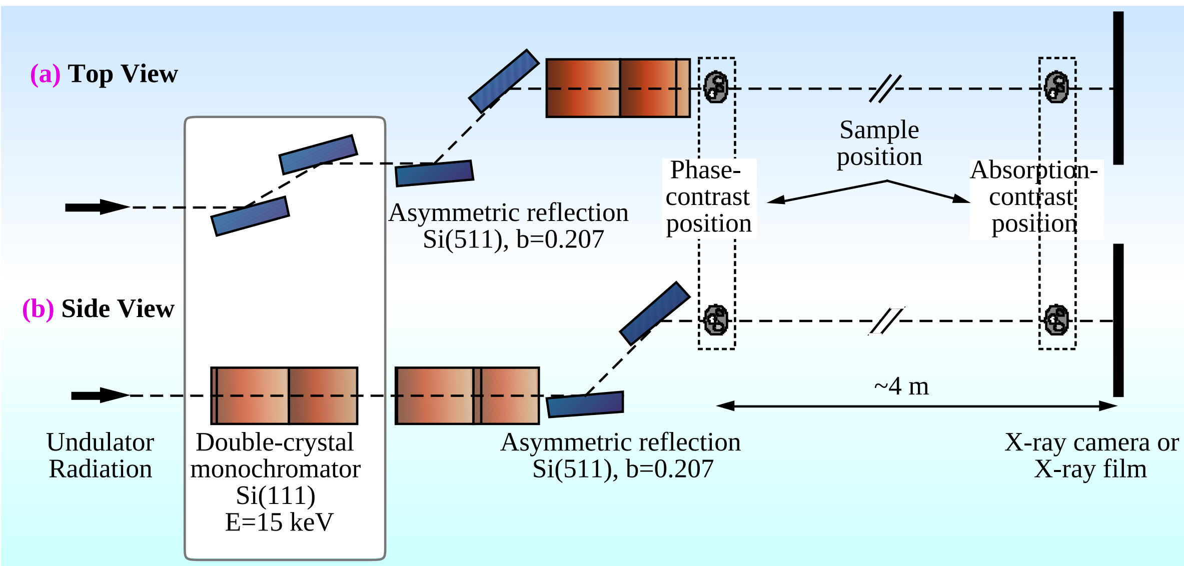

*Fig. 1. Optical system for phase-contrast X-ray imaging. **(a)** Top view and **(b)** Side view. The original beam size is expanded by using asymmetric Bragg reflection in both vertical and horizontal directions. Absorption-contrast imaging can also be performed simply by placing the sample just in front of the image sensor.*

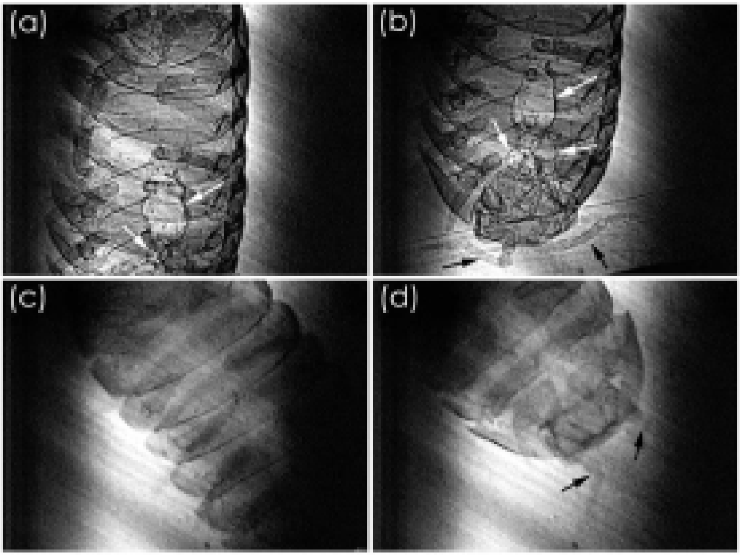

*Fig. 2. X-ray images of a living pill bug (Armadillidium vulgare) captured from videotape. **(a)** and **(b)**: phase contrast images, **(c)** and **(d)**: absorption contrast images. The image contrast of the phase-contrast images are much better than that of the absorption contrast images. Black arrows indicate the antennae. White arrows indicate the existence of air in the sample. These images were observed in real-time.*

larger density difference between an organ and air than between different organs. It is appropriate, therefore, to apply this method of phase-contrast X-ray imaging diagnosis to the human body, especially for diseases of the respiratory and digestive organs. Analysis of image blurring at structural edges led to an estimated spatial resolution of about 15 µm, which is almost equal to the theoretically expected value of 18 µm. Phase-contrast X-ray imaging is potentially a powerful tool for X-ray imaging applications such as microscopy for biology and materials science, as well as for medical diagnosis.

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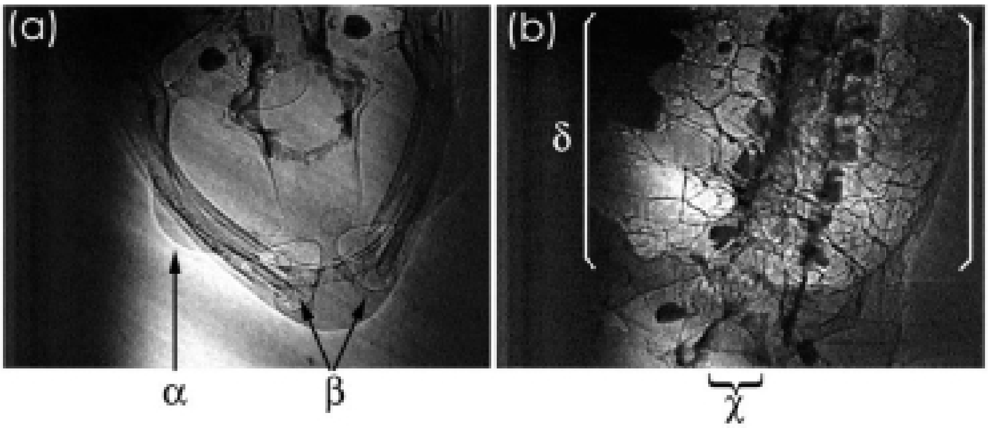

*Fig. 3. Phase-contrast images of a living frog captured from videotape. In **(a)** eyeballs (α) and nostrils (β), in **(b)** spine (χ) and cells inside lung (δ) are well observed. Those images were observed in real-time.*