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A video camera system for coaxial observation of a sample with an incident soft X-ray beam

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A video camera system for observing a sample from the direction of an incident soft X-ray beam has been developed. The sample is seen *via* two reflecting mirrors. The first mirror, which has a hole to allow the soft X-ray beam to pass through, is set on the beam axis in a vacuum. The second mirror is used to cancel out the mirror inversion of the image. This camera system is used for efficient positioning of samples in a soft X-ray beam.

Keywords: video camera; coaxial observation; soft X-ray; sample positioning.

By virtue of modern high-brilliance synchrotron radiation sources, focused soft X-rays with spot sizes of the order of 100 µm or less are now easily obtained using focusing mirror systems with sufficient working distances. Such focused beams provide opportunities to probe small samples of equivalent size. To probe a small sample, one must manage to position it in the focused beam. Moreover, for some experiments such as angle-resolved photoemission spectroscopy, frequent repositioning of the sample is required to correct positional deviation caused by repeated changing of the angle of the sample. When using soft X-rays, it is often difficult to recognize submillimetre-sized samples with the naked eye because they are located inside vacuum chambers. Sample observation using a magnifying video camera is thus helpful for sample alignment. Normally, to determine the position of a sample three-dimensionally, it should be observed from multiple directions. It is, however, often difficult to set up multiple cameras on a vacuum chamber owing to the lack of free viewports. Here we report on a video camera system with the capability of observing a sample from the direction of an incident soft X-ray beam. No extra port is required on a vacuum chamber for this system except a port for introducing a beam. Furthermore, a sample can easily be set on the beam axis despite using only one camera.

Fig. 1 shows schematically the developed camera system that has been installed in an experimental station for soft X-ray emission spectroscopy (Tokushima *et al.*, 2006) at the soft X-ray beamline BL27SU (Ohashi *et al.*, 2001) of SPring-8. The camera system is located between the sample position and a vertical focusing mirror for the soft X-rays placed 1.5 m upstream. A horizontal focusing mirror is placed 7.5 m upstream from the vertical mirror. The vertical and horizontal sizes of a soft X-ray spot measured at the sample position are 15 and 256 µm, respectively (Ohashi *et al.*, 2004).

The camera observes a sample *via* two reflecting mirrors for visible light. The first mirror, made of stainless steel, is the key part of the coaxial observation of the sample with the soft X-ray beam. This mirror is in a vacuum and has a hole to allow the soft X-ray beam to pass through. The position and angle of the first mirror can be adjusted by a two-axial positioning stage and a rotary feedthrough. The second mirror is located outside the vacuum near a viewport. This mirror is used to cancel out the inversion of the images caused by the first mirror. Fig. 2 shows an external view of the camera system. The second mirror, lens and camera are rotated by 90° in the horizontal plane compared with in Fig. 1 owing to spatial limitation. The distance between the sample and the first mirror is 310 mm, and the second mirror is placed 170 mm above the first mirror. The total distance from the sample to the end of the camera lens is 535 mm. A Nikon lens (Micro Nikkor 105 mm F2.8D) is used; the lens can be

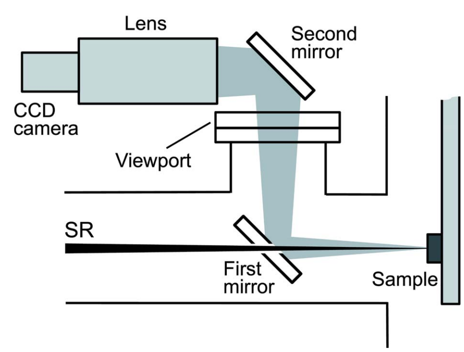


Figure 1
Schematic drawing of the video camera system for the coaxial observation of a sample with a soft X-ray beam.

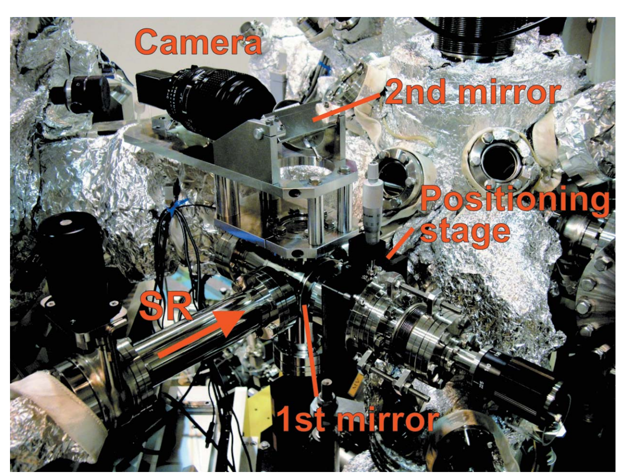


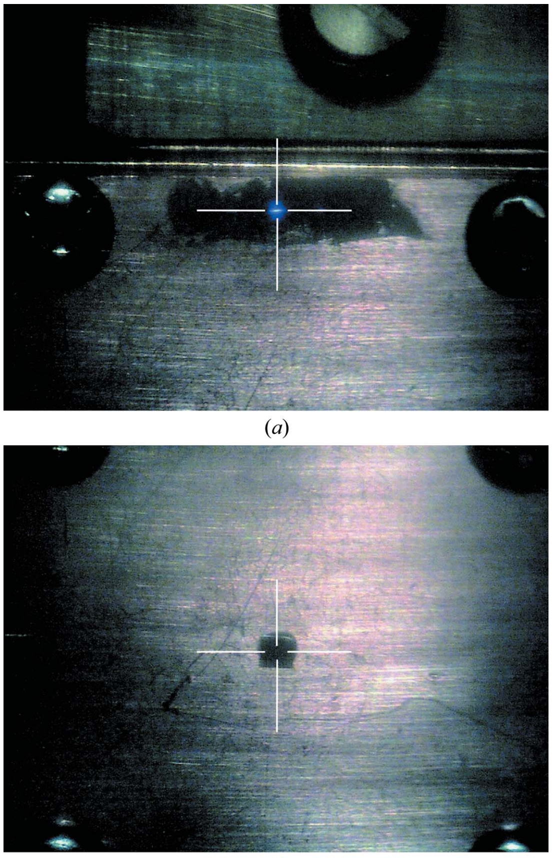
Figure 2
Coaxial camera system installed in an experimental station of BL27SU at SPring-8.

replaced depending on the required magnification. A camera which has a 1/3-inch CCD with 1280 × 1024 pixels is connected to the lens; the camera images can be loaded onto a PC. The total magnification of the camera is about 20 when a 17-inch monitor is used. The hole of the first mirror is on the central path of the light coming to the lens and partially intercepts it. If the size of the hole is too large in relation to the aperture of the lens, the central area of the camera image would disappear. To examine this effect, we made a test set-up under atmospheric conditions using double mirrors and the same camera and lens with the same distances as mentioned above. Circular-shaped black tape was attached to the first mirror instead of making a hole to obtain a non-reflecting central area. We tested several sizes of tapes. As a result, any lack in the image was not seen for tape diameters up to 10 mm when the aperture of the lens was fully opened, *i.e.* the *f*-number was 2.8. When the aperture was half closed, *i.e.* the *f*-number was 5.6, the largest tape diameter for observing a full image proportionally decreased to 5 mm. From this examination we employed a hole diameter of 3 mm so as to leave some adjustable range of the aperture and also so as not to intercept the soft X-ray beam. A well collimated beam of high-brilliance synchrotron radiation is advantageous for this technique. The surface of the installed first mirror was polished up with 0.5 µm alumina paste after making the hole.

Fig. 3 shows images of the sample holder observed by the coaxial camera system. The surface of the holder is perpendicular to the soft X-ray beam. Although the holder was observed *via* the two mirrors, there is no serious degradation of the images such as a lack of the central area. To check the suitability of the hole diameter against the beam width, we shifted the position of the hole perpendicularly to the beam while monitoring the drain current of the sample holder caused by exposure to the soft X-rays. There was no decrease in the current with small motions of about 0.1 mm in the vertical and horizontal directions; this means that the hole diameter is large enough for the beam.

In Fig. 3(*a*), a fluorescent spot of the soft X-ray beam is seen on the sample holder where phosphor powders are applied. The position of the beam spot is marked on the camera monitor as shown in the figure. Samples can be easily irradiated with the soft X-ray beam by setting them at the marked position, like the stainless-steel plate of ~1 mm × 1 mm in Fig. 3(*b*). In addition, the surface of a sample can be set roughly at the focus of the soft X-ray beam by using the camera focus preliminarily adjusted to the beam focus. Our sample holder has a blade at the end to measure the beam width by scanning its position against the beam. We can set the blade at the beam focus where the beam should have the minimum width. Then, the camera focus is set to the beam focus by adjusting it to the blade. The accuracy of positioning a sample at the beam focus depends on the focal depth of the camera lens.

We consider that the developed coaxial camera system is very efficient for adjusting the position of a sample to a focused soft X-ray beam. It would be particularly effective for submillimetre-sized samples. The magnification of the camera could be increased by using a high-magnification lens such as an optical microscope with a long working distance (Muro *et al.*, 2009). We are planning such an improvement.



(*a*)

(*b*)

Figure 3
(*a*) Fluorescent spot of the soft X-ray beam on the sample holder observed by the coaxial camera. White lines are marks on the camera monitor indicating the beam position. (*b*) A stainless-steel plate of ~1 mm × 1 mm positioned on the beam axis with the help of the marks on the monitor.

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