214
doi:10.1017/S1431927618013429

Microsc. Microanal. 24 (Suppl 2), 2018

Laboratory-size X-ray Microscope using Wolter Mirror Optics and an Electron-impact X-ray Source for Multi-energy Observation

Akira Ohba[1*], Tomoyasu Nakano[1], Shinobu Onoda[1], Takahiro Mochizuki[1], Katsuhiro Nakamoto[1], Hisaya Hotaka[1], Katsuyoshi Fujita[1], Shinji Ohsuka[1], Motosuke Miyoshi[2], Keita Soda[2] and Takao Hamakubo[2]

[1.] Hamamatsu Photonics K.K., 5000 Hirakuchi, Hamakita-ku, Hamamatsu-City, 434-8601, Japan
[2.] Research Center for Advanced Science and Technology, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan
* ohba@crl.hpk.co.jp

Since soft x-ray microscopy is suitable for imaging the internal structures of biological samples and light element materials, laboratory-size x-ray microscopes have been developed using plasma and electron-impact x-ray sources to make them more accessible as a standard laboratory tool [1] [2]. Previously, we developed a laboratory-size x-ray microscope using Wolter mirror optics and an electron-impact x-ray source. We reported a spatial resolution limit of 1.0 line pairs per micrometer (lp/μm) for two-dimensional imaging with oxygen Kα (525 eV) x-rays. It was further proved that it had the capability to resolve 1-μm scale three-dimensional (3D) structures and 3D imaging of a glomerulus in a dehydrated mouse kidney was demonstrated [3]. However, further improvements were necessary for practical applications such as observing the inner structures of cultured cells. Thus, we have improved the x-ray microscope so that it allows for high-resolution imaging to observe the inner structures of cells and for multi-energy observation to obtain different spectral information.

Figure 1 shows a schematic setup of our laboratory-size x-ray microscope. The basic arrangement is the same as the previous x-ray microscope [3]. However, the optical design parameters of the Wolter mirrors and the structure of the x-ray source were altered to attain the improvements described above.

The resolution limit of Wolter mirror optics is decreased due to fabrication errors. Even though the Wolter mirror has figure errors, by selecting a shorter working distance (distance between sample and mirror) the resolution limit can be improved [4]. Our earlier x-ray microscope had a working distance from the objective Wolter mirror of 30 mm. Therefore, we fabricated the new objective mirror with the working distance of 20 mm. The figure error and the surface roughness were less than 0.1 μm and around 2nm, respectively. These results were almost the same as those with the previous mirror. The condenser mirror was also fabricated to enhance the throughput of the optics. The magnification factor of the condenser mirror and the objective mirror were designed to 1/4.5 and 150, respectively. To evaluate the imaging performance of our x-ray microscope, a resolution chart made of 500 nm thick tantalum (XRESO-50HC, NTT Advanced Technology Corp., Japan) was observed. Figure 2 shows the image of the central part of the radial pattern. The x-ray source was operated at an acceleration voltage of 7 kV and exposure time was 90 min. The 0.2 μm line-and-space pattern was completely resolved. We confirmed that the resolution limit of 2.5 lp/μm was achieved with the x-ray microscope.

For multi-energy observation, an x-ray source with multiple x-ray tubes was developed, as shown in Fig. 1. Each x-ray tube has a target coated with different kinds of materials. We can select the x-ray energy by rotationally moving one of the tubes to the focal point of the condenser mirror from the outside of the vacuum chamber. As examples, Figure 3(a) and 3(b) show images of 3 μm diameter polystyrene beads observed with a Cr_2O_3 target emitting oxygen Kα (525 eV) x-rays and a diamond-like carbon target emitting carbon Kα (277 eV) x-rays, respectively. Exposure time was 15 min. and the x-ray source was operated at 7 kV for each image. Figure 3(a) has higher image contrast than Fig. 3(b) because the x-ray absorption of carbon at oxygen Kα is higher than that at carbon Kα. This result indicates that the x-ray source with multiple x-ray tubes and Wolter mirrors without chromatic aberration allow the multi-energy x-ray imaging.

In conclusion, we reported on improvements of our x-ray microscope with Wolter mirrors and the electron-impact x-ray source. By utilizing the objective Wolter mirror with a shorter working distance, the resolution limit was improved from 1 lp/μm to 2.5 lp/μm. An x-ray source with multiple x-ray tubes was developed and images of samples at the different x-ray energies were taken. We will further evaluate 3D tomographic imaging performance of the x-ray microscope in future studies.

References:
[1] E. Fogelqvist *et al,* Sci. Rep. **7** (2017) 13433
[2] S. Ohsuka *et al*, Rev. Sci. Instrum. **85** (2014) 093701.
[3] S. Ohsuka *et al*, AIP Conf. Proc. **1696** (2016) 020009.
[4] K. Sugisaki *et al*, Appl. Opt. **37** (1998) 8057

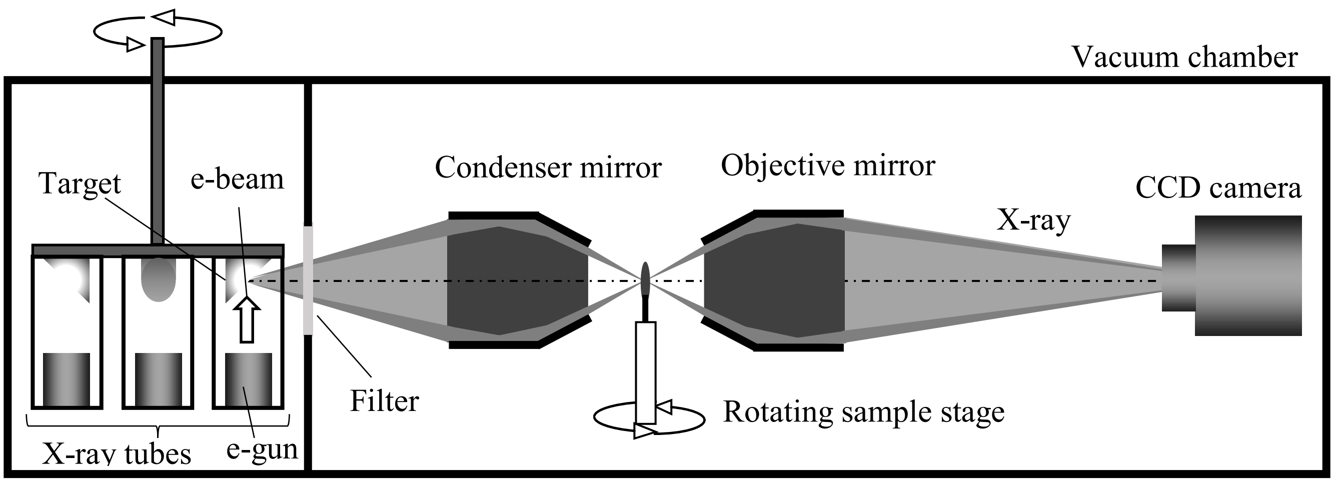

Figure. 1. Schematic drawing of 3D x-ray microscope.

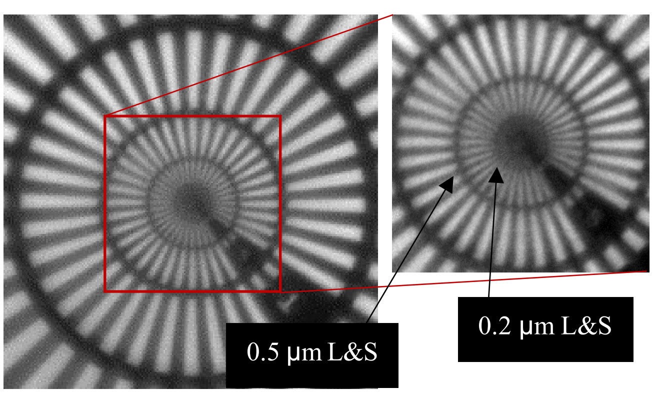

Figure. 2. Radial pattern image of X-ray resolution chart, with 0.2μm line-and-space (L&S) pattern resolve.

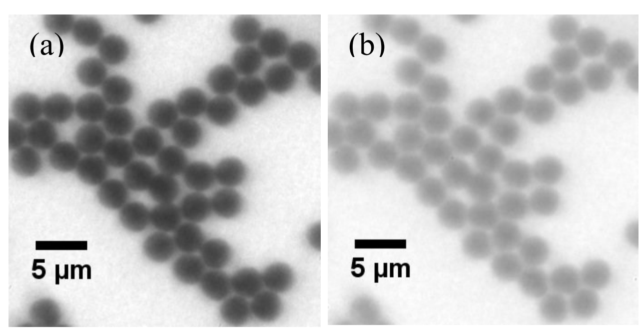

Figure. 3. Images of Polystyrene beads at x-ray energy of (a) oxygen Kα, (b) carbon Kα.

https://doi.org/10.1017/S1431927618013429 Published online by Cambridge University Press