Implementation of soft x-ray microscopy with several tens nanometers spatial resolution at NSRL

Shiping Jiang¹, Liang Chen
National Synchrotron Radiation Laboratory, the University of Science and Technology of China, Hefei 230029, China

E-mail: spjiang@ustc.edu.cn

Abstract. A transmission soft x-ray microscope (TXM), which is similar to the full-field x-ray microscopes installed on other synchrotron radiation sources in the world, was developed at National Synchrotron Radiation Laboratory (NSRL) in Hefei. An x-ray image taken with the microscope was acquired and its spatial resolution was estimated to be better than 70 nm.

1. Introduction
Soft x-ray microscopy has many advantages for biological imaging, especially in “water window” region (2.34–4.38 nm), where the absorption coefficients of organic materials are about one order of magnitude than that of water and organic materials show strong absorption while water shows almost transparent. Compared to charged particles (such as electrons), soft x-ray has higher penetration power and thick samples (up to 10 µm) can be imaged with no need to be sectioned. Some kinds of soft x-ray microscopes have been developed in the world. Among these, transmission soft x-ray microscopes (TXM) based on zone plates and synchrotron radiation have been attracted with much attention because of its short exposure time, real time imaging and high spatial resolution. At the same time, the low numerical aperture x-ray lenses of TXM, which lead to the large depth of field, makes it true to achieve microtomography on whole cells. This depth of field is the basic reason for the development of TXM in water window region, which matches the demand for whole cell 3D imaging [1]. The project of updating the beamline and endstation of soft x-ray microscopy was completed and a transmission full-field soft x-ray microscope working at water window region was built at National Synchrotron Radiation Lab (NSRL) in 2007 [2].

2. Instrumentation

¹ To whom any correspondence should be addressed.
The beamline of TXM at NSRL was basically based on a fully dedicated 800 MeV electron storage ring. It consists of a typical front end, a plane mirror chamber, a linear monochromator and a micro zone plate imaging system. The main components of the beamline are shown in figure 1. Synchrotron radiation from a bending magnet was irradiated on a plane mirror with the grazing incidence angle of 2.5 degree. The use of plane mirror was to suppress high energies of synchrotron radiation. The plane mirror used SiO$_2$ as the basis and the surface coated with 30 nm nickel.

![Figure 1. Schematic layout of the TXM](image1.png)

The reflected synchrotron radiation was then irradiated on a condenser zone plate (CZP). There was an annular aperture with a diameter of 10 mm in front of the CZP. The aperture was to restrict the radiation on the CZP and just made all of the CZP irradiated. The CZP together with a 15 µm pinhole consists of a linear monochromator which provide monochromatic soft x-rays. The diameter of CZP is 9 mm, with the outmost ring width of 50 nm. There was a central stop of CZP with diameter of 4 mm which used to prevent the zero-order radiation illuminating on the sample and reduce the background. The spectrum resolution ($\lambda/\Delta\lambda$) of x-ray beam behind the pinhole reach to about 600

![Figure 2. Photo of the TXM at NSRL (in part)](image2.png)

The far left is the Condenser zone plate and the center is the pinhole, sample and objective zone plate in the photo. CCD detector of the TXM is beyond the photo.
The selected monochromatic soft x-rays were then irradiated on the samples. The sample stage was a three-dimensional-driven stage and repeated precision was 200 nm. There was a micro zone plate for magnifying with $800 \times$ the imaging on the detector. The detector was a back-thinned illuminated open CCD (Andor, DO434) and the quantum efficiency was about 70% at the wavelength of 2.4 nm. There used a photo diode (AXUV-100G) to measure the intensity of the spot at the sample position and was about $3.4 \times 10^9$ photons/s at 2.4 nm, which could be calculated from the photo-current read from the AXUV photo diode.

3. Result
The first image taken with the TXM was used to measure its spatial resolution. The x-ray image of a resolution pattern is shown in Fig 3. It is obvious that the spatial resolution of the image is better than 70 nm. Time of the exposure was 60s when the electronic current in storage ring was about 90mA. The sample for imaging was part of a siemens star test pattern.

4. Conclusion
The X-ray microscope at NSRL will mainly apply in life science. The spatial resolution of the imaging can reach less than 70 nm. With the microscope, it comes true for single cell microtomography with soft x-rays at “water window” region. There is no doubt that it will become a new platform for cell biology researchers.

[1] Gerd Schneider. 2003, *Anal Bioanal Chem*, 376 558–561
[2] S.P.Jiang, L.Chen, L.B.Wan et al. 2006, *Proc.8th.Int.Conf.X-ray microscopy, Conf. Series 7*, edited by S.Aoki, Y.Kagoshima and Y.Suzuki, IPAP,Hyogo,Japan, 30-31.