Zoological Studies 34, Supplement I (1995)

Zoological Studies

Development of a Zone Plate Soft X-ray Microscope at the TRISTAN Accumulation Ring

J.-D. Wang[1], Y. Kagoshima[1], T. Miyahara[1], M. Ando[1], S. Aoki[2], E. Anderson[3], D. Attwood[3] and D. Kern[4]
[1]*Photon Factory, National Laboratory for High Energy Physics, Tsukuba, Ibaraki 305, Japan*
[2]*Institute of Applied Physics, University of Tsukuba, Tsukuba, Ibaraki 305, Japan*
[3]*Center for X-ray Optics, Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA*
[4]*Institut für Angewandte Physik, Universität Tübingen, Auf der Morgenstelle 12, Tübingen 1, FRG*

INTRODUCTION

In a zone plate soft x-ray microscope, the zone plate must be used with monochromatic illumination because of the strong chromatic aberration. A typical microscope employs a linear monochromator consisting of a zone plate and a pinhole (Niemann et al. 1983), which spectral resolution depends on the dimensions of the zone plate and the pinhole (Niemann et al. 1974). However, since such a linear monochromator can provide an appropriate spectral resolution only when the zone plate has a larger dimension and is illuminated effectively, it is suitable for radiation with a relatively large angular divergence such as from a bending magnet but may not be suitable for radiation with a small divergence such as from an undulator as well as the future light sources with a very low emittance such as the 3rd generation synchrotron radiation.

In addition, the object distance of a high resolution zone plate is very close to its focal length which is usually shorter than 1 mm, its focal depth is only several microns. The sizes of optical elements and objects are also very small. Therefore, it is very difficult to find a correct focus of a zone plate and align the x-ray optical system precisely without any auxiliary implement.

On the basis of the above consideration, we have introduced a grating monochromator and constructed a zone plate microscope associated with a visible light pre-focus unit. Here, we would briefly describe the optical system of the microscope and the visible light pre-focus unit. Some experimental results are also presented.

BEAMLINE, THE SOFT X-RAY MICROSCOPE AND THE VISIBLE LIGHT PRE-FOCUS UNIT

The microscope has been developed at the beamline NE1B of the 6.5-GeV TRISTAN accumulation ring (AR) in KEK, National Laboratory for High Energy Physics, where circularly polarized soft X rays are produced by a helical undulator (Yamamoto et al. 1989, Kitamura 1992). The wavelength of its first harmonic can be tuned from 0.8 nm to 5 nm. The NE1B is equipped with a 10 m vertical-dispersion grazing incidence spherical grating monochromator and a post-focusing mirror (Kagoshima et al. 1995). Fig. 1 shows the schematic diagram of the optical arrangement of the NE1B together with the soft x-ray microscope. The spectral resolution of the monochromator, $\lambda/\Delta\lambda$, is estimated to be about 280 ~ 290 at λ=2.37 nm and meets the monochromaticity requirement of the zone plate we used.

The optical system of the microscope consists of a ϕ500 μm pre-pinhole, a condenser zone plate (CZP), a ϕ20 μm pinhole, and an objective zone plate (OZP). The pre-pinhole placed at the focus of the post-focusing mirror is used as a monochromatic secondary source. The CZP generates a reduced image of the pre-pinhole in an object plane through the ϕ20 μm pinhole. The OZP generates a magnified image of the object in an image plane.

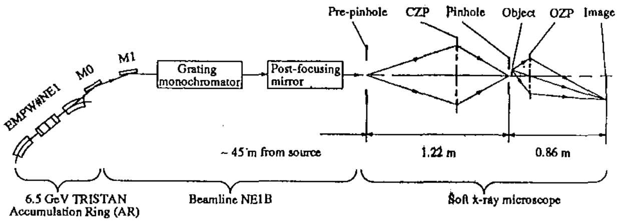

Fig. 1. Schematic diagram of the optical arrangement of the beamline NE1B and the soft x-ray microscope.

The x-ray image can be recorded directly with photographic film or converted into a visible image by using MCP. The numerical parameters of the zone plates are summarized in Table 1. The CZP was fabricated by NTT (Sekimoto et al. 1988), while the OZP was fabricated by IBM as a collaboration between LBL and IBM (Anderson et al. 1992).

Fig. 2 shows the visible light pre-focus unit. The unit works as a reflected illumination visible light microscope consisting of two objectives inside a vacuum chamber for the x-ray microscope and common eyepieces outside the chamber. One of the objectives is perpendicular to the x-ray axis and provides a relatively low magnification (10 ×). It is called coarse adjustment objective and is used to monitor an adjustment of the OZP, an object and the pinhole in its view field (~ ϕ1 mm) and to avoid any collision between them. Another objective is on the x-ray axis and provides a relatively high magnification (20 ×). It is called fine adjustment objective and is used to measure an object distance of the OZP and a distance between the pinhole and an object precisely along the x-ray axis. One of the two optical paths of the objectives can be selected by using a change-over splitter. The fine adjustment objective has a ϕ2 mm central hole to make x rays pass through.Its focal depth is designed to be about ±1.5 μm. Since that is less than the focal depth of the OZP, the object distance can be measured precisely. The working distance of the fine adjustment objective is designed as long as 10 mm. The distance between the pinhole and an object can also be measured. Therefore, the x-ray optical system of the microscope can be adjusted easily, quickly, and precisely by using the unit.

RESULTS

A spatial resolution test has been performed at λ=2.37 nm to evaluate performance of the micro-

Table 1. Parameters of zone plates

Parameters	CZP	OZP
Radius of the innermost zone	15.8 μm	1.41 μm
Number of zones	1000	200
Width of the outermost zone	0.25 μm	0.05 μm
Numerical aperture	0.048	0.24
Focal length (1st order at λ=2.37 nm)	105 mm	0.84 mm
Focal depth		±2.1 μm
Zone material	500 nm Ta	100 nm Ni
Supporting material	300 nm Si_3N_4	100 nm Si_3N_4

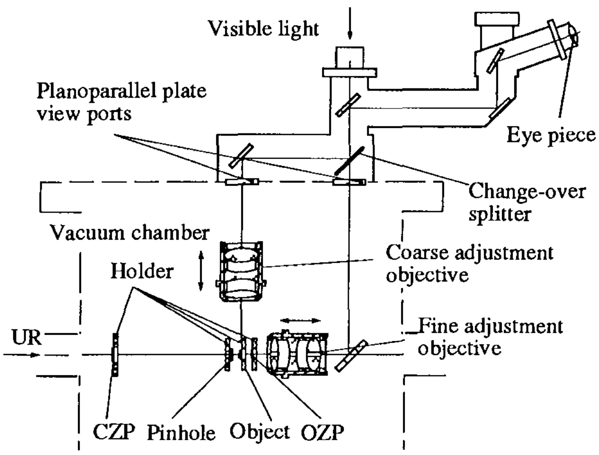

Fig. 2. Schematic diagram of the visible light pre-focus unit.

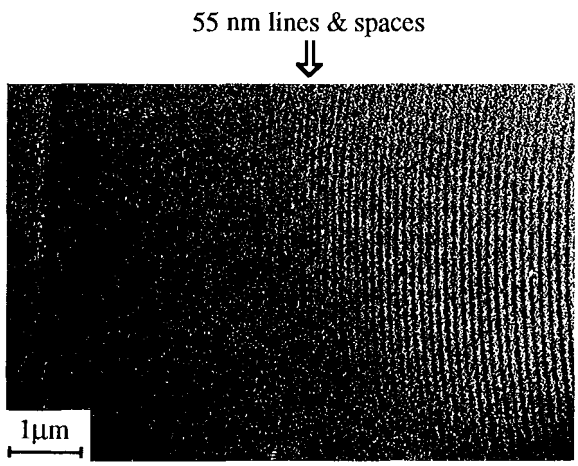

Fig. 3. An x-ray magnified image of the outer region of the zone plate test pattern. X-ray magnification ~ 1020.

scope. The test pattern is a zone plate with finer structures than the OZP. The diameter of this zone plate is 49 μm and its innermost radius is 1.5 μm. The width of the outermost zone is 45 nm. Here the test pattern serves as an object and is imaged by the microscope at a magnification of 1020. Fig. 3 shows a magnified x-ray image of the outer region of the zone plate. It is taken by Kodak T-Max 3200 Professional Film with an exposure time of 3 minutes. The small widths of zones down to 55 nm are successfully resolved. According to Rayleigh's criterion, the spatial resolution of a zone plate microscope is comparable to the width of the outermost zone. Since that width of the OZP is 50 nm, we would believe that the resolution of our microscope has almost reached its diffraction limit.

Some dry biological specimens, diatoms, have been clearly observed by the microscope. Fig. 4 shows their x-ray images. It has been confirmed that the microscope is applicable to biology.

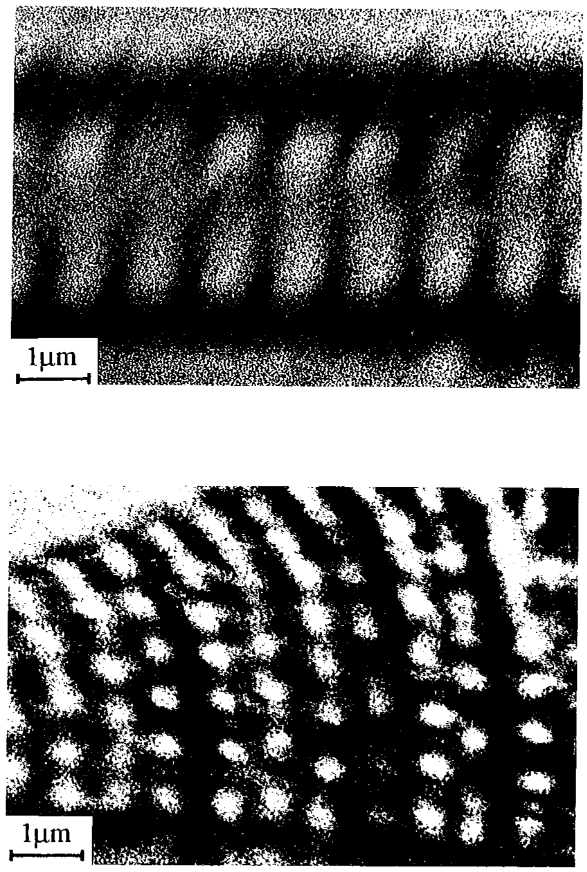

Fig. 4. X-ray magnified images of the diatoms.

FUTURE EXPERIMENTS

Some attempts will be performed in the future. First, an environmental chamber should be developed to observe biological specimens in their natural state. Second, since the circularly polarized soft x rays are available at the beamline NE1B, helical structures which are much attractive in biology may be observed by using circularly polarized soft x rays (Kagoshima et al. 1992, Keller et al. 1985). Thus we may obtain much novel information about helical structures using circularly polarized light which is unobtainable using non-circularly polarized light.

REFERENCES

Anderson E, D Kern. 1992. Nanofabrication of zone plates for x-ray microscopy. in X-Ray Microscopy III, edited by A G Michette, G R Morrison, C J Buckley (Springer-Verlag, Berlin), pp. 75-78.

Kagoshima Y, T Miyahara, M Ando, S Aoki. 1992. Present status and future plan of soft x-ray microscopy at the Photon Factory. Rev. Sci. Instrum. **63:** 605-608.

Kagoshima Y, T Miyahara, S Yamamoto, H Kitamura, S Muto, S-Y Park, J-D Wang. 1995. Construction and performance of the beamline NE1B for circularly polarized soft x-rays in the TRISTAN Accumulation Ring. Rev. Sci. Instrum. **66:** (in press).

Keller D, C Bustamante, M F Maestre, I Tinoco, Jr. 1985. Imaging of optically acitve biological structures by use of circularly polarized light. Proc. Natl. Acad. Sci. USA **82:** 401-405.

kitamura H. 1992. Production of circularly polarized synchrotron radiation. Syn. Rad. News Vol. 5, No. **1:** 14-20.

Niemann B, D Rudolph, G Schmahl. 1974. Soft x-ray imaging zone plates with large zone numbers for microscopic and spectroscopic application. Opt. Commun. **12:** 160-163.

Niemann B, D Rudolph, G Schmahl. 1983. The Göttingen microscopes. Nucl. Instrum. and Methods. **208:** 367-371.

Sekimoto M, A Ozawa, T Ohkubo, H Yoshihara, M Kakuchi, T Tamamura. 1988. X-Ray Zone Plate with Tantalum Film for an X-Ray Microscope. In X-Ray Microscopy II, edited by D Sayre, M Howells, J Kirz, H Rarback (Springer-Verlag, Berlin), pp. 178-181.

Yamamoto S, H Kawata, H Kitamura, M Ando. 1989. First production of Intense circularly polarized hard x-rays from a novel multipole wiggler in an accumulation ring. Phys. Rev. Lett. **62:** 2672-2675.

Yamamoto S, T Shioya, S Sasaki, H Kitamura. 1989. Construction of insertion devices for elliptically polarized synchrotron radiation. Rev. Sci. Instrum. **60:** 1834-1837.