Schwarzschild type X-ray microscope

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I will present the results of x-ray microscope imaging experiments using a Schwarzschild objective as an application of x-ray multilayer mirrors. X-ray microscopes using an x-ray optics, which consist of multilayer mirrors, zone plates or grazing incidence mirrors, are being developed by various research groups. They are divided into two categories; an imaging type and a scanning type. In the imaging type, an x-ray image of a sample to be observed is formed on a detector. In the scanning type, x-ray micro-beam is scanned on a sample and the image is constructed. The main purposes of an x-ray microscope are the observation of biological specimens and the local area analysis. In the wavelength region from 2.33nm (O K-edge) to 4.37nm (C K-edge), which is called "water window" region, the difference of absorption coefficients between water and protein is relatively large. Using this wavelength region, wet biological specimens, which can not be observed by an electron microscope, can be observed with higher resolution than that of an optical microscope. The local area analysis is mainly performed using a scanning type. Photoelectrons or fluorescent x-rays generated by incident x-rays are analyzed. We are developing multilayer mirrors using an ion-beam sputtering apparatus. To confirm the applicability of the multilayers which we fabricated to practical x-ray optics, we made a Schwarzschild objective and performed imaging experiments. The objective was tuned to the wavelength of 4.48nm, which was easy to be generated using carbon Ka radiation and was slightly longer than "water window" region.

A Schwarzschild objective comprises two concentric spherical mirrors. In our objective, the magnification, the total length from object to image and the numerical aperture (NA) were x32, 1300mm and 0.2, respectively. We employed 50 layer pairs of NiCr(80:20 wt.%)/C multilayers with the thickness period of 2.25nm. Thin nickel layers tend to form an island structure, which causes interface roughness. The addition of chromium to nickel has a marked effect on preventing island formation. These multilayers were deposited using appropriately shaped masks to control the thickness distribution. Though the calculated reflectivity of these multilayers without interface roughness was about 20%, the actual reflectivity were about 4%. First, we performed imaging experiments using CKa radiation. A commercial fine-focus x-ray source, operated at 10kV acceleration voltage and 10 microamperes target current, with a 2.2 microns thickness of carbon film target was employed as an x-ray source of 4.48nm radiation. The sample was placed at a distance of 0.5mm from the target and a carbon filter was employed to screen visible light. The magnified image of 1000 lines/mm of gold transmission grating was taken on Fuji NEOPAN SS film with exposure time of 2 hours. 0.5 micron-L&S patterns were resolved.

Next, imaging experiments using a laser-plasma x-ray source were performed. The radiation from high density plasma produced by the irradiation of a high peak intensity pulse laser on a solid target is utilized in a laser-plasma x-ray source. We employed tantalum tape target with the thickness of 15 microns and Q-SW YAG laser with the pulse width and the repetition rate of 8nsec and 10Hz, respectively. The laser intensity on the target was 3x1012W/cm2. To screen visible light and debris emitted from a plasma, a carbon filter was employed. An ellipsoidal condenser mirror coated with 100 layer pairs of Cr/C multilayers was employed. Incidence angle of the condenser mirror was 65 degrees and the NA was 0.022. Because the NA of the condenser mirror was smaller than that of the objective, a portion of pupil of the objective was utilized. Using 1000 lines/mm gold transmission grating as a sample, 0.5 micron-L&S patterns were clearly resolved on Fuji NEOPAN SS film after 8000 shots of

exposure, which was equivalent to the exposure time of 13.3min. The exposure time was much shorter than that in the experiments using CKa radiation. Furthermore, the 0.6 micron-scale structure of a diatom sample could be observed.

Although the resolution was restricted to around 0.5 microns due to the granularity of films in these experiments, 0.1 micron-L&S patterns were delineated in the reduction lithography experiments using the same Schwarzschild objective. Normal incidence reflectivity of present multilayers at "water window" region is much lower than the theoretical value owing to their interface roughness. I eagerly expect that the optimization of materials and the improvement in deposition technology will increase the reflectivity of x-ray multilayer mirrors.