Development of a Compact Scanning Transmission X-Ray Microscope (STXM)

A new compact X-ray microscope has been developed at the soft X-ray undulator beamlines of the Photon Factory. Piezo-driven linear stages used as coarse stages realized a microscope with a very compact shape, thermally and vibrationally stable, and suitable for use at the “free-port” endstations of multipurpose beamlines. Fully digitized control electronics for pulse counting, scanner drive, and position sensing have been developed to realize efficient data acquisition. Imaging and microspectroscopic results obtained with the microscope are presented.

Scanning transmission X-ray microscopy (STXM) provides images and absorption spectra of a specific region of interest by scanning the sample position against focused X-rays [1]. STXM provides useful information about elemental composition, chemical states, magnetic properties by using circularly polarized X-rays [2], and molecular orientation by using linear dichroism [3] with a spatial resolution of 20–100 nm. In Japan, however, soft X-ray STXM has not been available until very recently [4].

Figure 1 shows the optics of our new STXM at the Photon Factory [5]. Soft X-rays from an undulator in the Photon Factory ring are monochromatized and focused by a toroidal mirror. The four-way aperture slit is placed at the focal point of the mirror to provide a virtual source point for illuminating the Fresnel zone plate (FZP). The FZP is a diffractive lens which has the focal distance of, in the present case, 0.7–5 mm depending on the photon energy. The first-order diffraction through the order sorting aperture (OSA) is focused onto the sample, and the intensity of the transmitted X-rays is then measured.

The scheme of the coarse stages in our STXM is in principle the same as that of the conventional STXM [1]. We utilized piezo-driven linear stages instead of stepping motors, resulting in: (1) a very compact shape of the main chamber with interior dimensions of 220 × 310 × 200 mm, (2) precise positioning of ~50 nm by using optical encoders implemented in the stages, and (3) high thermal stability since the piezo-driven stages produce less heat than do stepping motors. As shown in Fig. 1, the components from the aperture slit to the detector are placed on a single optical table, which is vibrationally isolated from the floor with protruding rubber pads. Thanks to this design, the compact STXM can be easily connected to and removed from the beamline, and so is suitable for use at the “free-port” endstations of multipurpose beamlines in the Photon Factory.

The transmitted X-rays can be detected in several ways: using an Si photodiode, Si avalanche photodiode, or the scintillator–optical fiber–photomultiplier (PMT) assembly. The precise sample position is scanned by piezoelectric scanners and the position is monitored with laser interferometric sensors. The X-ray detection, scanner drive, and position sensing functions are implemented in a field-programmable-gate-array (FPGA) circuit to realize fast and efficient data acquisition. The FPGA and user-interface programs were developed on a National Instruments LabVIEW platform, and the output data is fully compatible with the analysis software aXis2000 [6].

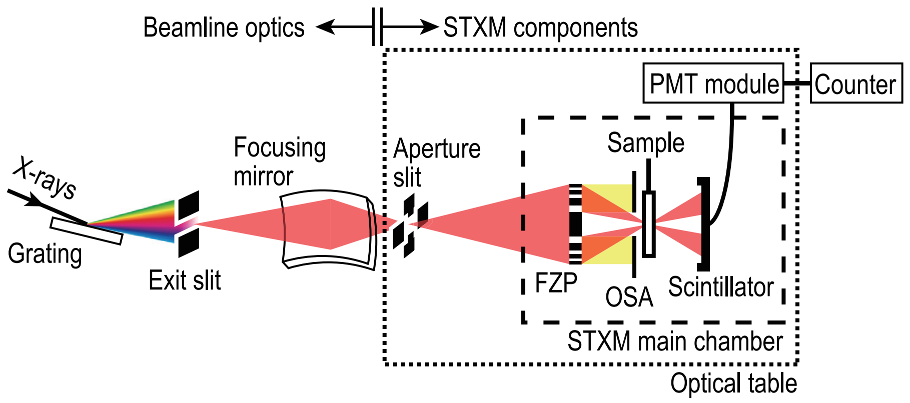

Figure 1: The optics of the compact STXM.

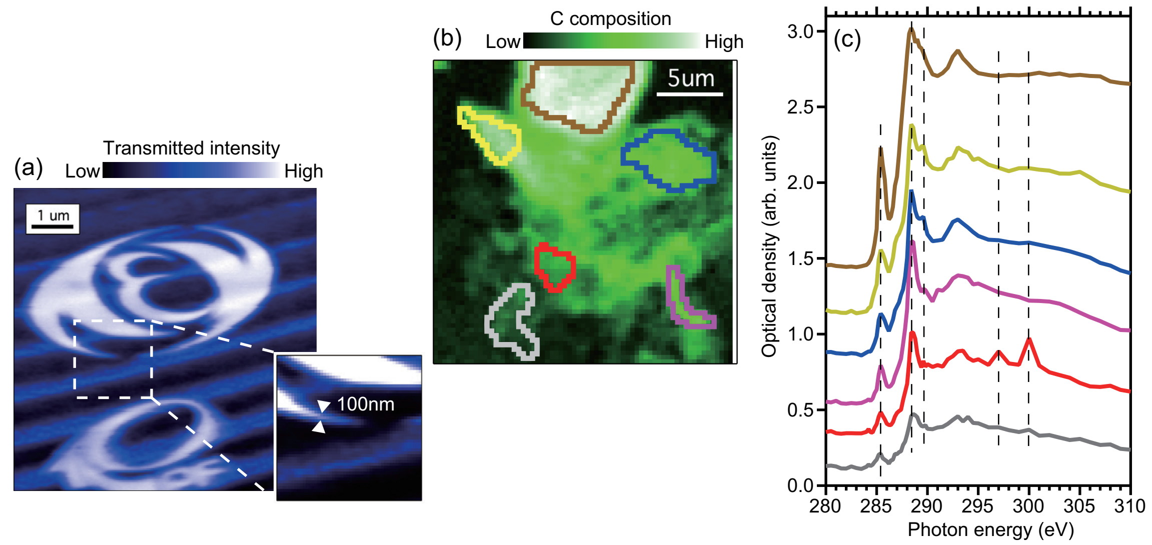

Figure 2: (a) X-ray transmission image of KEK and PF logomarks, which were patterned on ~300 nm-thick tungsten deposited onto an Si_3N_4 membrane. (b) C elemental composition map of particulate matter from the Pripyat River. (c) X-ray absorption spectra of the specific regions of interest. The colors of the spectra correspond to the regions indicated in (b).

Figure 2 shows the results obtained with the compact STXM. Figure 2(a) is the transmission X-ray image of logomark patterns measured using $h\nu$ = 350 eV [7]. The patterns were fabricated using a focused ion beam on ~300 nm-thick tungsten film deposited onto an Si_3N_4 membrane. The spatial resolution of our STXM is significantly better than 100 nm. Quantitative evaluation is currently in progress.

Figures 2(b) and (c) show the result of image stack measurement. The sample was particulate matter from the Pripyat River in Chernobyl City [8]. The photon energy was varied from 280 to 310 eV with the energy resolution of $E/\Delta E$ ~5000. Sixty-four images of 70 × 70 points were obtained at each point of photon energy. The total acquisition time was about two hours. Figure 2(b) shows the elemental composition map of C obtained by taking the difference of the images taken at the pre- and post-edge of the C *K* absorption edge. Figure 2(c) shows the absorption spectra obtained by collecting the data points in the region of interest indicated in Fig. 2(b). As shown here, STXM enables spatially resolved chemical speciation based on functional group or valency. Note that great care was taken to reduce carbon contamination in the beamline optics used here (BL-13A) [9], enabling quantitative characterization using C *K* edge absorption spectra.

A wide range of photon energy from 200 to 1500 eV is available with the compact STXM. It is now being utilized for the characterization of photovoltaic polymer blends [10], aerosols, clay minerals [8], and permanent magnets. Microspectroscopy using the compact STXM will be useful for a wide range of research in physics, chemistry, environmental science, and material engineering.

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BEAMLINES

BL-13A and BL-16A

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