X-RAY IMAGING WITH SUB-100 NM SPATIAL RESOLUTION AT 4 KEV

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The ID21 transmission X-ray microscope is an instrument which, in addition to offering the opportunity for sub-100 nm imaging with exposure times in the second and minute range, extends the imaging technique to spectro-microscopy applications thanks to the specific design of its monochromator.

A transmission X-ray microscope (TXM) for the photon energy range of 3-7 keV has been installed on the ID21 beamline. The optical scheme of the TXM (Figure 1) is analogous to that of a visible light microscope where the incident radiation is condensed onto the object and a magnified image of the sample is formed by an objective lens onto a spatially resolving detector. Zone plates are used as the condenser and imaging objective optics [1]. When compared to a TXM for soft X-rays, the major difference is that the setup for spectro-microscopy applications includes a Si monochromator with an energy resolution of about 10^{-7} [2]. The other difference is a consequence of the low emittance of insertion device sources at third generation synchrotrons; the low numerical aperture illumination makes it difficult to use a condenser as the unique beam-condensing element. To overcome this limitation, a rotating two-mirror assembly can be introduced into the condenser system to match the numerical aperture between the condenser and the imaging objective and to generate quasi-incoherent illumination [3,4]. The strategy adopted for the ID21 TXM was to favour mechanical stability for sub-100 nm spatial resolution imaging by keeping the design compact. The microscope's construction is highly modular and readily adaptable to different imaging modes. This approach allows sufficient space to be reserved for a variety of sample stage environments and, in particular, will allow later implementation of specialised stages for tomographic and cryogenic imaging.

To illustrate the imaging capabilities of the microscope, a customised test object was manufactured. The 400 nm-thick Au object was a variable line-spacing grating with line widths from about a micrometre down to 85 nm. The grating was imaged using an Au micro-zone plate with an outermost zone width of 70 nm. Both test object and micro-zone plate were generated at the Institute for X-ray Physics (IRP), Goettingen, Germany [5]. The 1 mm-diameter Au condenser zone plate was fabricated at the IESS/CNR, Rome, Italy [6] and has a diffraction efficiency of 19%. Figure 2 shows an absorption contrast X -ray image of the Au grating which was acquired at a photon energy of 4 keV with an exposure time of 1 s. The smallest lines of 85 nm can clearly be resolved with good contrast - this is the best performance reported for such a microscope at these energies.

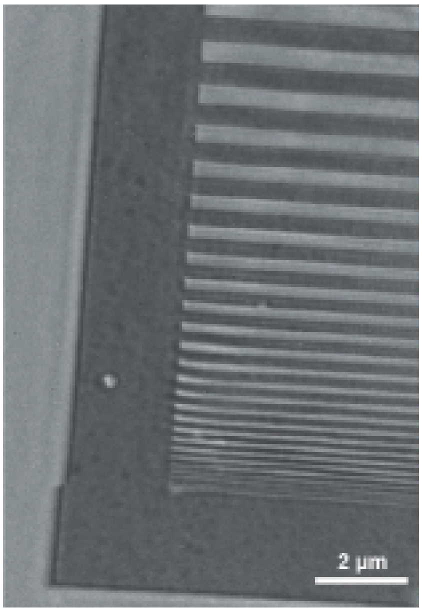

Fig. 2: High spatial resolution X-ray image of an Au test grating with varying line width from a few micrometres down to 85 nm. The image was taken at a photon energy of 4 keV, the exposure time was 1 s. The smallest structures of 85 nm can clearly be resolved with good contrast.

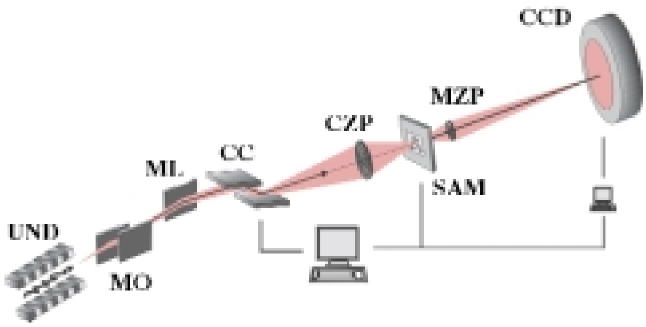

Fig. 1: Optical scheme of the transmission X-ray microscope at the ID21 beamline with the low bandpass filtering double mirror (MO), the beam-steering multilayer (ML), a channel-cut monochromator (CC), a large diameter zone plate (CZP) which condenses the beam onto the sample (SAM), and a micro zone plate (MZP) which produces a magnified image at the detector (CCD).

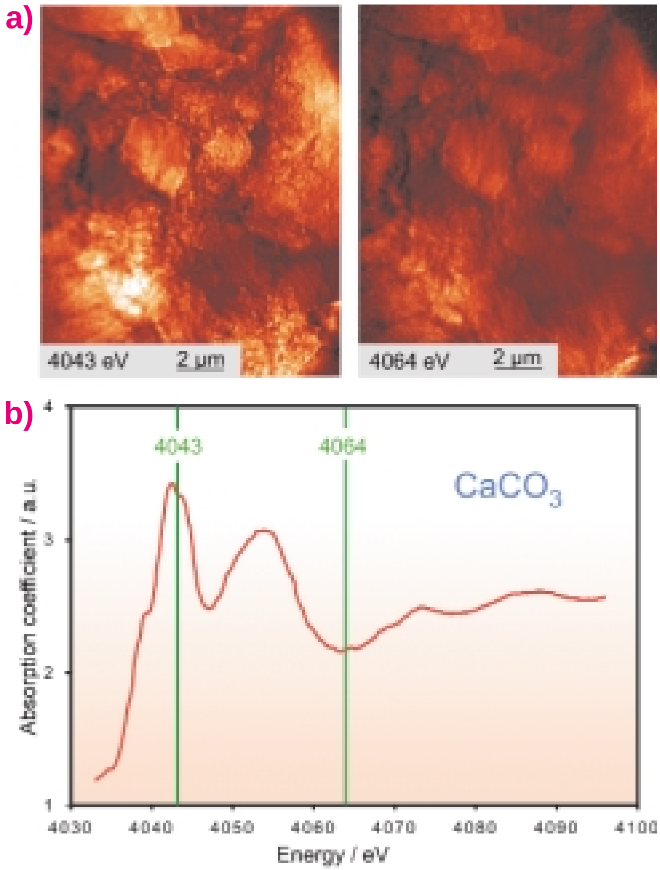

Fig. 3: X-ray spectro-microscopy: (a) Two sections of an energy stack of X-ray images of a concrete sample after the Ca K-edge, (b) the $CaCO_3$ spectrum recovered from a region of interest through the image stack.

The feasibility of spectro-microscopy was demonstrated by imaging concrete samples. A series of a hundred images was taken across the Ca K-edge (4038 eV), with energy steps of 0.6 eV and 30 s exposure time. The flat-field corrected images were aligned and organised in a three-dimensional array or energy stack, allowing quick access to the spectrum of any region of interest in the image (Figure 3).

The microscope is now being used for a wide variety of applications. It is suitable for the use of complementary imaging modes like absorption, Zernike phase or interference contrast. It offers the possibility of near-edge absorption studies for elemental mapping and analysis of the chemical states of the sample with sub-100 nm spatial resolution within the 3-7 keV energy range.

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ACKNOWLEDGEMENTS

The authors thank L. André, R. Baker, P. Bernard, G. Berruyer, A. Koch, F. Demarcq, D. Fernandez, P. Noé, S. Ohlsson, D. Rolhion, G. Rostain, M. Soulier, F. Thurel, and H. Witsch for their invaluable technical assistance and contributions. The performance of this microscope benefits from the high-quality phase zones plates produced by E. Di Fabrizio, M. Panitz and P. Charalambous. The conception of the microscope was aided greatly by many hours of fruitful discussion with many collaborators, especially B. Niemann, G. Schneider, T. Wilhein, and W. Meyer-Ilse.

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