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2009 J. Phys.: Conf. Ser. 186 012064

(http://iopscience.iop.org/1742-6596/186/1/012064)

Ellipsoidal capillary as condenser for the BESSY full-field x-ray microscope

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Abstract. The BESSY x-ray microscopy group has developed a new full-field x-ray microscope which employs an advanced x-ray optical concept. Traditionally, zone plate based condensers are used in x-ray microscopes providing an energy resolution of only $E/\Delta E \leq 500$. In addition, this conventional monochromator concept requires a pinhole close to the sample restricting the available space for tomography applications. In our new BESSY microscope, a standard monochromator beam line provides a high energy resolution of up to 10,000 which permits NEXAFS studies. An elliptically shaped mono-capillary is used to form the hollow cone illumination necessary for sample illumination and to match the aperture of the objective. Calculations regarding the performance and accuracies needed are presented and characterizations of capillaries especially made for the BESSY soft x-ray microscope are shown. For the first time, we demonstrate that glass capillaries are well suited as condensers in the soft x-ray energy domain. Their focusing efficiency was measured to be 80% which is about an order of magnitude higher than the diffraction efficiency of zone plate based condensers.

1. Introduction

The new optical setup for the BESSY full-field transmission x-ray microscope at the undulator U41 [1] is shown in Figure 1. The main advantage over other full-field soft x-ray microscopes is the absence of a monochromator pinhole close to the sample. Therefore, high spatial resolution and high tilt tomography of cryogenic or heated samples on flat sample holders are possible. As opposed to the zone plate condenser monochromator used so far, monochromatization and object illumination are independent from each other. Without changing or moving the condenser optic a wide energy range is available and the monochromaticity can be tuned. With this new optical setup, spectromicroscopy studies are routinely feasible in the full-field microscope.

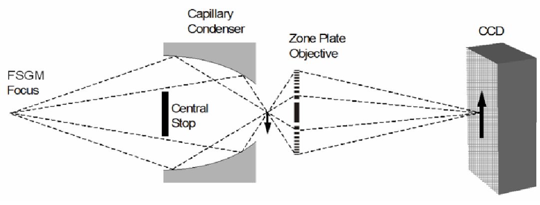


Fig. 1: The new optical setup for the BESSY full-field transmission x-ray microscope at the undulator U41 using a standard monochromator (FSGM) and an ellipsoidal glass capillary as condenser.

2. Ray tracing calculations

The parameters of the ellipsoidal capillary are determined by the beam divergence of the monochromator and by the desired aperture matching to the high resolution objective of the microscope. A homogeneous illumination of the capillary is required for an isotropic distribution of the radiation in the hollow cone illumination of the specimen. Therefore, ray tracing calculations for the monochromator beam line at the specific undulator source were carried out. Figure 2 shows the illumination of the capillary in different distances. Further results from these calculations show that the slope error of the capillary should be below 100 µrad and the alignment accuracy in the tilt angle of the capillary with respect to the incoming beam should be better than 100 µrad.

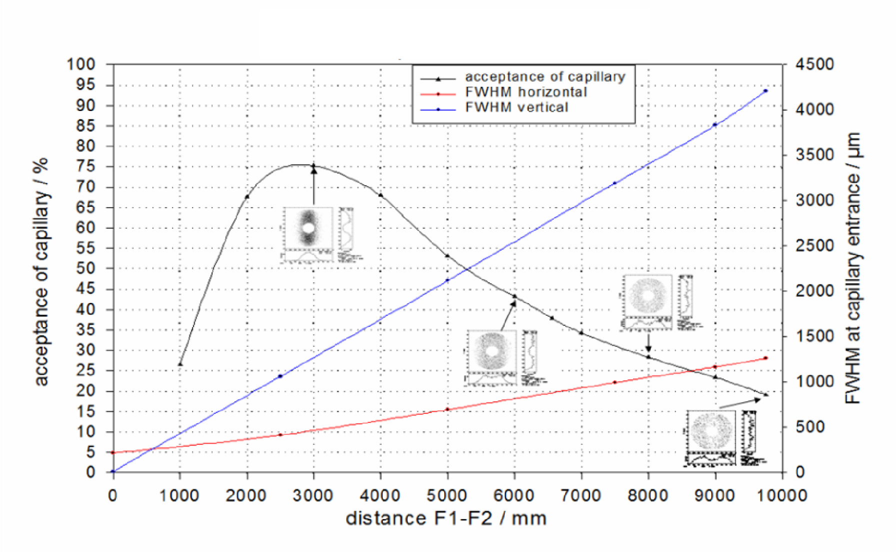


Fig. 2: Determination of the optimum distance F_1-F_2 of the focus of the capillary to the focus of the monochromator.

3. Results

The single-bounce ellipsoidal glass capillary was fabricated and evaluated by optical measurements during and after fabrication by Xradia [2]. The resulting slope error of 80 µrad is well below the limit calculated by ray tracing and is shown in Figure 3.

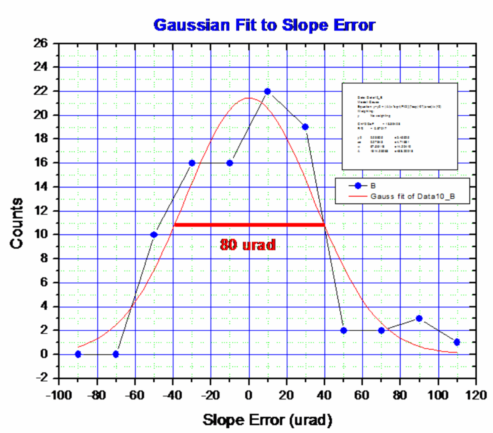
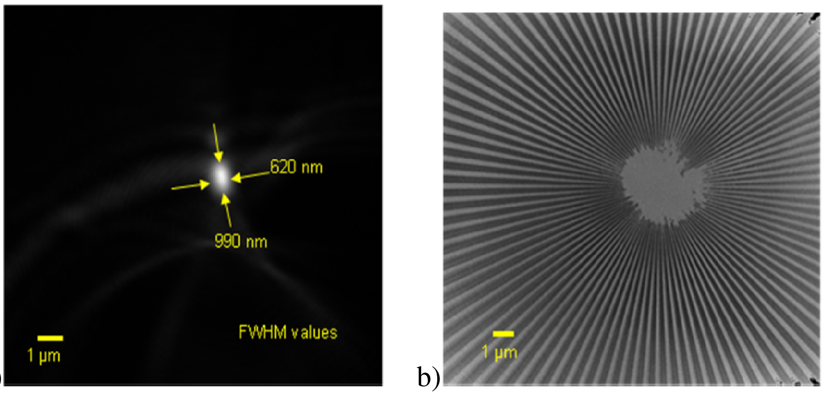


Fig. 3: Slope error of the fabricated single-bounce ellipsoidal capillary measured by optical methods by Xradia.

The x-ray performance of the capillary was tested with the BESSY x-ray microscope at the U41-FSGM beam line at a photon energy of 510 eV. Firstly, the capillary was adjusted to get the smallest possible focus. Figure 4a shows an x-ray image of the focus which is in size 620 nm x 990 nm (FWHM-values). Secondly, a Siemens star test pattern was used to demonstrate the imaging capabilities of the x-ray microscope using a capillary as condenser. To obtain a large homogeneously illuminated object field, the condenser is helically scanned. Figure 4b shows the x-ray image of this test pattern using a micro zone plate objective with 25 nm outermost zone width.

a) 

b)

Fig. 4: a) Focus of the capillary imaged by a micro zone plate at ΔE/E ≈ 9000, 510 eV, 100 ms exposure time. b) Test pattern imaged by a micro zone plate (both fabricated at BESSY by S. Rehbein, S. Werner) at ΔE/E ≈ 9000, 510 eV, 2 s exposure time with scanned condenser.

To analyze the performance of the new condenser, quantitative measurements were performed to measure the efficiency of the capillary. The focusing efficiency of the capillary was measured to be 80% for a photon energy of 510 eV. Note, this value exceeds the efficiency of zone plate condensers by nearly an order of magnitude.

4. Conclusions and outlook

For the first time, it is demonstrated that single-bounce ellipsoidal glass capillaries are well suited as condensers in the soft x-ray domain for full-field transmission x-ray microscopes. We report the highest focusing efficiency of 80% measured so far for soft x-rays. In the near future, it is planned to improve the slope errors of the capillaries and to increase the numerical aperture of the capillaries.

Acknowledgments

This work has been funded by the German Federal Ministry of Education and Research (BMBF) under contract number 05KS4BY1/7 and by the Human Frontier Science Program (HFSP) Research Grant Ref. RGP0053/2005-C.

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