Advanced X-ray Waveguide Optics for Nano-Beam Diffraction Experiments

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Two-dimensional channel waveguide can be used as a quasi-point source for coherent x-ray imaging [1] as for nano-beam diffraction experiments [2]. For these applications the transmission *T* of a channel waveguide and the mode structure are key parameters. In this experiment, we have recorded the farfield diffraction pattern of the waveguide exit radiation to determine the transmission *T* of single waveguides channels with controlled and varied cross section .The channel waveguides have been fabricated by e-beam lithography and reactive ion etching in combination with wafer bonding [3].

The measurements were performed at the Nanofocus end station EH2 of the P03 beamline at 13 keV. The beam was focused by Kirkpatrick-Baez-Mirrors (KB-Mirrors) down to 306 nm in horizontal and 339 nm in vertical direction (FWHM), respectively. The entrance of the waveguide channels were aligned in the KB focal plane. Additionally a pinhole with a diameter of 200 µm was introduced at the exit side of the waveguide to block the primary beam (i.e. overillumination due to KB streaks). The farfield images were recorded by a single photon counting pixel detector (Pilatus 1M, 172×172 µm^2 pixel size) placed 2.6 m behind the waveguide. The integrated intensity of the KB beam was 3.9×10^8 cps. The transmission is defined as $T=(I_{WG}/I_{KB})/(A_{WG}/A_{KB})$, where I_{WG}/I_{KB} is the ratio of the integrated intensity exiting the waveguide I_{WG} to the integrated intensity of incident beam I_{KB}, and A_{WG}/A_{KB} (geometry factor) is the ratio of the area of the guiding core A_{WG} to area of the incident beam A_{KB}. The transmission rates and the parameters of the measured channel waveguides are shown in Table 1.

Width as designed physical properties	750 nm	500 nm	300 nm	200 nm	150 nm	100 nm
Actual width (nm)	1001	617.4	389.7	252.3	193.7	150.7
Depth (nm)	9.5	41.3	35.7	26.8	31.7	25.7
Geometry factor	0.09	0.25	0.14	0.07	0.06	0.038
T (%)	2.47	9.47	11.09	7.76	3.62	0.053
I_{WG}	8.75×10^5	9.01×10^6	5.77×10^6	1.96×10^6	8.296×10^5	7.61×10^3

Tab.1: The characterization of channel waveguides at photon energy 13 keV.

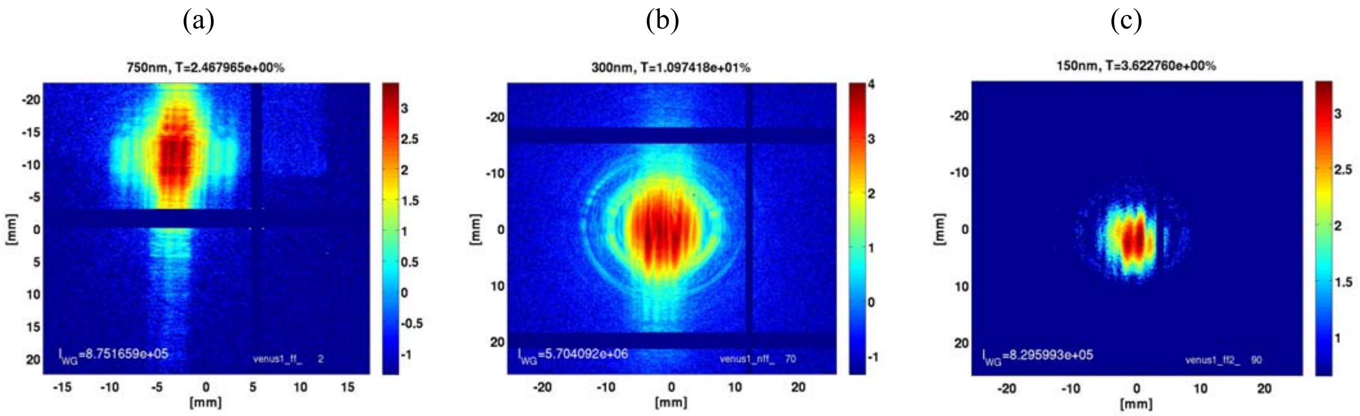

Fig.1: Example of farfield diffraction patterns corresponding to waveguides channels with lateral width of (a) 750 nm, (b) 300 nm and (c) 150 nm at photon energy 13 keV (intensity in logarithmic color code). The farfield patterns reflect the mulit-modal structure. The near-field distribution in thee waveguide exit plane (data not shown) can be obtained from iterative algorithms such as the error reduction algorithm

A selection of farfield images of waveguides with widths from 150 nm to 750 nm and 5 mm in length is shown in Fig.1. In the farfield images vertical stripes can be observed at the center of the diffraction patterns that indicate a mode beating effect in the exit plane. This effect implies a multimodal waveguiding and therefore its impact increases with the channel width. During the measurement, we observed significant changes in the recorded farfield patterns and the intensity, although no parameter was changed manually. To quantify this phenomenon, we recorded farfield images of the same waveguide (200 nm) as a function of time (see Fig.2). The integrated intensity of the farfield images changed by an order of magnitude during the measurement. This drift must be attributed either to thermal drift in the hutch or to the pointing instabilities of the incoming beam (orbit drift). In fact, the beam had shifted significantly with respect to the waveguide position over a timescale of only one minute by 475 nm in x- (horizontal) and 100 nm in y-direction (vertical), showing that the waveguide can also be used as a diagnostic tool to monitor beam/sample drift.

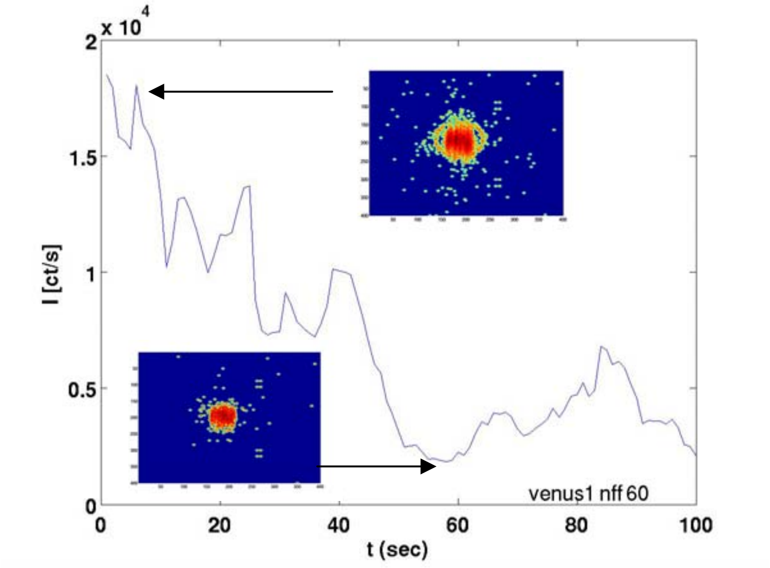

Fig.2: Variation of the integrated farfield intensity over time. The farfield patterns at 8 s and 58 s are shown exemplarily.

To reduce the impact of the thermal drift movement, the door to the experimental hutch EH2 should not be opened at least a few hours before the measurement begins. This ensures that a thermal equilibrium has been established in the whole hutch. In this manner a decrease of the relative shift between beam and waveguide with time was achieved..

For a two-dimensional channel waveguide to be used as quasi-point source for imaging, the most important requirements are:small beam size, high transmission rate T and a homogeneous farfield pattern.The present results indicated a significant amount of deviation from the design and simulated values. The fabricated channels depth and transmission strongly decreased as a function of its width, indicating fabrication problems in the etching and bonding process, which have then been further investigated after the experiments. An improved fabrication protocol has now solved the problems [2]. To further increase the transmission rate T, waveguides in tapered geometry have been designed and fabricated (see Fig. 3).

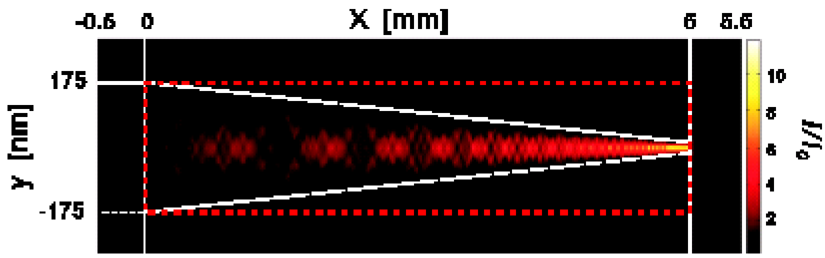

Fig.3: Simulated wavefield inside a tapered waveguide channel. The entrance width is adjusted to the KB focus. Simulation show that the usable flux can be increseaed by up to a factor of 20 (tapre only in one dimension).

Reference:

[1] M. Bartels et al, Optical Nanoscopy 2012, **1**:10; C. Krywka et al., J. Appl. Cryst. (2012). 45, 85-92

[2] H. Neubauer, S. Hoffmann, M. Kanbach, J. Haber, S. Kalbfleisch, S.P. Krüger, T. Salditt, submitted to J. Appl. Phys (2014)