Setup of an 8 keV laboratory transmission x-ray microscope

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Abstract. This article presents a concept and the first results for the setup of an 8 keV laboratory transmission x-ray microscope with a polycapillary optic as condenser at the BliX in Berlin. The incentive of building such a microscope is that the penetration depth for hard x-rays is much higher than in the soft x-ray range, e.g. the water window. Therefore, it is possible to investigate even dense materials such as metal compounds, bones or geological samples. The future aim is to achieve a spatial resolution better than 200 nm.

1. Introduction

Full field laboratory hard x-ray microscopes have been developed in the last decade and the achieved resolution is below 40 nm [1, 2]. One of the challenges of setting up a hard x-ray transmission microscope in the lab is the long focal length of several millimeters of the objective lens, which leads to very long image distances to get a high detector resolution. Additionally, in order to get a high photon flux in the image plane, the numerical apertures of the condenser and the objective lens should match. This leads to further implications for the design of the condenser lens as well as for a suitable detector system with proper spatial resolution to avoid long image distances. In this article we are showing the first results obtained with a polycapillary optic as condender in our laboratory hard x-ray transmission microscope.

2. Experimental Setup

The experiment setup, see figure 1, consists of a copper x-ray tube (A), a polycapillary optic (B), the object within a pinhole (C), a zone plate as objective lens and central stop (D) and a x-ray CCD (E). In the following the different components are described.

2.1. X-ray source

The x-ray source of the laboratory x-ray microscope is a micro focus tube. The tube has a copper target to get the characteristic line emission at 8.05 keV and a source size of about 50 µm

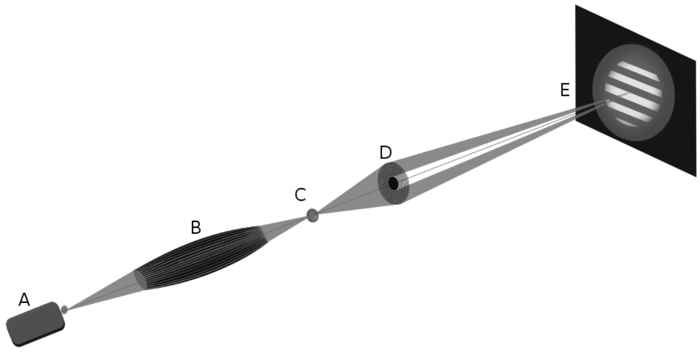

Figure 1. Schematic setup of the transmission microscope.

(FWHM)[3]. Reducing radiation damages to the CCD the maximum acceleration voltage of the tube has been set to 30 kV.

2.2. Condenser

A polycapillary is used as condenser. This optic consists of very thin and bowed hollow glas capillaries acting as wave guide based on total external reflection [4]. All capillaries are pointing to the focal spot resulting in 50 µm spot size (FWHM). A proper condenser should have a high acceptance angle at the entry, a divergence angle at the exit of the capillary matched to the numerical aperture of the zone plate and a high efficiency. In practice, not all conditions can be realized in one device and one has to make a compromise. In our setup the aperture of the condenser optic does not match to the zone plate aperture, i.e. light collected by the condenser does not completely contribute to image formation. But due to the focusing properties of the polycapillary, an increase of the intensity in the object plane is reached and the object is illuminated under different angles. In figure 3 one can see the illumination cone of the capillary optic in a distance of 405 mm to the focal spot.

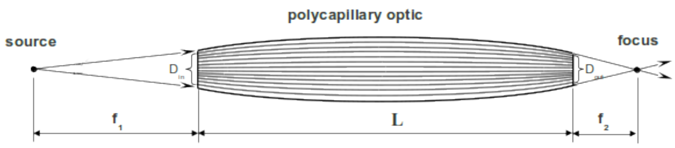

Figure 2. Schematic drawing of a polycapillary optic. Image taken from [4].

Table 1. Parameters of the polycapillary optic. Values are denoted in mm.

f_1	D_{in}	L	f_2	D_{out}
62.3	2.2	45.4	18	1.2

2.3. Objective lens and central stop

A tungsten zone plate with a focal length of about 32.5 mm at 8.05 keV and an outermost zone width of 50 nm is used as objective lens. The zone plate produces a magnified image of the illuminated object on a CCD with 20 µm · 20 µm pixel size. The central stop (CS) is mounted in front of the zone plate and the illumination cone of the polycapillary forms a shadow of the CS on the CCD preventing background illumination. In this shadow the magnified image of the object is formed by the objective. Ideally, the position of the CS is at the exit of the condenser optic. But due to the beam divergency of each capillary a CS on a polycapillary would not form a sharp shadow on the CCD.

3. First results

In the first steps a 30 µm in diameter Pt/Ir-pinhole was used as an object. The resulting image with 108-fold magnification is shown in figure 4. An aluminium aperture with 4 mm in diameter in front of the detector blocks all the light around the image area.
To get a first valuation of the achievable spatial resolution a gold mesh with 5.5 µm bar width and 10.5 µm spaces was used. The resulting 143-fold image is shown in figure 5. For a 143-fold magnification and a pixel size of 20 µm the resulting effecitve pixel size is 140 nm and therefore the Shannon-Nyquist-theorem gives a maximum spatial resolution of $4 \cdot 140\,\mathrm{nm} = 560\,\mathrm{nm}$. The corresponding line plot through the edge of a mesh bar is shown in figure 6 and the measurement from 10% to 90% edge profile gives an estimated spatial resolution of about 580 nm, i.e. the resolution of the system is mainly detector limited.

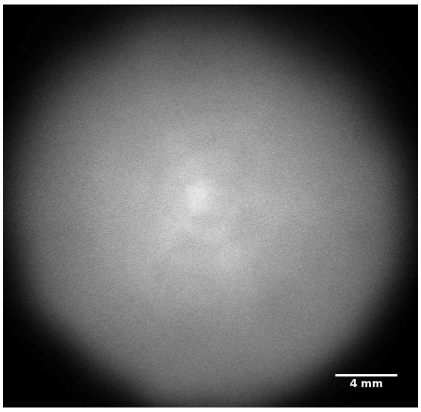

Figure 3. Image of the polycapillary illumination cone. Focal spot to CCD distance is 405 mm.

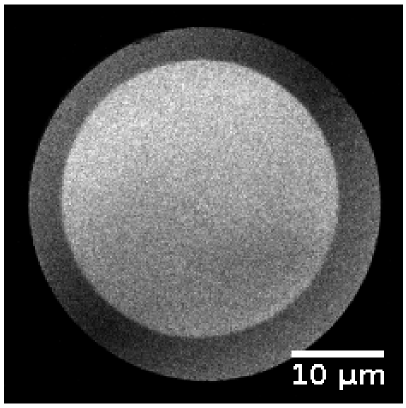

Figure 4. Image of a 30 µm in diameter Pt/Ir-pinhole. 108-fold magnification.

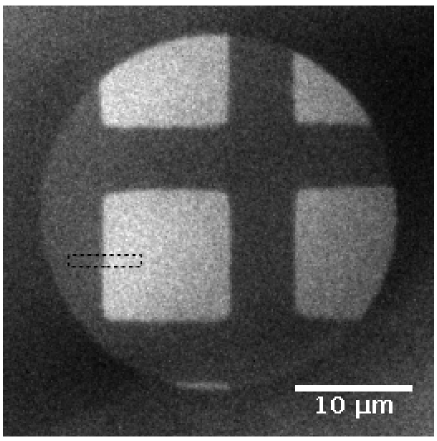

Figure 5. Image of a gold mesh with 1500 line pairs per inch. 143-fold magnification.

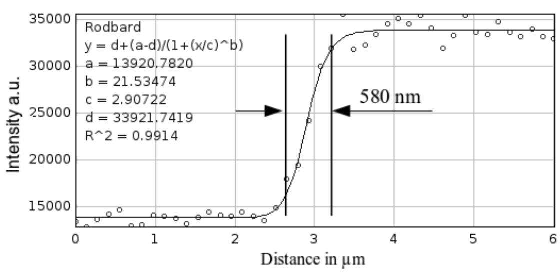

Figure 6. Line plot through the egde of a mesh bar, (black box in figure 5).

4. Summary and Outlook

We have shown that a polycapillary optic can be used as an x-ray condenser in a laboratory 8 keV x-ray transmission microscope. The resolution of the current system is in the sub micro meter region and is still detector limited. A better detector resolution would be achieved with a higher magnification, respectively a longer image distance. But a detector system with smaller pixel sizes, e.g. an image intensifier and a phosphor screen with grain sizes about 2 µm would be the proper choice. In future it is planned to optimize the condenser optic in order to increase the photon flux in the object plane and to get a more adapted output angle to the zone plate. With the described improvements a resolution below 200 nm would be feasible.

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