The use of zoneplates for point projection imaging

Stefan Baumbach[1] **and Thomas Wilhein**[1]

[1] Institute for X-Optics, RheinAhrCampus Remagen, University of Applied Sciences Koblenz, Suedallee 2, 53424 Remagen, Germany

E-mail: `baumbach@rheinahrcampus.de`

Abstract. For point projection and phase contrast imaging very small x-ray spot sizes are the key to achieve high resolution images. This article shows a concept of demagnifing the spot of an 8-keV micro focus x-ray tube with a zoneplate. The zoneplate in combination with an order selection aperture acts as a monochromator, which is an enhancement especially for phase contrast imaging. With this concept, the resolution in our point projection microscope has been improved by a factor about two.

1. Introduction

Point projection or projection based phase contrast imaging is very well known. But, due to technical limitations, very small spot sizes are difficult to achieve. In a point projection microscope the resolution is primarily limited by the spot size. So, the idea was to demagnify the x-ray spot with a zoneplate to improve the contrast transfer function (CTF) of the system and therefore to gain higher resolution.

2. Experimental setup

Figure 1 shows a schematical drawing of the experimental setup. A microfocus tube (1) with a copper target to get the Cu-K-α line at 8.05 keV was used as an x-ray source. Zoneplate nr. 1 (3) (for technical information see table 1) forms a demagnified image of the x-ray source into the plane of the order selecting aperture (OSA)(4). This image is now the source of the projection microscope forming an absorption and/or phase contrast image of the object (5) on the detector (8). A beam stop (7) is placed in front of the detector to block the 0^{th} order of the zoneplate.

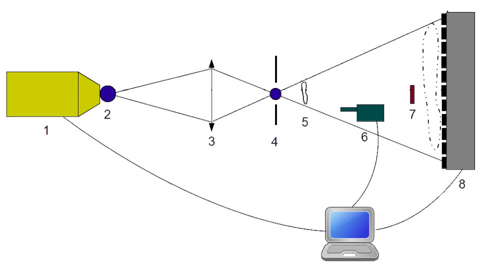

Figure 1. Schematical setup: (1) x-ray tube, (2) tube spot, (3) zoneplate, (4) OSA and demagnified tube spot, (5) object, (6) x-ray spectrometer, (7) beam stop, (8) CCD.

Table 1. Zoneplates technical information.

	Zoneplate nr. 1	Zoneplate nr. 2
Material:	900 nm Tungsten	500 nm Tungsten
Diameter:	180 μm	120 μm
Outer zone width:	80 nm	50 nm
Focal length at 8.05 keV:	93.5 mm	38.96 mm

3. Comparison of the spot sizes and spectral bandwidth

To get quantitative information about the tube spot and the demagnified spot, zoneplate nr. 2 was used as an objective lens forming a magnified image of each x-ray spot on the detector. Figure 2 shows an image of the original tube spot (left) and an image of the demagified spot (right). The tube spot size in diameter is about 3.3 μm (FWHM). The demagnified spot size has a diameter of about 2.10 μm (FWHM). Due to the wave length dependency of the focal

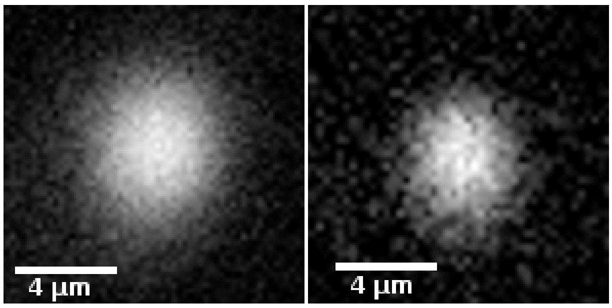

Figure 2. Left: Image of the original tube spot. **Right:** Image of the demagnified tube spot.

length of the zoneplate and the use of an OSA, the spectral bandwidth of the demagnified source is much smaller than the spectral bandwidth of the original tube spot. A comparision of the images in figure 3 shows that the Cu-K-β line emission as well as the continuous spectrum is extenuated. The degree of monochromatisation is proportional to the ratio between zoneplate diameter and two times the diameter of the OSA [1], so a smaller OSA would produce a smaller spectral distribution.

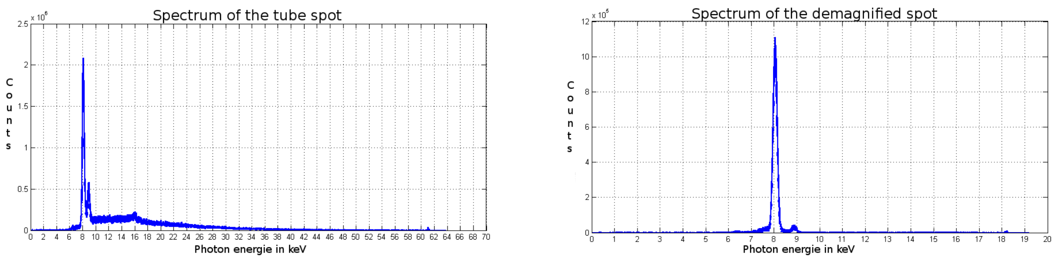

Figure 3. Left: Spectrum of the original tube spot. **Right:** Spectrum of the demagnified spot using a zoneplate and an OSA as monochromator.

4. Contrast Transfer Function (CTF)

The CTF of a projection based phase contrast microscope mainly depends on the x-ray source size (spatial part of the CTF) [2] and on the spectral distribution of the incident radiation (spectral or temporal part of the CTF) [3], assumed that the resolution is not detector limited. The contribution of the source size to the CTF is simply the fourier transform of the spatial distribution of the source. The contribution of the spectral part is given by the following formula [3]:

$$D(u, v) = e^{-(\pi z(f_x^2+f_y^2)\Delta\lambda)^2/8}. \quad (1)$$

Hereby, $\Delta\lambda$ is equal to the gaussian spectral bandwidth of the x-ray source, f_x and f_y are the spatial frequencies in the x and y direction and z is the source to object distance. So, with decreasing z and/or decreasing $\Delta\lambda$, the system is able to visualize smaller object features in propagation based phase contrast images. Figure 4 shows a comparison of the spatial and spectral part of the CTF for the tube spot and the demagnified spot and a combination of both parts in figure 5. Due to the demagnification and the monochromator setup, the resolution has been improved by a factor of about two, assuming 50% contrast as resolution criterion.

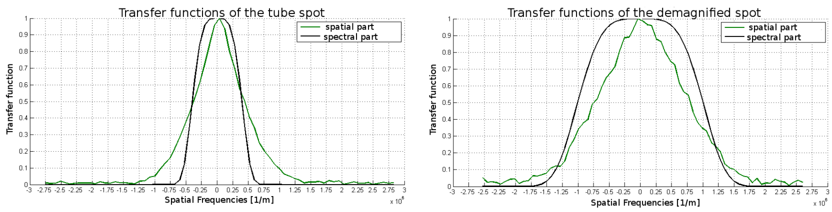

Figure 4. Left: Spatial and temporal CTF of the tube spot **Right:** Spatial and temporal CTF of the demagnified spot.

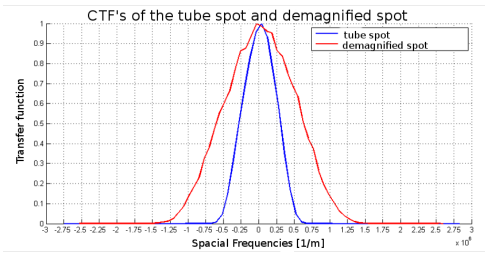

Figure 5. Combined CTF's.

5. Experimental results

An optical fiber core with 125 μm diameter was used as an object and point projection images were taken. Figure 6 shows the images of the core taken with the tube spot (left) and with the demagnified spot (right), respectively.

In figure 6 (right) the more enhanced phase contrast features of dark and bright fringes at the edges of the core are clearly visible.

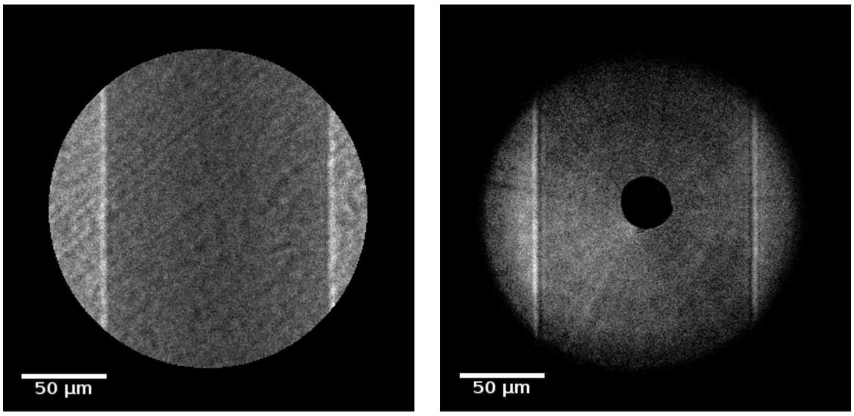

Figure 6. Phase contrast image of a fiber core, illuminated with the tube spot (left) and with the demagnified spot (right).

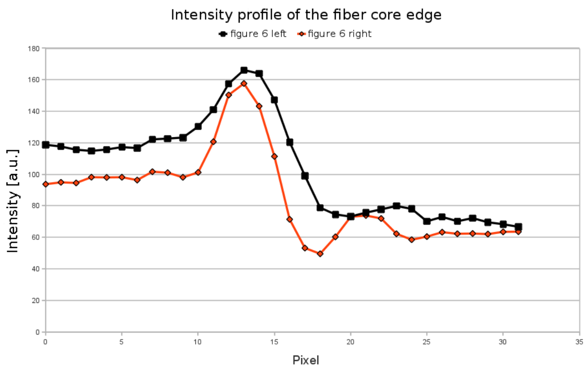

Figure 7. Lineplot through the left edge of figure 6 (left), and through the edge of figure 6 (right), respectively.

6. Conclusion

In this article we have shown that zoneplates can be used to improve the contrast transfer function of a point projection microscope by demagnifying the source of a laboratory x-ray tube. Simultaneously one achieves a smaller spectral bandwidth by using an order selecting aperture. This results in more enhanced dark and bright fringes in projection phase contrast images and smaller object features are visible.

References

[1] Hambach D 2001 *Nanostrukturen mit hohem Aspektverhaeltnis als lichtstarke diffraktive Roentgenoptiken fuer hohe Beugungsordnungen* (Cuvillier Verlag)
[2] Gureyev T and Wilkins S 1998 *Optical Society of America* **15, No.3** 579 – 584
[3] Mayo S and Miller P 2002 *Journal of Microscopy* **207** 79 – 96