FRESNEL ZONE PLATES FOR IMAGING AND FOCUSING NEUTRONS

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The high penetration power of neutrons makes them ideal for non-destructive studies of materials and enables *in situ* measurements of the environment-dependent properties. The requirement of non destructive characterisation tools, coupled to the ability of manipulating the neutron beam in the sub-millimetre scale by novel neutron optics, would make neutron diffraction and imaging a powerful technique in the rapidly evolving fields of biophysics and nano-science research. Here we report on the results obtained in focusing a cold neutron beam by means of two newly developed optical devices, which exploit the Fresnel zone plate (ZP) concept, and have been designed to intercept a large portion of the beam and to minimise flux losses.

Recently innovative applications of neutron radiography and imaging have been presented [1-2], which stimulate the development of novel optical devices for neutron beam focusing [3-6]. Long ago [7], it was demonstrated that a phase reversal ZP can be successfully employed to focus and image a cold neutron beam ($\lambda \approx 20$ Å). It is only in recent times that progress achieved in nano-fabrication has made possible the production of high-efficiency and high-resolution ZPs for focusing of short wavelength x-rays [8] (see figure 1).

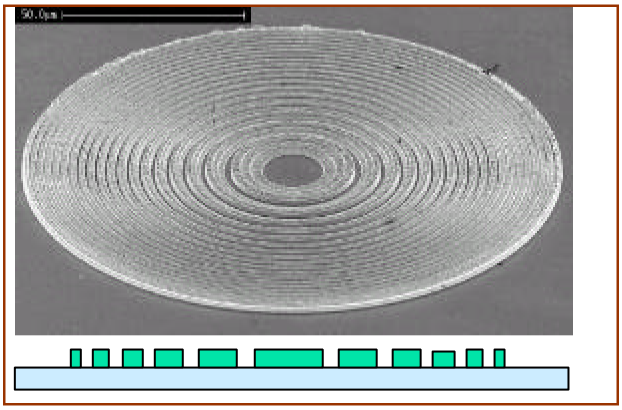

Figure 1 : (top) MEB image of a Fresnel zone plate (bottom) side view of the lens, in blue the Si substrate and in green the Ni rings.

Exploitation of the modern nano-lithographic techniques will give a new impetus to the field of neutron optics while opening challenging possibilities for neutron microscopy.

We have developed two devices characterised by a relatively large aperture and size of the lens, and rather short focal length. The first is a large aperture phase reversal ZP, with 5 mm diameter and 13.5 m focal length at 1.54 Å thermal neutron wavelength. The second is a square matrix, 1 cm^2 surface, consisting of 900 zone plates, 0.3 mm diameter each and 1 m focal length at 3 Å. The matrix is capable of focusing the neutron beam from a point source into 900 small spots. The thickness of the phase shifter (natural Ni) was larger than 3.5 µm, resulting in aspect ratios of ~11 and ~5 for the two devices respectively.

A series of neutron tests was carried out on the monochromatic neutron beam of the TPA diffractometer. The performances of the ZP were measured at $\lambda = 6.85$ Å, which corresponds to focal length of 3 m and a theoretical efficiency of ~ 40%. A 1 mm hole was inserted at 3 m upstream the ZP, so that a parallel beam 5 mm diameter was expected at the image plate detector (0.15 mm resolution), 4 m downstream the lens (Fig. 2).

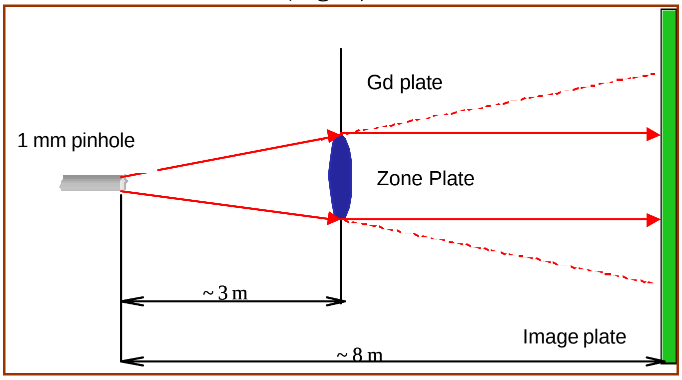

Figure 2 : experimental configuration

The difference between the intensities collected with and without insertion of the ZP is shown in figure 3. The focusing effect is clearly visible and a measured efficiency in excess of 20% was obtained.

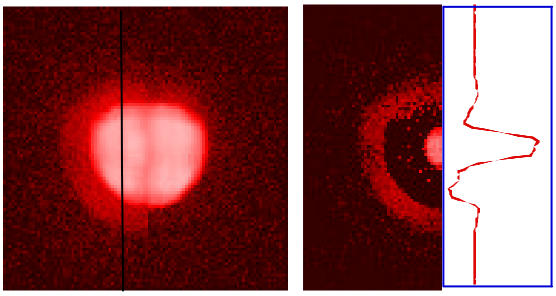

Figure 3. (left) images without and with the lens (right) measurement of Intensity map obtained by taking the difference between the measurement with ZP and without it.

The zone plate matrix (Fig. 4) was tested at λ = 13.7 Å, with a 0.8 mm pinhole placed at the image position, 23.6 cm from the lens, where 900 spots, 70 μm in diameter each, are formed. In the experimental configuration, a sharp spot is expected without the matrix, whereas a broad image is formed at the detector position when the matrix is in place. This is apparent from figure 5, where the intensity difference is shown.

The present test clearly demonstrates the excellent operation of these new devices which enable an easy focusing of neutron beams at sub-millimetre scale, with potentially useful applications in high-resolution neutron imaging.

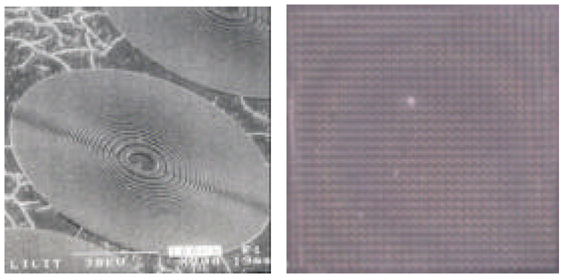

Figure 4. (left) matrix of zone plates (30x30) (right) an individual zone plate. scanning electron microscope image of a portion of the ZP matrix.

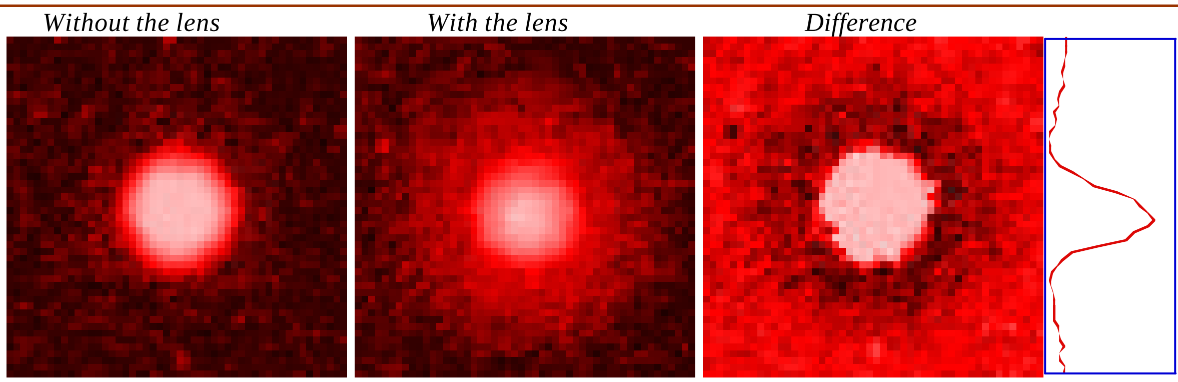

Figure 5: Intensity map obtained by taking the difference between the measurement with the matrix and without it.

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