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61st Annual Meeting of the American Physical Society  
Division of Plasma Physics, Fort Lauderdale, FL  
21-25 October 2019

High-Resolution X-Ray Imaging with Fresnel Zone Plates on the University of Rochester’s OMEGA and OMEGA EP Laser Systems

Fresnel zone plate image  
OMEGA EP shot 30382  
Au grid backlit with 4.75 keV x rays

Ti backlit (4.75 keV) FZP images taken with a high speed framing camera ($\Delta t \sim 30$ ps)

LANL Revolver double shell implosion (Inner shell after collision)
Experiments performed on the OMEGA and OMEGA EP Laser Systems have used Fresnel Zone Plates (FZP’s) obtaining x-ray images with a best resolution of ~1.5 µm

FZP* resolution tests at LLE have achieved ~1.5 to 1.6 µm resolution by direct x-ray detection using CCDs and film and ~3 to 4 µm resolution using high-speed framing cameras.

We have performed a number of experiments on both OMEGA and OMEGA EP using FZPs to obtain radiographs of driven foils and imploding shells as examples.

X-ray imaging with single or arrays of FZPs is being implemented for a magnification of 25 in the OMEGA and OMEGA EP diagnostic inserters.

*FZPs manufactured by Applied Nanotools Inc., Edmonton, AB
S.T. Ivancic, C. Mileham, P.M. Nilson, and J.J. Ruby
University of Rochester, Laboratory for Laser Energetics

B.S. Schiener, M.J. Schmitt, and C.A. Wilde
Los Alamos National Laboratory
Fresnel Zone Plates obey a simple focus equation dependent on wavelength and are best used for monochromatic backlighting.

FZPs obey the thin lens equation:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

The FZP focus length is given by:

$$f_{FZP} = \frac{4N(\Delta r)^2}{\lambda}$$

where

- $p =$ object to optic distance
- $q =$ optic to image distance
- $R_{mirror} =$ mirror radius of curvature
- $N =$ number of zones
- $\Delta r =$ width of outermost zone of FZP
- $\lambda =$ wavelength of x-rays

500 zone, 216 µm OD, 1.3 µm thick Au FZP with 108 nm outer bars, for 8 keV x rays

www.appliednt.com
We currently have a set of FZPs that can be used over an energy range from 1.9 to 9 keV

<table>
<thead>
<tr>
<th>FZP</th>
<th>Z</th>
<th>$dt$ (µm)</th>
<th>N</th>
<th>$D$ (µm)</th>
<th>$\Delta Rn$ (nm)</th>
<th>$f$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu(8 keV)</td>
<td>Au</td>
<td>1.3</td>
<td>500</td>
<td>216</td>
<td>108</td>
<td>156.4</td>
</tr>
<tr>
<td>Ti(4.8 keV)</td>
<td>Au</td>
<td>1.3</td>
<td>512</td>
<td>281</td>
<td>120</td>
<td>151.9</td>
</tr>
<tr>
<td>P(2.1 keV)</td>
<td>Ni</td>
<td>0.9</td>
<td>258</td>
<td>300</td>
<td>291</td>
<td>151.8</td>
</tr>
</tbody>
</table>

Each case is not restricted to the central energy
The focal length however is linearly proportional to energy ($1/\lambda$)
We currently have a set of FZPs that can be used over an energy range from 1.9 to 9 keV.

Example FZP efficiencies are shown for Au zoneplates and are accurately calculated from the atomic scattering factors.
Fresnel zone plates can dramatically increase the x-ray image resolution over that obtained with a pinhole

Spoke averaged star patterns (407 micron diam) taken with an x-ray CCD in the LLE X-Ray Laboratory at M=14.4

FZP image at Ti K$_\alpha$ (4.51 keV)

20 10 3 µm

1.5 µm

~1.5 µm resolution

10 µm diam pinhole image

~10 µm resolution
We are currently able to obtain a resolution of \( \sim 1.5 \) to \( 1.6 \) \( \mu \)m using Fresnel zone plates, limited by the choice of detector.

\[ *LSF(x) = \frac{d}{dx}(ESF(x)) \]

**OMEGA EP shot 31019**
- V He\( \alpha \) backlighter (5.2 keV)
- FZP CCD image

- 0.8 micron thick Au grid
  - (6 micron bars, 19 micron gaps)

**Edge spread function ESF(x)**

![Graph of Edge spread function](image)

- Signal (a.u.)
  - 0
  - 0.4
  - 0.8
  - 1.2
- Pixel number
  - 0
  - 200
  - 400
- Distance (microns)
  - 500 µm

**Line spread function LSF\(^*\)(x)**

![Graph of Line spread function](image)

- FWHM=1.54+/-0.16
  - (10 edge values)
We are currently able to obtain a resolution of ~1.5 to 1.6 µm using Fresnel zone plates when images are recorded with a CCD.

**OMEGA EP shot 30382**
Ti Heα (4.75 keV) backlit grid

**FZP CCD image**
Au grid with 6 µm bars
19 µm gaps

**Full width half max (FWHM)**
LSF*(FWHM)=1.62±0.31 µm
Measured over 8 grid edges

**Distance (microns)**
**Signal derivative (a.u.)**

Δx=1.62±0.31 µm (average over 8 edges)

* Nyquist limit = 2 pixels = 1.21 µm
A Fresnel zone plate image of a resolution grid was obtained with a high speed framing camera ($\Delta t \sim 30$ ps) with $\sim 3$ to 4 um resolution.

XRFC1 film recording
Ti backlighter (4.75 keV)

FZP image
OMEGA shot 94697

Grid pattern averaged over region

Intensity (a.u.)

Distance (µm)

~3-4 micron blurring

Au grid 6 µm bars, 19 µm gaps
Framed FZP imaging is used to study the collision of the outer shell with the inner shell in LANL Revolver double shell implosions on OMEGA.

Mode structure evident in earlier post collision images.

Revolver-19B Experiments
B. S. Scheiner, M. J. Schmitt, LANL
F. J. Marshall, P. M. Nilson, LLE
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Backup slides
When imaged with a framing camera the limiting resolution of FZP images is ~2.5 to 3 µm at a magnification of ~20.
We are currently able to obtain a resolution of ~1.5 to 1.6 µm using Fresnel zone plates, limited by the choice of detector.

OMEGA EP shot 31019
V Heα backlighter (5.2 keV)

0.8 micron thick Au grid
(6 micron bars, 19 micron gaps)

Edge spread function
FWHM=1.54+/−0.16
(10 edge values)
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Spoke averaged star pattern (407 micron diam) taken with an X-ray CCD at M=14.4

OMEGA EP shot 30382
1 kJ in 0.5 ns on Ti foil
Fresnel zone plate image of 1000 mesh 0.8 micron thick Au grid
6 micron bars, 19 micron gaps

FZP image at Ti Kα (4.51 keV)

20 10 3 µm

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Spoke averaged star pattern (407 micron diam)
FZP X-ray CCD at M=14.4 (4.51 keV)
20 10 3 µm (bar widths)

Ti backlit (4.75 keV) FZP images taken with a high speed framing camera (Δt~30 ps)

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