High-Resolution X-Ray Radiography with Fresnel Zone Plates on the OMEGA and OMEGA EP Laser Systems

F. J. Marshall,[1] S. T. Ivancic,[1] C. Mileham,[1] P. M. Nilson,[1] J. J. Ruby,[1] C. Stoeckl,[1] B. S. Scheiner,[2] and M. J. Schmitt[2]

[1]Laboratory for Laser Energetics, University of Rochester
[2]Los Alamos National Laboratory

In this summary we report on the development of, along with the results from, the use of Fresnel zone plates (FZP's) to image x rays emitted by laser-generated plasmas on the OMEGA and OMEGA EP Laser Systems.[1,2] An FZP manufactured by Applied Nanotools[3] was used in this work. The FZP specifications are a 284.9 μm outer diameter, 512 zones, a 140-nm outermost zone width, and a resulting focal length of 151.86 mm for an energy of 4.750 keV (Ti He$_\alpha$ resonance line). The FZP zone bars consisted of 1.3-μm-thick Au bars on a 1.0-μm-thick Si_3N_4 support membrane. For an example distance from object to image of L = 3708.4 mm, calculated values are then p = 158.65 mm, q = 3549.75 mm, and M = 22.37. At best focus, for a single-line energy, the FZP resolution is given by the diffraction limit $\delta = 1.22\Delta r_n$, where Δr_n is the width of the outermost zone.[4] For the above example FZP, this implies a best single-line resolution of 171 nm. A range of possible resolutions is obtainable, limited not by the FZP, but by the detector. As an example, for a magnification of ~20, the best obtainable resolution with a CCD (charge-coupled device) having 13.5-μm pixels is when the feature can be discerned by only two pixels (Nyquist limit), yielding a resolution limit of δ(CCD) $\approx$ 27 μm/20 = 1.35 μm. Other example detector resolutions of those used on OMEGA and OMEGA EP are δ(film) $\approx$ 10 to 20 μm, δ(image plate) $\approx$ 90 μm, and δ(framing camera) $\approx$ 50 to 60 μm. The higher the magnification, the better for these cases since all can severely compromise the resolution obtained at low magnification.

A resolution grid test was performed on the OMEGA EP target chamber using the same FZP assembly. The FZP was positioned to be focused on a grid placed at target chamber center, with a Ti foil 5 mm behind the grid. A pulsed OMEGA EP beam with 1 kJ of UV (351-nm) light in a 0.5-ns pulse was used to generate Ti He$_\alpha$ x rays. The magnification of the arrangement was M = 22.37, with L = 3708.4 mm, p = 158.65 mm, q = 3549.8 mm, and f = 151.86 mm, respectively, corresponding to the focus for Ti He$_\alpha$ x rays. The grid, which consisted of 6-μm-wide by 20-μm-thick Au bars, spaced by 25 μm, was covered by a 25-μm-thick Ta foil into which a 100-μm-diam aperture (mask) was laser cut. Figure 1(a) shows the grid image obtained with an SI800 CCD. A lineout through the image is shown in Fig. 1(b); Fig. 1(c) shows the line spread function (LSF) calculated by taking the derivative of the lineout. When averaging over eight edges, the width of the features implies an LSF full width at half maximum (FWHM) of 1.62$\pm$0.31 μm. In this case the Nyquist limit is 27 μm/22.39 = 1.19 μm, implying that the resolution obtained is partly detector limited and partly by spectral content, provided that the focus positioning was otherwise effectively perfect.

A series of experiments known as the *Revolver* experiments,[5] whose principal investigators are the Los Alamos National Laboratory co-authors of this summary, were performed on the OMEGA target chamber. Fe backlighters were used to radiograph a set of concentric, double-shell implosions, where the outer shell was ~1200 μm in diameter and the inner shell was ~400 μm in diameter. The inner shell consisted of a 15- to 2-μm-thick Cr shell, held in place by a two-photon polymerization, 3-D–printed lattice with a volume-averaged density of 50 to 200 mg/cm^3. The outer 25-μm-thick CH shell was driven by 40 beams with 11.4 kJ of UV light in a 1-ns pulse. Two backlighter foils were used per double-shell implosion. One foil backlit a pinhole array in front of a framing camera, and the other backlit the single FZP in front of a framing camera. The Fe-foil backlighters had principal line emission of the He-like line at 6.701 keV. Six beams were used to illuminate the pinhole-imaged framing camera backlighter and eight beams for the FZP-imaged framing camera backlighter. All backlighter beams were ~423 J/beam in a 1-ns pulse. Figure 2 shows a qualitative comparison between an Fe backlit image obtained with the pinhole arrays and an image

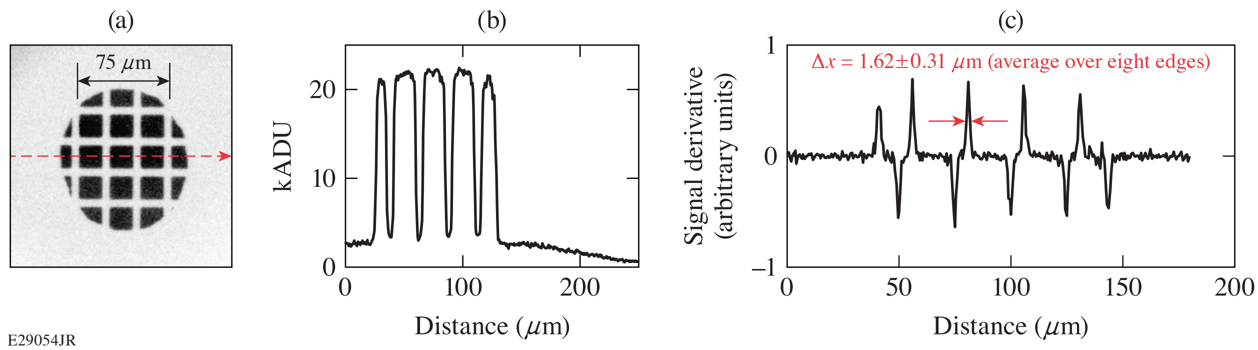

Figure 1
FZP image of a backlit grid obtained on OMEGA EP shot 30382 using a Ti-foil backlighter (4.75 keV). (a) CCD image of the grid with a 100-μm-diam mask over the grid; (b) lineout through the grid showing the grid bar shadows; (c) LSF (derivative) from which the resolution of 1.62±0.31 μm is inferred.

obtained with the FZP. The image from the FZP is shown in Fig. 2(a) and the pinhole image in Fig. 2(b) (both at t = 4.5 ns). Whereas the expected resolution of the framed FZP image is ~3.3 to 4.0 μm, the pinhole image was acquired with a 15-μm-diam pinhole d_{ph} at a magnification of 4. The two ten-inch–manipulator (TIM)-based framing cameras were nearly orthogonal to each other on the target chamber sphere, so only a qualitative comparison between the resolution of features is possible. The pinhole image was geometrically limited to a resolution of $(M+1)d_{ph}/M = 18.75\ \mu$m. The framing camera increases that to ~22.5 to 27.0 μm when taken in quadrature. Figure 2(c) shows the FZP image blurred to the approximate resolution of the pinhole image dramatically illustrating the loss of detail in the pinhole image as compared to the FZP image.

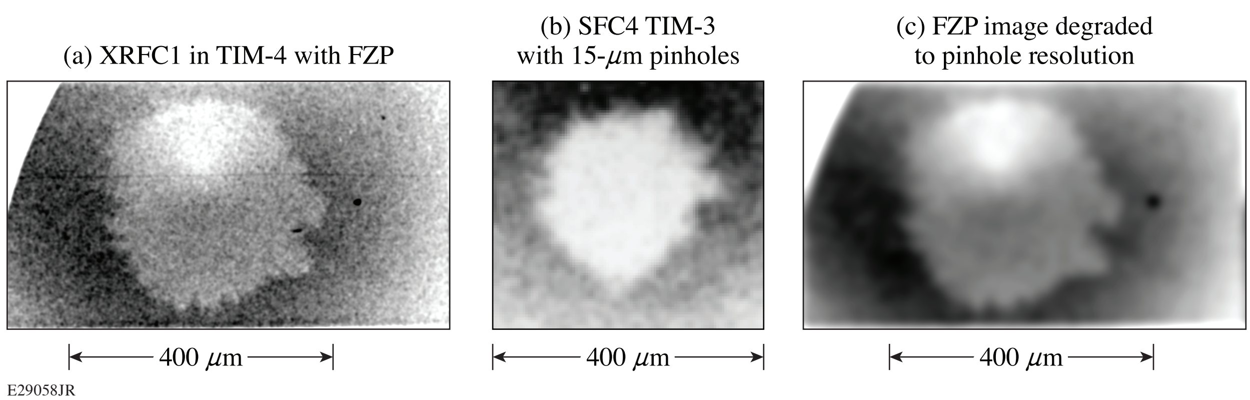

Figure 2
Comparison of a framed FZP image and pinhole image of a *Revolver* double-shell implosion on OMEGA, each backlit by Fe-foil emission (6.70 keV) at t = 4.5 ns. (a) The FZP image, (b) the pinhole image, and (c) the FZP image blurred to the resolution of the pinhole image.

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