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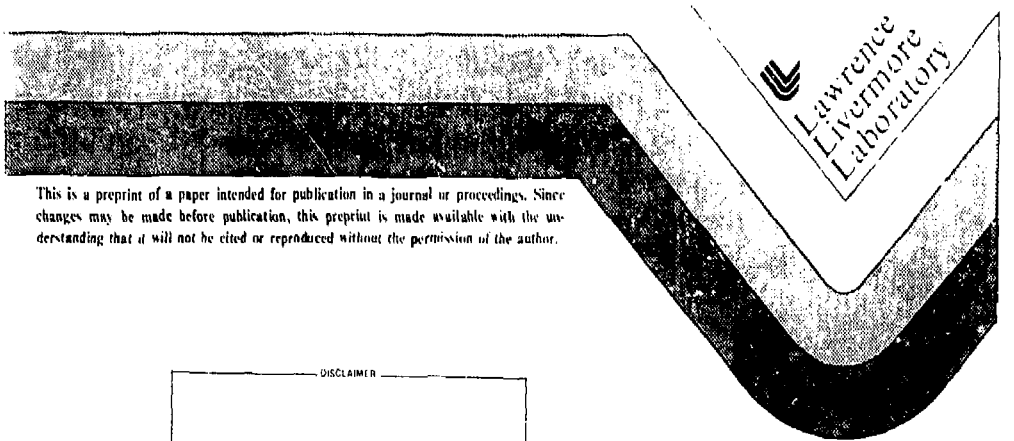

X-RAY AND EXTREME ULTRAVIOLET MICROSCOPY USING FRESNEL-ZONE PLATES*

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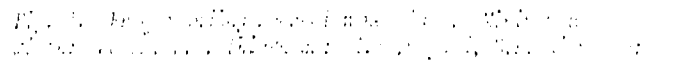
Fresnel zone plates are being used for x-ray microscopy over a broad spectral range (1.5 - 100 Å). They can be used as diffractive focusing elements for high resolution (~ 50 Å), "soft" x-ray (~ 44 Å) imaging, and as coded apertures (with a pinhole casting mode) for moderate resolution (~ 1 μm), "hard" x-ray (~ 8 keV) imaging applications.

FRESNEL ZONE PLATES AS HIGH RESOLUTION X-RAY LENSES AND APERTURES

A Fresnel zone plate may be viewed as a circularly symmetric x-ray transmission grating with alternately transparent and opaque zones of equal area. As such it is a diffraction limited focusing (imaging) element providing a focal spot diameter (resolution) approaching the minimum feature size (outermost zone width) of the zone plate structure.[1] Significant advances in microfabrication technology have allowed the fabrication of aberration free zone plate patterns having linewidths as small as 50 nm with the real possibility of extending this capability to even narrower linewidth, higher resolution structures.[2] A true standing-wave Fresnel zone plate structure *fabricated* using scanning electron beam lithographic techniques is shown in Fig. 1. Such structures - fabricated at LLNL, Lincoln Laboratory - are being tested and used as x-ray focusing elements in experiments at Lawrence Livermore National Laboratory. Fig. 2 shows x-ray imaging test results from an experiment in which the zone plate focusing element was used to image a resolution test pattern backlit with Au M_α radiation (λ = 44.7 Å). The resolution test pattern was in this case a "grad," zone plate having 2.0 μm minimum zone width. The results show the 1.0 μm lines and spaces clearly resolved, although the

data suffers from shot noise due to x-ray source intensity limitations.



Additional resolution test experiments are being carried out using test patterns having sub-micron linewidths.

FRESNEL ZONE PLATE AS CONDENSER FOR X-RAY SOURCE IMAGING

Fresnel zone plates used as diffraction x-ray lenses become appear most interesting for "soft" (0.5 to 1.5) x-ray applications. At x-ray energies in this range the zone plate transmission through the solid zones, and reduced diffract-

tion efficiency (f/number = minimum zone width/x-ray wavelength) significantly compromise the usefulness of the x-ray lenses. However, Fresnel zone plates used as shadowcasting apertures in two-step coded imaging schemes are being used across a broad spectral range from 2.7 kev to 4.5 kev.[4] The Fresnel zone plates used in coded imaging applications have much larger minimum feature sizes (minimum zone width 40-50 μ) and zones of significantly greater opacity (gold thickness 5-15 μm) than the x-ray focusing elements discussed earlier.[1]

Fig. 3 illustrates how the two-step coded imaging technique is applied. A Fresnel zone plate is used to image x-ray (or part of the emissions) from a self-luminous source.[5] In the first step the radiation emitted from the source casts a shadow through a Fresnel zone plate aperture onto a recording film. (Diffraction effects are negligible because the minimum zone width is many wavelengths). Each point in the source casts its own zone plate onto the recording film, and each zone plate is characterized by its size and position, the size and position of the zone plate's axial point. In the second step the processed shadowgram zone plate (fresnel zone plate hologram) is illuminated with a visible light laser beam. Since in the shadowgraph step the visible laser wavelength diffraction effects are negligible and each zone plate shadow focuses the incident laser light to a diffraction limited spot - the incorrectly located image of its associated source point.

Fig. 3. Imaging principles of the two-step zone plate coded imaging technique.

This technique is currently being used to image high energy x-rays[6] and particles[7] emissions from laser fusion targets at Lawrence Livermore National Laboratory. Such an image of suprathermal x-ray emission (2.7-2.9 kev) from a laser imploded microballoon target is shown in Fig. 4 and discussed in Ref. 8).

Fig. 4. Reconstructed x-ray emission (2.7-2.9 kev) from a laser fusion target. Image was made using the 20 slit zone plate shown in the figure. Resolution (11-30 μm).

Continued advances in microfabrication technology allowing the production of x-ray imaging elements having narrower linewidths (<1000Å) and deeper aperture or greater thickness (>100 μm) will extend x-ray micro-optic imaging into new parameter regimes (resolution <2 μm, x-ray energy >10 keV,

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2. Shaver, D. C., Flanders, D. C., Ceglio, N. M., Smith, H. I., J. Vac. Sci. Tech. 16, 1626 (Review., 1979)
3. Ceglio, N. M., Shaver, D. C., Flanders, D. C., Smith, H. I.; Annals of New York Academy of Sciences, Vol. 342, (Ultra soft X-Ray Microscopy) P.65.
4. Ceglio, N. M. and Lorsen, J. T., Phys. Rev. Lett. 33, 579 (1974).
5. Clarke, D. R. and Ceglio, N. M., Proceedings SPIE Conf. on Scanning Electron Microscopy (March, 1980) also (LLNL report UCRL-85587, April. 1980).
6. Mertz, L. and Young, N. O., Proc. Int. Conf. on Opt. Instr., London. 1961, P.305.
7. Ceglio, N. M. and Lorsen, J. T., Phys. Rev. Lett. 39, 20 (1977)

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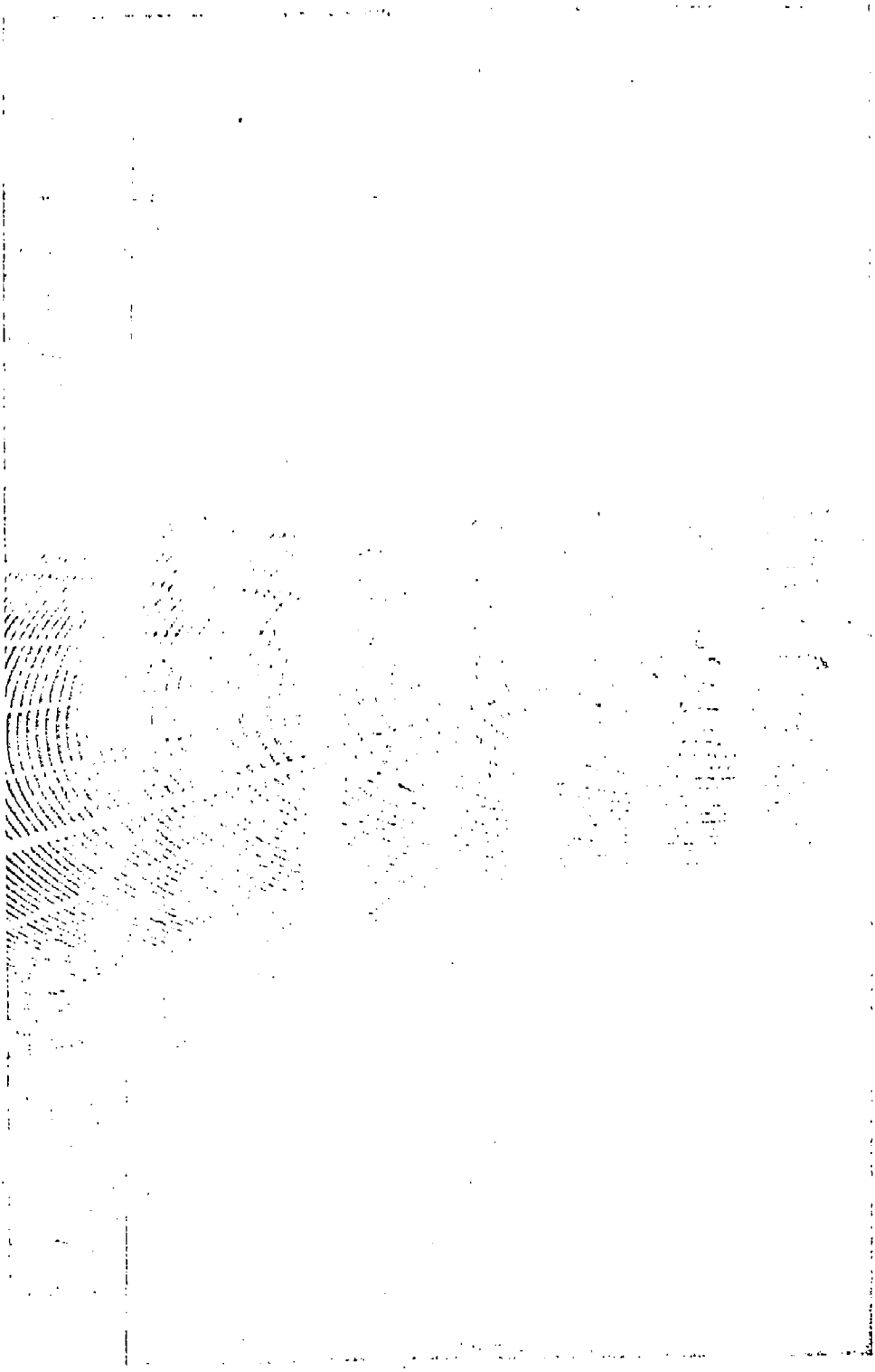
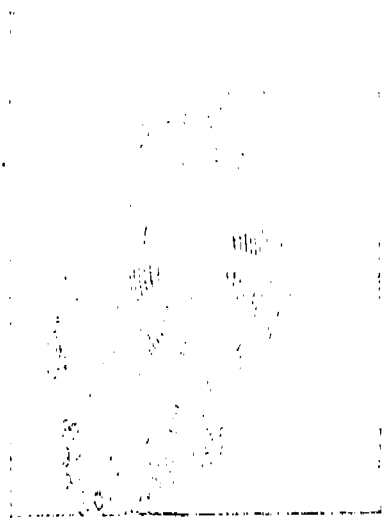
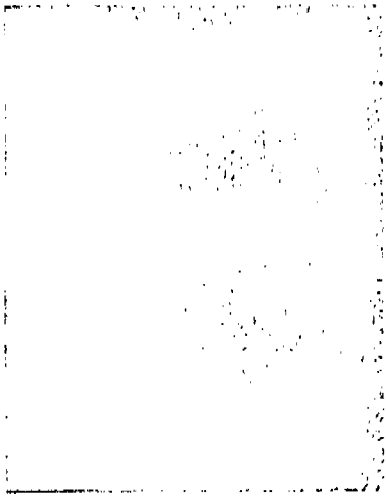
FIG 1



Initial results

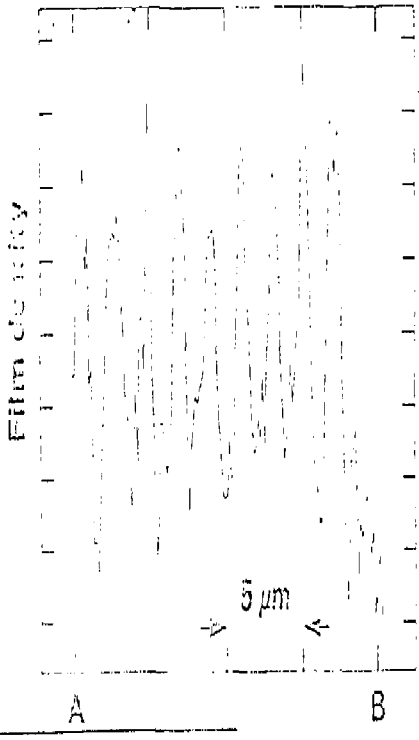


Test pattern
1.0 μm lines



X-ray "lens" image

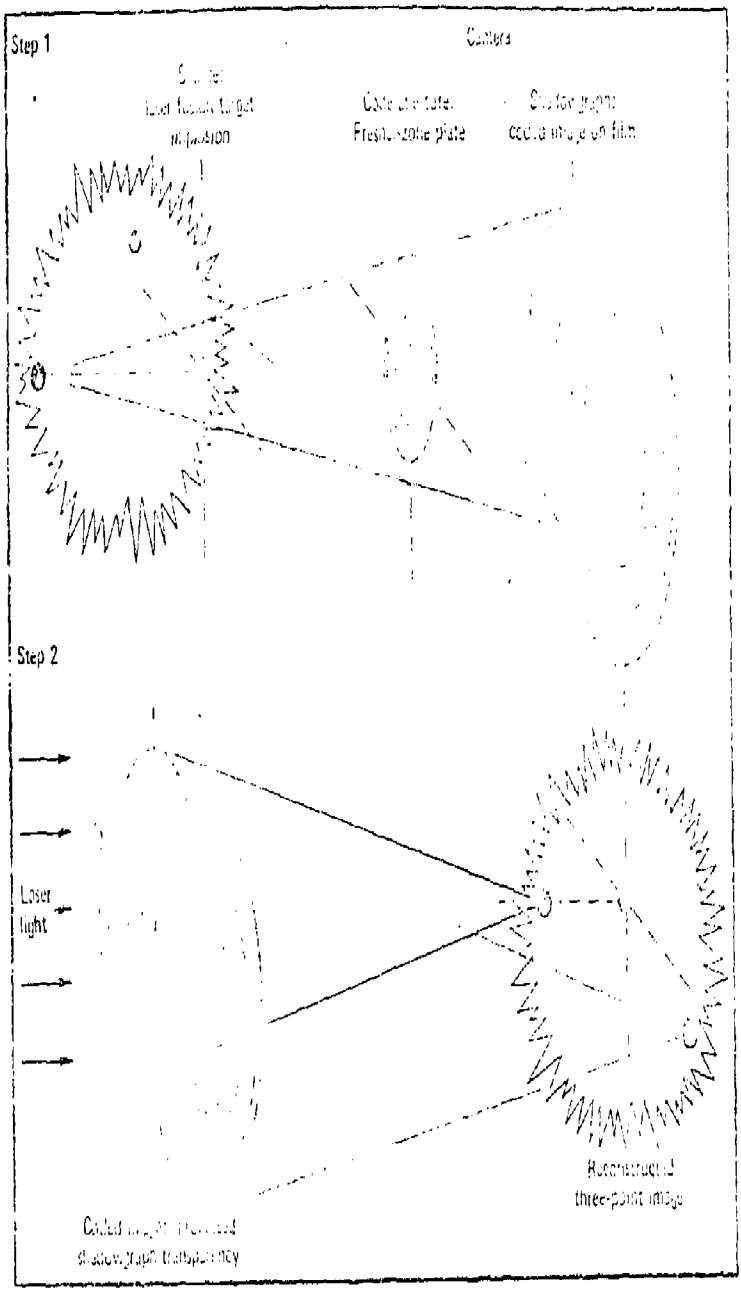
X-ray "lens" image



Conclude:

- 1.0 μm lines and spaces are clearly resolved

Fig 3


Step 1
Camera
Step 2
Laser light
Reconstructed three-point image

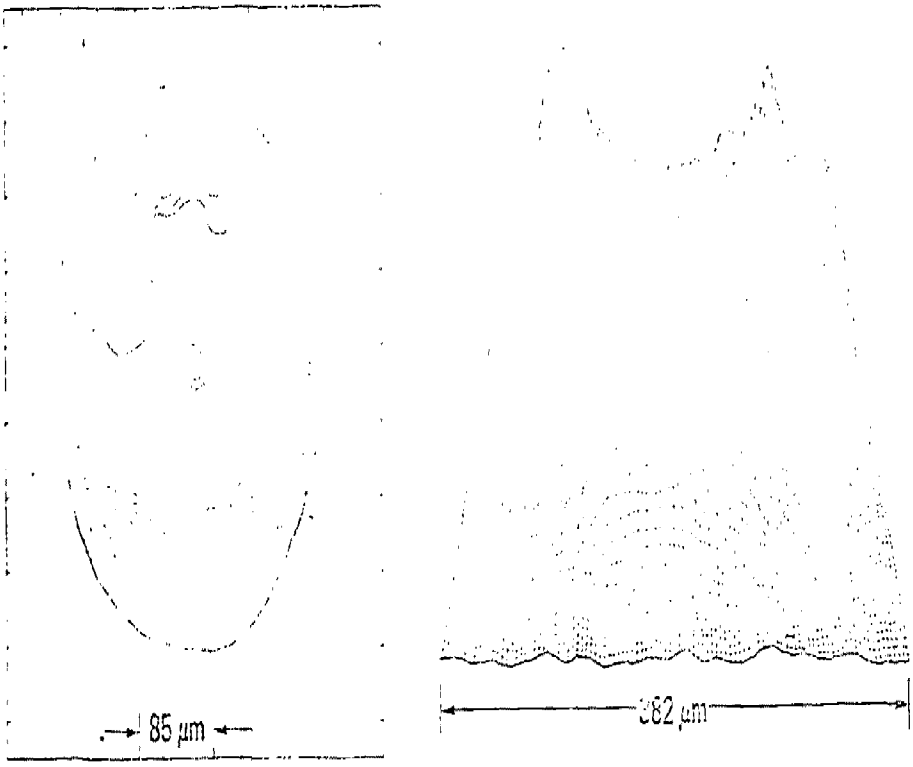


FIG 4