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A PROTON SHADOW CAMERA USING CR-39 TRACK DETECTORS*

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ABSTRACT

We have developed a capability for imaging proton sources of moderate energy (6 MeV), with moderate spatial resolution ($\approx 9 \mu\text{m}$), as a diagnostic for laser fusion research. Our technique involves the use of Fresnel zone plate coded imaging combined with nuclear track detectors (CR-39). We report on a series of test experiments in which a zone plate shadow camera successfully produced images of a proton source distribution. The zone plate shadow patterns were optically reconstructed in higher order producing diffraction-limited point response images with FWHM values of $\approx 9 \mu\text{m}$ for a 6 MeV proton source.

KEYWORDS

Proton shadow camera; charged particle imaging; CR-39 imaging detectors; Zone Plate Coded Imaging.

INTRODUCTION

Producing high resolution images of short wavelength sources (such as x-rays, γ -rays and charged or neutral particles) is difficult using conventional techniques. A two-step technique, Fresnel Zone Plate Coded Imaging (ZPCI) (Mertz and Young, 1961), has been successfully employed in producing high resolution images of the x-ray and alpha particle emission from laser fusion targets (Ceglio and Coleman, 1977; Ceglio and Larsen, 1980). The ZPCI technique involves geometric shadow casting to encode the source information and a simple optical technique to decode or reconstruct the data. The ZPCI technique offers a significant advantage in collection solid angle ($\approx 10^4$ to 10^5 times greater) over a pinhole camera of equivalent resolution.

There is an interest in the laser fusion diagnostics community in extending these techniques to higher energy thermonuclear reaction products (protons, neutrons), in order to image the thermonuclear burn region in high density targets. This requires thick zone plate coded apertures and suitable particle detectors.

We report on the development of techniques using high efficiency, high resolution nuclear track detectors (CR-39) to record proton shadowgraphs for coded imaging. We developed methods for enhancing the contrast of the etched track detectors, producing coded image transparencies with contrast suitable for optical reconstruction. We experimentally measured the point response function of the zone plate shadow camera and demonstrated diffraction-limited results with a point response FWHM value of $\approx 9 \mu\text{m}$ using 6 MeV protons.

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EXPERIMENTAL TECHNIQUE

The zone plate shadow camera, as used in laser fusion experiments, consists of a coded aperture, camera body, and detector package as shown in Fig. 1. The major components of the camera are the gold micro-Fresnel zone plate at the front of the camera and the detector and filter materials at the rear. The gold zone plate is 75 μm thick, with a 30 μm minimum zone and is 12 cm in diameter. The detector used for the proton imaging is CR-39 nuclear track detector. The camera normally views the laser fusion target from a short distance (typically 1 - 5 cm), and records the geometric shadow pattern of the zone plate in the detector material. The details of the microfabrication of the coded apertures used for this experiment are provided elsewhere. (Stone, 1983)

The source of protons used for these imaging tests was the LLNL Cyclograff Facility - Tandem Van deGraff Accelerator. This provided a beam of monoenergetic protons ($\Delta E/E \ll 1$), with a beam spot size = 1 mm in diameter. The coded aperture was placed in intimate contact with the shadowgraph recording medium (ie. image distance $\ll$ object distance) to simulate point source imaging conditions. The zone plate/detector package was then irradiated at a flux level of 3×10^6 protons/ cm^2 at the CR-39 detector. Specific details of the source operating characteristics and experimental geometry are provided elsewhere (Stone, 1983). A thin Be absorber filter ($t = 75 \mu\text{m}$) was placed between the gold zone plate and the CR-39 track detector to ensure that no proton exposure would be detected beneath the solid regions of the zone plate. The exposed CR-39 was etched for 450 minutes, with no agitation, in a 6.25N NaOH solution at 70° C ($\pm 0.1^\circ\text{C}$), with a surfactant added at [5cc/l]. The sample was removed from the solution and rinsed in de-ionized water and blown dry with N_2 gas. Figure 2 shows an optical photograph of the entire coded image transparency (2a), an optical micrograph of a sector of the coded image (2b), and detailed views showing the individual tracks (2c and 2d). The coded image consisted of shallow, conical tracks on a transparent background. (Note the distribution of track sizes in the shadow pattern and the presence of tracks in areas in between the zones. The larger tracks are produced by lower energy protons that were scattered from thin over-plated regions of the gold coded aperture. Such random zone plate pattern defects did not significantly degrade the point response of the system.) For optical reconstruction, the CR-39 coded image was transferred onto a high resolution glass plate using a darkfield optical technique to enhance the contrast level.

RESULTS

The coded image data was optically reconstructed using a collimated HeNe laser beam. The single zone plate shadow pattern focused the incident laser light to a point response image. A high resolution photographic plate was placed at the reconstructed image plane to record the data. The photographic image was then scanned with a microdensitometer producing a digital computer file of the data. Details of the optical reconstruction process and coded image production techniques can be found elsewhere (Stone, 1983). Figure 3 shows the 3rd order reconstructed image data from the 6 MeV proton coded image. In Figure 3a, the image is displayed as a 3-D representation of the data showing relative source intensity plotted vertically versus the two spatial dimensions. It is also displayed in Fig. 3b as a 1-D linear scan of the relative source intensity versus position, taken as a single scan line through the maximum of the data. The measured FWHM for the 6 MeV proton image is = 9 μm , slightly less than the anticipated diffraction-limited result.

CONCLUSIONS

We have demonstrated the use of CR-39 as the imaging detector for 6 MeV protons, in a Fresnel zone plate shadow camera. We developed methods for producing coded image transparencies from the etched track detectors with contrast suitable for optical reconstruction and produced diffraction-limited point response images of a 6 MeV proton source with a FWHM of = 9 μm .

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Fig. 1

A Fresnel zone plate shadow camera employing a multilayer filter-detector pack

Fig. 1. A Fresnel zone plate shadow camera as used in laser fusion diagnostics. The major components of the zone plate shadow camera are the gold coded aperture at the front and the CR-39 track detector/filter-foil package at the rear.

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Fig. 2. The 6 MeV proton coded image shadowgraph (2a), an optical micrograph of a sector of the shadowgraph (2b) and detailed views showing the individual tracks (2c and 2d).

Fig. 3a

Fig. 3b

Fig. 3. The point response image for a 6 MeV proton source distribution. The 3-D plot (3a) of the point response image shows relative source intensity plotted vertically versus the two spatial dimensions and the 1-D linear plot (3b) shows the relative source intensity plotted versus position, taken as a single scan line through the peak of the data.

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