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The α-particle imaging of a compressed core of microtargets in a pinhole camera with a regular multi-pinhole diaphragm

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Abstract. The α-particle imaging of a compressed core of microtargets using a multi-pinhole regular diaphragm is proposed. The image reconstruction technique is described. The results of the α-particle imaging of a compressed core of microtargets obtained at the 'Iskra-4' laser facility are reported.

1. Introduction

The parameters of the compressed DT fuel, in particular, the shape and dimensions of the microtargets and their compression degree, are of great importance in the laser inertial confinement fusion experiments. One of the methods for measuring these parameters is the imaging of the compressed microtargets with the help of neutrons, protons, or α-particles emitted in thermonuclear reactions [1 – 3].

Using the 'Iskra-4' laser facility [4], a number of experiments were performed in which high-aspect-ratio targets [5] (the aspect ratio $R/\Delta R > 300$) were irradiated, with the principal results presented in Ref. [6]. The high aspect ratio targets allowed obtaining a high neutron yield (up to 10^7) in some experiments, which is sufficient to develop some techniques for particle diagnostics of the compressed DT fuel. In particular, α-particle images of a com-pressed core of the target were obtained using diaphragms of different types. The α-particle imaging of the compressed core of high-aspect-ratio microtargets using linear- and circular-slit diaphragms was reported in Ref. [7].

The efficiency of an ordinary pinhole camera with a single 20 μm-diameter hole is 4×10^{-7} for the 1 cm distance between the target and the diaphragm. Therefore, even for the α-particle yield of 10^7, only about 2 to 6 particles participate in the image production. It is obvious that having such a small number of imaging particles, one cannot determine the shape of the compressed region but only estimate its dimensions. The use of multi-pinhole diaphragm allows one to increase the efficiency and, therefore, to obtain images in the case of relatively low α-particles yields [8].

In this paper, we report imaging of compressed regions of high-aspect-ratio targets in the 'Iskra-4' laser facility with the help of a special regular multi-pinhole diaphragm.

2. Experimental

In our experiments, we used glass shells with an aspect ratio of more than 300 that were filled with the DT mixture up to a pressure of 2 – 4 atm. The targets were irradiated by the second harmonic of an iodine laser. The energy of the laser radiation incident on to the target was ~ 250 J and the FWHM pulse duration was ~ 0.5 ns. Scatterers were used to smooth large-scale inhomogeneities of the intensity distribution in the spot. In most of the experiments with high α-particle yields, the laser radiation was sharply focussed on the target surface.

In the experiments, we used special regular multi-diaphragms with 19 or 37 pinholes. In these diaphragms, the pinholes were arranged with high precision (~ 1 – 2 μm) at the nodes of a regular lattice with equilateral-triangle cells, thereby forming a compact hexagonal structure. The spacing between the pinholes was chosen so that the distance between the neighboring images was 2 to 3 times greater than the expected dimensions of the compressed region image. According to Ref. [9] and our own measurements, the dimensions of the region emitting α-particles did not exceed ~ 1/3 of the diameter of the high-aspect-ratio targets. Fig. 1 shows the multi-diaphragm with 19-pinholes 30-μm in diameter spaced at 200 μm.

The images were recorded by a CR-39 plastic track detector (TASTRAK, UK) [10] with 2- to 2.5-fold magnification. To protect the detector against the scattered laser radiation and the plasma ion flux, we covered it with an Al filter 5.8 μm thick. It was installed in immediate contact with the track detector to avoid blurring of the image due to scattering of α-particles inside the filter. To visualise the α-particle tracks, the track detector was etched in the 6N-solution of NaOH at the temperature 70°C for 16 – 20 hours after each experiment.

The CR-39 track detector possesses high optical quality and a low density of the background tracks. The α-particle tracks had virtually the same diameter (~ 15 μm) and were easily distinguishable with a microscope. The etched track detector was photographed against the background of a coordinate scale with the help of a large-magnification optical microscope. Using the obtained photographs, we could determine the coordinates of separate tracks in the track detector with an accuracy of 3 – 5 μm.

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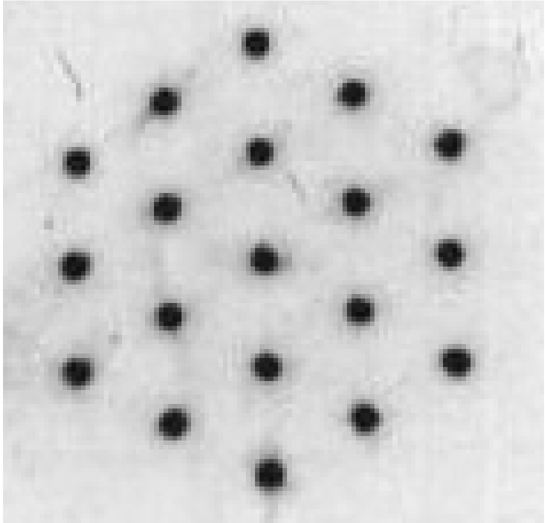

Figure 1. Multi-diaphragm with 19 pinholes of 30 μm diameter; the spacing between the pinholes is 200 μm.

3. Image reconstruction technique

To simulate the results of imaging with the regular multi-diaphragm and test the image reconstruction technique, we used the following procedure. The intensity distribution $I(r, \varphi)$ of the model particle-radiation source was specified in the polar coordinates by

$$I(r,\varphi) = I_0 \exp\left[-\ln 2\left(\frac{r}{R_{0.5}}\right)^G\right] \times \left[1 + \left(\frac{A}{A+2}\right)\cos(m\varphi)\right], \quad (1)$$

where I_0 is the intensity in the radiation source centre; $R_{0.5}$ is the radius of the radiation source at half the maximum intensity; G is the power of the supergaussian distribution; m is the number of beams in the radiation source; A is the modulation amplitude, i.e., the relative excess of the source radius in a beam over $R_{0.5}$. This distribution describes both smooth profiles (for small values of G) and steep plateau-like ones (for large values of G).

The azimuthal distribution can describe sources in the form of multi-beam stars. The source randomly emits particles in accordance with the spatial intensity distribution, which pass through the pinholes of the multi-diaphragm and are finally registered by the detector. Our analysis shows that, for a 19-pinhole multi-diaphragm and the number of detected particles ~ 300, the images from each pinhole already decently represent the source shape. Such a source is convenient for modelling the techniques of image detection using various diaphragms: linear and circular slits, single- and multi-pinhole diaphragms, Fresnel-zone plates and large-diameter apertures. The latter diaphragm type is currently used for the neutron imaging of compressed regions.

Reconstruction of images formed with a multi-diaphragm is based on the following idea. If we somehow could superimpose the projection of the multi-pinhole diaphragm over the image recorded in the track detector, providing the necessary angular orientation and the actual experimental magnification, we would be able to derive the required source image by superposing the individual images from different pinholes when pinhole projections are superposed in a single point.

Note that only the relative positions of individual images with respect to the corresponding pinhole projections are important. In this case, the source intensity distribution can be reconstructed, in principle, using only a few individual images. Thus, the problem of image reconstruction consists in correct determining the parameters of the projection of the multi-diaphragm. This idea is the basis for a simple method for reconstruction of the radiation source image.

To reconstruct the image in the first-order approximation, we calculate the centres of gravity of the two remotest images and use these basic points to determine the projections of the remaining pinholes; the first-order approximation image is 'convoluted' with respect to these projection points. Then, the position of one of the basic images is fixed at the corresponding centre of gravity and the position of the other basic point is varied in a given vicinity of the other centre of gravity. This allows one to simultaneously vary the magnification and the angular orientation of the multi-diaphragm projection. For each position of the second basic point, we reconstruct the first-order approximation image and determine its root-mean-square radius, which serves as the measure of quality of the reconstructed image. The optimal reconstructed image corresponds to the minimum root-mean-square radius. Our analysis shows that, for a large number of particles in each individual image ($\sim 10 - 20$), the image reconstructed using only the centres of gravity of the basic images already provides a good approximation.

Note that a multi-diaphragm allows one to obtain images even when the average number of particles in individual images is less than unity, i.e., the images corresponding to some of the pinholes contain no particles at all.

The reconstruction can also be performed by superposing the images in a different way. If the protecting aluminium filter is not used, the α-particle tracks are detected against the background of the target images formed by the ions. These ion images can then serve as reference points for recombining the individual α-particle images. The energy of the ions is much lower than that of the α-particles, and they travel significantly shorter distances in the track detector. Choosing an optimal etching time, one can therefore obtain high-contrast images of the α-particle tracks against the background of the ion target images. Note that, using this method, one can determine not only the dimensions of the compressed region but also its position with respect to the target centre.

4. The results of image recording and reconstruction

In the present work, we recorded and reconstructed images of the compressed core of high-aspect-ratio targets using 19- and 37-pinhole multi-diaphragms. Fig. 2 shows the photographs of the track detector containing images of the compressed microtarget region formed by α-particles coming from several different pinholes for two experiments with different α-particle yields. Fig. 3 shows the reconstructed images of the compressed region and the histograms of the track distribution over two perpendicular cross sections. In both cases, one can see that the compressed core has an almost circular shape. In experiment 1, the dimension of the compressed core image obtained with α-particles was 100 – 110 μm FWHM for the target diameter 400 μm; in experi-

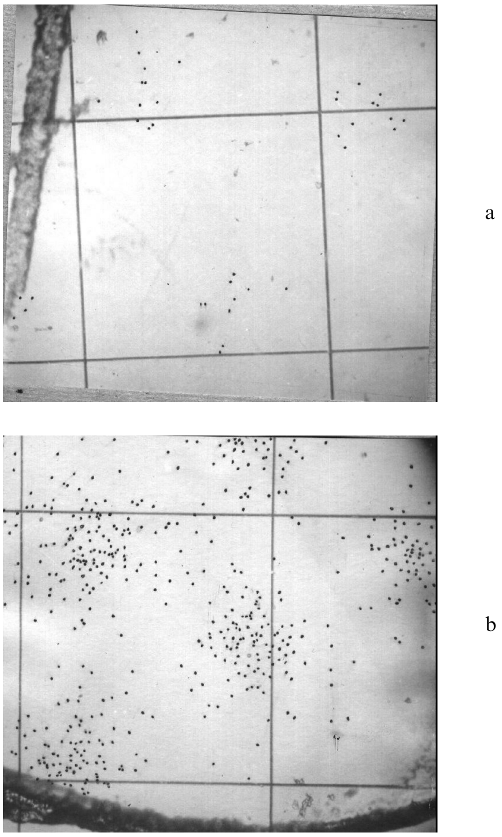

Figure 2. Images of the track detectors with α-particle tracks from several pinholes against the background of the coordinate scale with a 1 mm side, as obtained in experiments 1 (a) and 2 (b) for different α-particle yields.

ment 2, it was 135 – 145 μm for the target diameter 404 μm. Note that if we take the multi-diagram efficiency into account, the number of the detected α-particles agrees well with the neutron yield.

Obviously, this method for detecting the image of the compressed region by means of a regular multi-diaphragm and a track detector can be successfully employed to obtain images with the help of protons produced in the DD reaction. This is particularly important for microtargets with such an $\rho \Delta R$ (ρ is the shell density) that α-particles are completely stoped by the target shell, and only DD reaction protons, which have higher penetrating power, are emitted.

5. Conclusions

We have proposed to use a high-aperture-ratio diaphragm of regularly arranged pinholes in a pinhole camera for α-particle detecting the microtarget compression. A simple method for reconstructing the image of the particle source has been developed for this diaphragm.

Using the 'Iskra-4' laser facility, we detected and reconstructed the α-particle images of compressed DT fuel in high-aspect-ratio targets by means of 19- and 37-pinhole multi-diaphragms.

The described high-aperture-ratio diaphragm can be used to obtain two-dimensional images of particle-radiation sources in the case of a relatively low number of the emitted particles.

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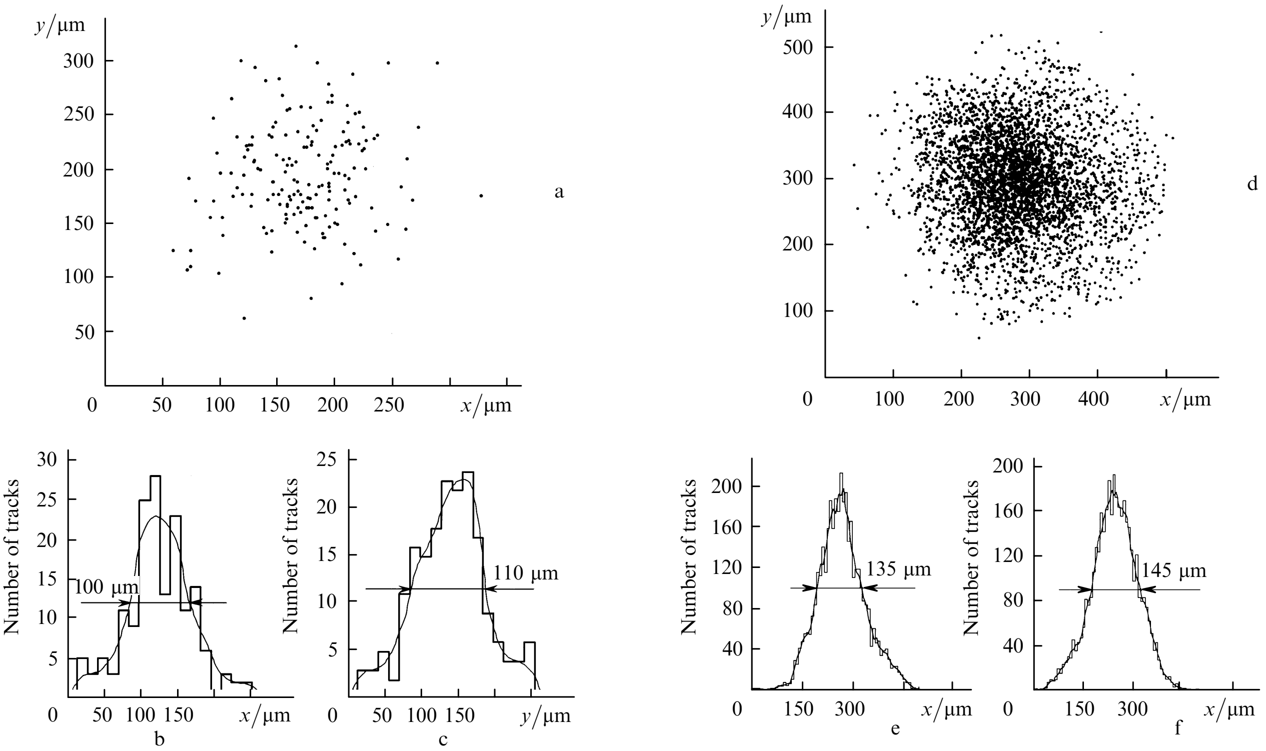

Figure 3. Reconstructed images of the compressed core and the histograms of distribution of tracks in two perpendicular cross sections obtained with a 19-pinhole (a – c) and a 37-pinhole (d – f) diaphragm.

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