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Observation of fast ignition core plasma with monochromatic x-ray backlight imaging

単色X線バックライト画像法による高速点火プラズマの密度診断

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A new type of x-ray monochromatic backlight imaging technology was developed to diagnose laser-driven core plasma parameters including density, areal density and spatial position. The imaging system consists of a spherically-bent crystal and a short-duration, 4.51 keV x-ray backlight source produced by a sub-picosecond high intensity laser to capture fast evolution of implosion dynamics. The feasibility of this scheme was tested by measuring a image of an imploded deuterated plastic sphere. The density of the core was inferred from the measured 2-D x-ray image.

1. Introduction

Fast ignition (FI) is one of promising approaches to inertial confinement fusion [1, 2]. In order to show the proof of principle of the FI concept, we have intensively studied the formation of a high density imploded core (ρ = 100 g/cc) and heating of the fuel by fast electrons to greater than 5 keV at the Institute of Laser Engineering (ILE), Osaka University. A typical laser-driven implosion core is very short life (~ 50 ps) and small (~ 100 μm). To capture the dynamics of the implosion, it is required to develop an imaging diagnostic with high spatial, temporal and spectral resolutions. A monochromatic flash x-ray backlighter for a laser-driven imploded core has been developed by W. Theobald *et al.* using a quartz crystal for 8.05 keV Cu K-alpha x-ray produced by 10 ps OMEGA EP high-energy, short-pulse laser [3]. Here, we have focused on the development of the backlight imaging using 4.51 keV Ti K-alpha x-ray. We developed a "monochromatic x-ray backlight camera" to overcome these constraints. The goal of this diagnostic techniquetechnology is to achieve a time resolution less than 10 ps by using a very short pulse backlight source, produced by sub-picosecond-pulse LFEX laser, and a monochromatic x-ray imager by using a Bragg crystal to attain a spatial resolution less than 30 μm.

2. Experiment

The backlighting experiment was conducted at ILE Osaka by using Gekko-XII (GXII) and LFEX lasers. Figure 1 shows a schematic of the experimental layout. A cone-in-shell target, consisted of a 200 μm-diameter deuterated plastic sphere and a Au cone, was irradiated by 9 GXII beams with a 0.53 μm laser pulse of 2 kJ in a 1.3 ns duration. This laser drove the shell to attain a high density core. At the maximum compression, a 1.06 μm laser pulse of 1 kJ in 1.6 ps duration from LFEX system irradiated on a Ti foil positioned at 2 mm away from the implosion target to generate 4.51 keV Ti K-alpha line emission. The x-ray from the source transmitted through the imploded core and reflected off with a spherically bent crystal to focus the image on an imaging plate (IP) detector. The intensity of the K-alpha x-ray was measured with time-integrated x-ray spectrometer. The timing of the implosion with respect to the backlighter x-ray was monitored with an x-ray streak camera. It is predicted that K-alpha emission produced by a petawatt, short-pulse laser lasts 5 ps [4], determining the temporal resolution of the diagnostic.

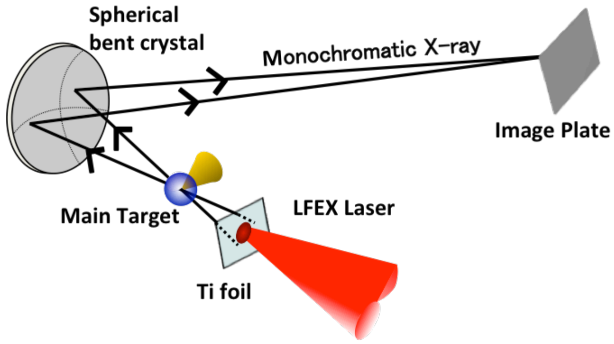
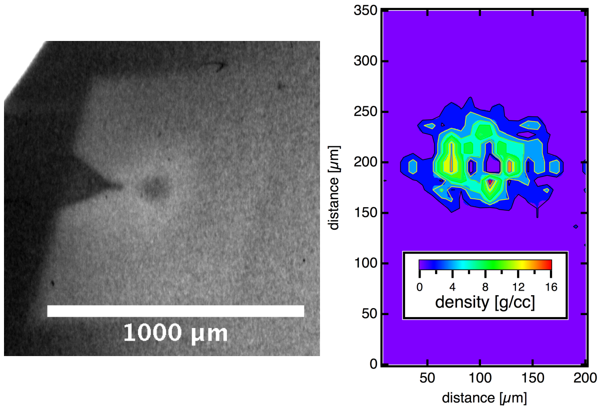


Fig.1. A schematic of the monochromatic x-ray backlight system setup.



(a) (b)

Fig.2. (a) A shadowgraph of imploded core plasma (b) density profile got by Abel inversion to shadowgraph (a).

3. Results

Figure 2 (a) shows a radiograph of the imploded core plasma taken with this imaging system. The spatial resolution was estimated from the sharpness of the Ti foil edge to be less than 20 μm. The backlighter source image recorded on the IP was hundred times more intense than that of self-emission from the imploded core. The measured image was analyzed with Abel inversion to provide density distribution of the compressed core assuming axial symmetry. The absorption cross-section of fully ionized carbon is used to infer the areal density by assuming the core electron temperature of ~ 400 eV [5]. Based on the above assumption, we have deduced the mass density contour of the core as shown in Fig.2 (b). The peak core density is inferred to be ~10 g/cc. As shown in Fig.2 (b), the density profile appears to be "donut shape". Therefore observation time is before the peak compression. This is confirmed by theoretical prediction for hyperspherical shock waves [6], but it is hard to specify accurate timing only with this image. In this way, we were able to demonstrate the effectiveness of the density measurement of imploded core plasma by using the monochromatic x-ray backlight camera.

4. Summary

A monochromatic x-ray imaging system with a spherically bent quartz crystal and 4.51 keV Ti K-alpha x-ray has been developed for the fast ignition experiment at ILE Osaka. The feasibility of this diagnostic technique has been successfully demonstrated by showing the spatial resolution of the diagnostic to be less than 20 μm and the core density distribution deduced from the experimental image.

5. Acknowledgments

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