UCRL-CONF-221179

Multispectral X-ray Imagaing for Core Temperature and Density Maps retrieval in Direct Drive Implosions

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May 7, 2006

High Temperature Plasma Diagnostics
Williamsburg, VA, United States
May 7, 2006 through May 11, 2006

Disclaimer

Multispectral X-ray Imaging for Core Temperature and Density Maps retrieval in Direct Drive Implosions

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We report on the experiments aimed at obtaining core temperature and density maps in direct drive implosions at the OMEGA Laser Facility using multi-monochromatic X-ray imagers. These instruments use an array of pinholes and a flat multilayer mirror to provide unique multi-spectral images distributed over a wide spectral range. Using Argon as a dopant in the DD-filled plastic shells produces emission images in the Ar He-b and Ly-b spectral regions. These images allow the retrieval of temperature and density maps of the plasma. We deployed three identical multi-monochromatic X-ray imagers in a quasi-orthogonal line-of-sight configuration to allow tomographic reconstruction of the structure of the imploding core.

Introduction

The determination of temperature and density maps of the imploding core is an important problem of inertial confinement fusion (ICF): it provides a detailed characterization of the symmetry and the hydrodynamics of the hot dense core plasma and the benchmark tests for hydrodynamic simulation codes.

Multispectral x-ray imaging using array of pinholes and a Bragg mirror [Yaakobi, 1998] represents a simple and effective way for obtaining narrowband x-ray images over a spectral range covering emission lines (e.g from dopant) used as density and temperature tracers. When coupled with gated imaging detectors this technique provides both spatial and temporal resolution allowing the retrieval of the time evolution of temperature and density maps of the inertial-confined plasma.

Here we report on the realization of a multiple monochromatic imager [Koch, 2005] for use in direct drive ICF implosions and the experimental results at the OMEGA Laser Facility [Bohely, 1997].

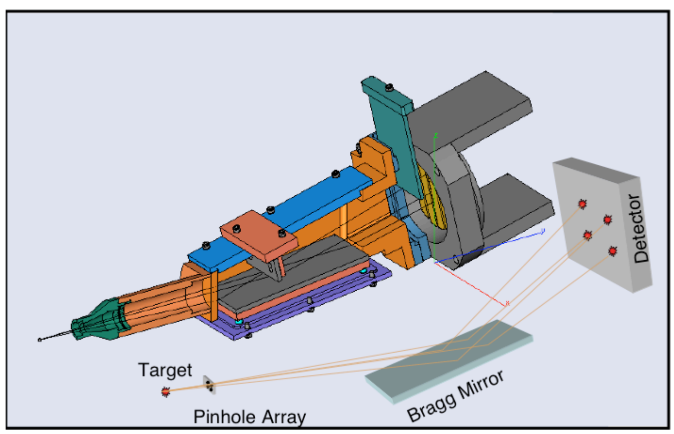

Figure 1: Geometry of the Direct Drive MMI (DDMMI) and actual realization of the instrument allowing operation at the OMEGA Laser Facility.

Instrument description

A detailed description of the working principles of the pinhole-based multiple monochromatic imager (MMI) has been given by Koch et al. [Koch, 2005]. Here we review the main characteristics of the modified version suitable for the diagnostics of Direct Drive implosions at OMEGA. The schematic of the instrument geometry and actual realization are shown in figure 1.

One of the main features of the instrument is the possibility of recording a large number of images. This has two important consequences: it allows for a fine transition in the spectral content between adjacent images and allows several images within a fixed x-ray energy bandwidth to be summed up, therefore increasing the signal-to-noise ratio (S/N). To maximize the number of images over the detector we used an array of hexagonally packed pinholes. To provide uniform spectral coverage at all X-ray energies within the total spectral range [Yaakobi, 1998], the pinhole array must be rotated about the optical axis by an angle χ given by:

$$\chi \approx \arctan\left[\cos(\vartheta) l (M+1)/K\right]$$

where l is the pinhole interspacing, M the instrument magnification, and K the width of the detector. θ is the angle describing the pinholes packing geometry, i.e. $\theta = (0, \pi/6)$ for square and hexagonal packing, respectively. Therefore in the present case $\chi \approx \arctan\left[\sqrt{3/4}\, l (M+1)/K\right]$. The pinhole interspacing, l, must be chosen according to the source size F, in order to avoid overlapping of the images at the detector plane: $l \geq MF/(M+1)$. In our case the source size is function of time, as the imploding core evolves towards bangtime, and was estimated from simulations to be about 60-80μm at peak compression. To maximize the number of photons per resolution element at the detector plane and the spatial resolution, for a given pinhole aperture, the pinhole array was placed as close as possible to the target, with the constraint of avoiding interference with the laser beams driving the implosion.

Experimental results

The target for the direct-drive experiments at the OMEGA Laser Facility consisted of a plastic capsule filled with deuterium gas and Ar as a dopant for spectroscopic diagnostics. The target design was based on 1D hydrodynamic simulations (LILAC) with the goal of keeping the electron temperature and density at the collapse of the implosion in the 1 keV to 2 keV and 1×10^{24} cm^{-3} to 2×10^{24} cm^{-3} ranges, respectively, so that argon K-shell line emission can still be used as temperature and density diagnostics for the core. The 60 OMEGA laser beams, delivering an energy of about 23kJ on target in approximately 1 ns, were used to drive the implosion.

Three identical DDMMI were fielded in a quasi-orthogonal line-of-sight configuration. Each instrument was designed to provide multiple narrowband images across the ~ 3500-4100 eV spectral range, covering the He-β, He-γ and Ly-β optically-thin emission lines of Ar. This was achieved using a W/B_4C multilayer mirror with depth graded interplanar spacing centred at ~1.51nm and spectral resolution of $E/\Delta E$ ~ 200.

A sketch of the instrument setup is shown in fig.1. The target-mirror distance was ~188mm while the hexagonally-packed pinhole arrays were placed at a distance of ~31.5mm from target. The instruments were coupled with gated X-ray framing cameras [Kilkenny,1991] providing four individually timed stripes. The resulting magnification was ~8.5X and the images were recorded using either Charge-Coupled-Devices (CCD) or film. We performed measurements with varying start times and temporal intervals, using arrays with different inter-pinhole spacing and tilt angle in order to have the maximum number of non-overlapping images compatible with the variations of the core size within the temporal window of observation.

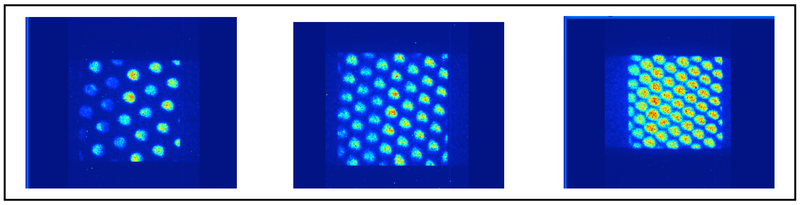

Figure 2: Image sequence with different pinhole interspacing corresponding to source sizes of ~160,115,100 um.

Figure 2 shows an example of recorded narrowband images using different pinhole interspacing corresponding to core sizes of ~160,115,100 um. Fielding three identical DDMMI's on three different and (quasi-)orthogonal diagnostic ports at OMEGA (namely TIM2, TIM3 and TIM4) made it possible simultaneous time-gated imaging of the core from three orthogonal directions. As shown in figure 3 this kind of images is rich in information. At early times (t_0) the images of the core observed along both directions are similar: large and circular in shape: consistent with 3D object having spherical symmetry. Approximately 100 ps later the core gets smaller. It is still rounded along one direction (TIM3 in figure) but elongated along the other one, corresponding to a 3D object of ellipsoidal shape. We notice that the images are in the Ar Heβ and Lyβ spectral range.

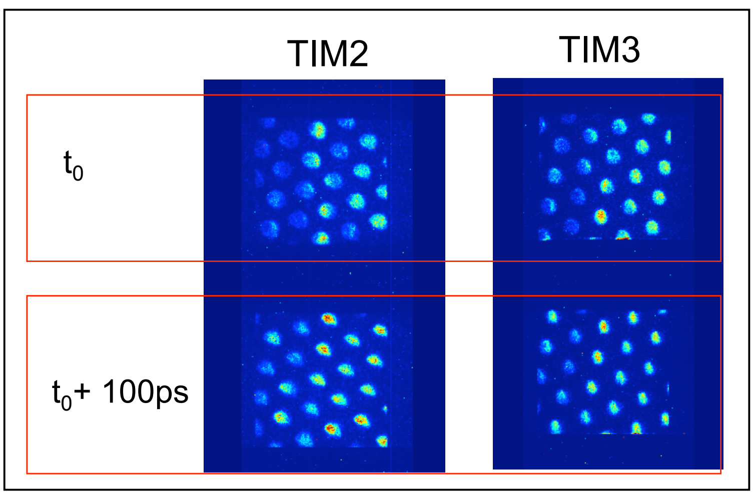

Figure 3: simultaneous time-gated images of the core from two mutually orthogonal directions.

One of the main possibilities given by the DDMMI is that multiple images within an X-ray energy band can be added to improve S/N ratio and to decouple spatial from spectral information. Two main approaches are being used for this image reconstruction process, based on the location of the sub-images centroids by either image contours or fitting to a regular pattern determined by the known symmetry of the pinhole array [Koch, 2004; Welser, 2003;; Izumi, 2004].

In figure 4 we show gated images of the core reconstructed from sub-images within the linewidth of the argon Lyβ line, recorded at the collapse of the implosion. The gating time is 50 ps and the time interval between images is 140 ps. The images reveal the dynamics of the imploding core as it progresses through compression from an approximately rounded shape with an off-center bright spot of Lyβ emission (Fig.4, left) to a less symmetric and smaller shape with the Ly-β bright spot in a different location, 140 ps later (Fig.4 right).

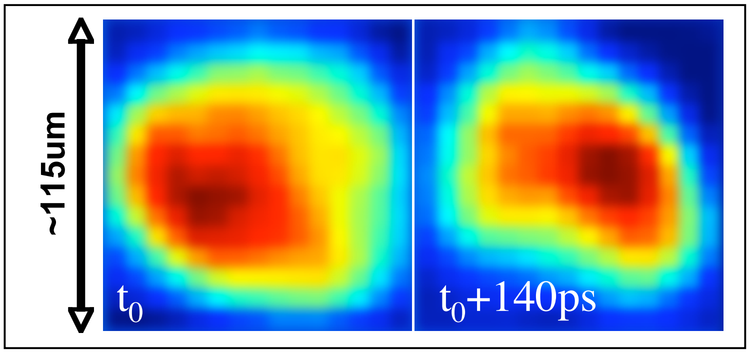

Figure 4: gated images of the core reconstructed from sub-images within the linewidth of the argon Lyβ line, recorded at the collapse of the implosion. The gating time is 50 ps, the time interval between images is 140 ps.

Discussion and conclusions

We reported on the design and optimization of multi-monochromatic X-ray imagers for diagnostics of direct drive implosions. We deployed three identical multi-monochromatic X-ray imagers in a quasi-orthogonal line-of-sight configuration a the OMEGA Laser Facility to allow multiview imaging of the structure of the imploding core. Using Argon as a dopant in the DD-filled plastic shells produced emission images in the Ar He-β and Ly-β spectral regions. Preliminary results of the experiments have been shown. The time-gated recorded images will allow the tomographic retrieval of temperature and density maps of the core as it evolves towards peak compression.

Acknowledgements

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48, and DOE-NLUF Grant No. DE-FG03-03SF22696 to the University of Nevada, Reno.

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