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Determination of the laser intensity applied to a Ta witness plate from the measured x-ray signal using a pulsed micro-channel plate detector

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ABSTRACT

The laser intensity distribution at the surface of a high-Z material, such as Ta, can be deduced from imaging the self-emission of the produced x-ray spot using suitable calibration data. This paper presents a calibration method which uses the measured x-ray emissions from laser spots of different intensities hitting a Ta witness plate. The x-ray emission is measured with a micro-channel plate (MCP) based x-ray framing camera plus filters. Data from different positions on one MCP strip or from different MCP assemblies are normalized to each other using a standard candle laser beam spot at $\sim 1 \times 10^{14}$ W/cm^2 intensity. The distribution of the resulting dataset agrees with results from a pseudo spectroscopic model for laser intensities between 4 and 15 $\times$ 10^{13} W/cm^2 . The model is then used to determine the absolute scaling factor between the experimental results from assemblies using two different x-ray filters. The data and model method also allows unique calibration factors for each MCP system and each MCP gain to be compared. We also present simulation results investigating alternate witness plate materials (Ag, Eu and Au).

1. Introduction

High intensity lasers provide a means to investigate exotic states of matter and laboratory fusion experiments. Determination of the laser energy delivered to the target surface can become a complex problem when gas and plasma are in the path of the beam. For high intensity ($> 2 \times 10^{13}$ W/cm^2) laser beams the far-field intensity is most often inferred from calculations using the delivered energy, the pulse shape of the laser, and the expected spatial profile at the surface of interest, which is often situated close to the focus of the beam [1]. When a gas or plasma is in the beam path, scattering, filamentation, absorption and other power loss mechanisms must be accounted for when estimating the delivered power. If multiple laser beams are interacting, cross beam energy transfer (CBET) [2,3] can also come into play. It is beneficial in complex geometries to have a direct measure of the power at the surface of interest, and for high intensity lasers the abundant x-ray self-emission can provide such a witness.

We are interested in applying a direct measurement technique to visualizing the laser beams that propagate to the waist of an indirect drive Inertial Confinement Fusion (ICF) hohlraum [4] at the National Ignition Facility (NIF) [5]. The hohlraum is shown in Fig. 1a. In this configuration, 192 beams grouped into 48 quads of two outer cones (16 quads, 64 beams each in 50° and 44.5° cones) and two inner cones (8 quads, 32 beams each in 30° and 23.5° cones) heat a cylindrical Au hohlraum that may be filled with low-Z gas, e.g He. The outer beams hit the hohlraum wall near the Laser Entrance Holes (LEH) and the inner beams hit near the center (or waist) of the hohlraum.

In order to map the intensity profile of the inner quads near the waist, we have designed a shortened gas filled hohlraum target, with a length of $\sim$1/4 to 1/3 of the standard length, which we call the ‘quartraum’ [6,7]. The quartraum is shown in Fig. 1b. The 96 beams from the lower half of the NIF chamber enter the single LEH; the quartraum is long enough so that the outer beams terminate on the wall but the inner beams escape and two inner quads hit a flat ‘witness plate’ at almost normal incidence. The plate is positioned outside of the quartraum at approximately the location of the waist of the hohlraum. The quartraum is designed to preserve the plasma conditions in the LEH region and replicate the plasma conditions the inner beams must traverse before hitting the hohlraum wall. The quartraum experiment laser drive was designed to mimic the ‘picket’ [8] of a High Foot [9] ICF laser drive. There is significant CBET during the picket and we desired to test the hypothesis that the CBET was not uniform across the laser beam cross-section. The laser intensity hitting the witness plate was expected to be $\sim 1 \times 10^{14}$ W/cm^2. Images of the x-ray emission from the inner

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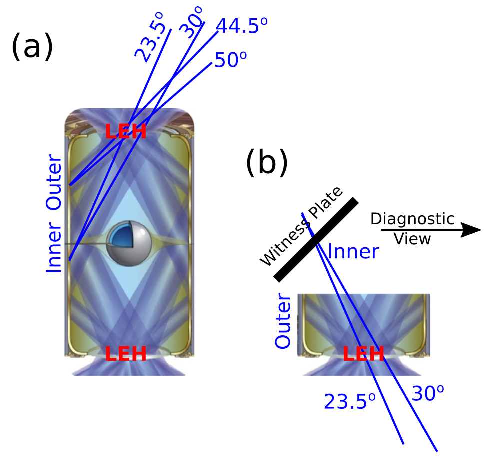

Fig. 1. (a) Diagram of the ICF hohlraum showing the inner and outer beam intersections on the wall. The lasers drive x-ray emission of the Au hohlraum which ablates the outer surface of the capsule, imploding the capsule inner surface at a very high velocity. (b) the quartraum target [6,7] is a shortened hohlraum which preserves the interaction of one half of the NIF beams in the region of the lower laser entrance hole (LEH). The inner beams escape the quartraum and 2 sample 'quads' (a quad is 4 beams originating from the same port in the NIF chamber) are captured on a witness plate.

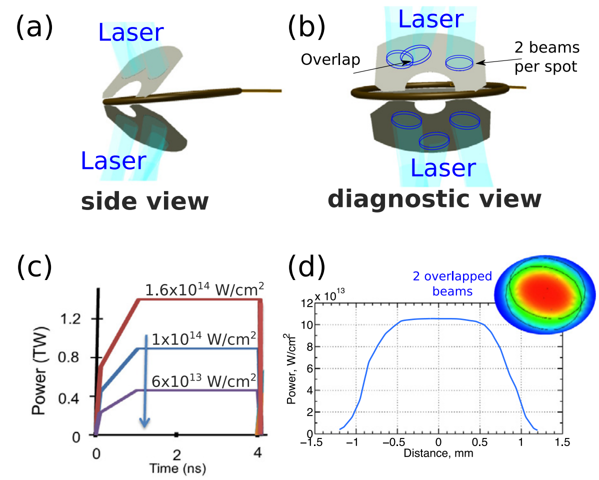

Fig. 2. The witness plate experiment; (a) and (b) show the witness plate calibration target with intersecting laser beams. The beams arrive at the target near best focus. The upper and lower plates are tilted 45° from the view of the diagnostic, to match the plate shown for the quartraum target (Fig. 1b). (c) The laser pulse shape. The peak power is varied between separate beam spots to view different intensities on the same target. (d) Predicted spatial intensity variation in the applied laser intensity as estimated by VISRAD [12] (image) and a line-out through the center of the VISRAD image.

beam laser spots on the plate are taken ∼1.3 ns after the beams first hit the plate using a time resolved detector with 100 ps integration. This allows flexibility in the experimental platform to observe time dependent changes in the laser beam intensity profile.

This paper presents the calibration required to infer the laser intensity spatial distribution on the witness plate from the x-ray self-emission. We achieve this goal in a separate calibration experiment by imaging laser spots with different known intensities onto the witness plate. We then compare the measurements with simulations and find that the experimental results from the calibration experiment closely follow the simulated relationship of laser intensity and x-ray emission. We perform the experimental calibration for three separate micro-channel plate (MCP) based x-ray framing camera detectors. The technique itself is self-calibrating, and does not require accurate knowledge of plasma conditions, though agreement to the simulations presented here helps build our understanding on the behavior of the observed x-ray emission and validates extension outside of the exact experimental configurations described in this paper.

While the geometry and conditions for the calibration described here are closely matched to the quartraum experiment, it is significant to note that the technique is readily applicable to other experimental conditions of interest to the high energy density physics community [10].

2. Calibration experiment

The calibration experiment consists of a tilted witness plate with a number of separate laser beam spots incident on its surface, as shown in Fig. 2a. The witness plate target has two separate 25 μm thick Ta witness plates at 45° to the horizontal. Each laser spot consists of two overlapped beams from the same quad, (in the quartraum experiment the four beams from one single quad will overlap to create a beam spot). The witness plate is almost normal to the beam propagation direction so the x-ray spot is elliptical (∼1.8 mm × 1.4 mm FWHM) as the NIF phase plates produce an elliptical spot near focus [11]. Three well separated laser spots are produced on each witness plate by six independently pointed laser beams. One laser spot visible to the MCP will be at an intensity of $\sim 1 \times 10^{14}$ W/cm^2. The upper witness plate has two laser beam spots that partially overlap (see Fig. 2b) to allow the investigation of a adjacent laser intensity region being different (the central region of this beam spot is twice as bright as the outer region, forming a 2:1 intensity profile).

The x-ray emission produced by the laser beam spots is imaged using a pinhole camera attached to a time resolved MCP [13–15] x-ray detector, see Fig. 3. The pinhole camera views the front (laser) side of the witness plate at 45° to the witness plate normal, as shown in Fig. 3b. We investigated a range of laser intensities from 3.9 to $\sim 14.3 \times 10^{13}$ W/cm^2 , which was controlled by the delivered laser pulse, shown in Fig. 2c. This laser pulse was designed to mimic the time evolution of the laser intensity on the quartraum witness plate accounting for CBET, absorption and the time to burn through the windows that hold the gas in the quartraum. Fig. 2d shows the expected laser intensity distributions at the witness plate for one of the laser spots in the calibration experiment, which traverses chamber vacuum before intersecting the witness plate.

The laser spots are imaged by a 2 × magnification pinhole camera, shown in Fig. 3. The pinholes are 15 μm in diameter and located 190 mm from the witness plate. The detection region of the camera is two co-timed strips ∼35 mm × 15 mm. The four pinholes produce four separate images. We differentially filtered the images so that the spectral content of the images would be sensitive to different

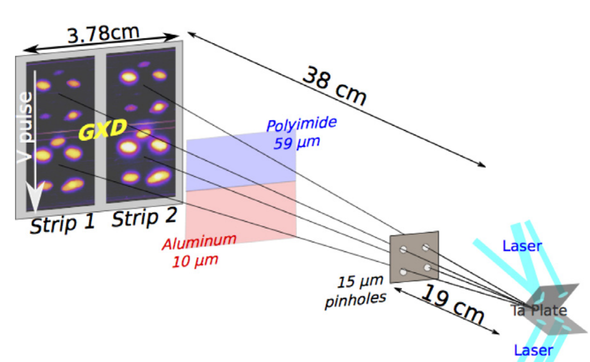

Fig. 3. A schematic showing the experimental set up. A set of four pinholes produces four images with magnification 2 × on a two-strip microchannel plate (MCP) detector. Each image is filtered with either a 59 μm thick polyimide or 10 μm thick Al filter such that each strip contains one image from each filter. The two strips have different gains and are co-timed.