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A diagnostic for micrometer sensitive positioning of solid targets in intense laser-matter interaction

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ABSTRACT

A target position monitoring diagnostic, relevant to intense laser-solid interaction, is presented. The alignment system, having a sensitivity of few micrometers, consist of an infinity corrected long working distance objective, a broadband illuminating source and a CCD camera. The imaging system, placed along the axis of incident laser pulse, serves the dual purpose of laser focus diagnosis and precise positioning of the target in three dimension axis. By employing this technique, solid targets with thickness varying from opaque micrometer thick foils to few nanometer thin transparent foils can be aligned precisely. The effectiveness of the entire alignment system is demonstrated in enhanced acceleration of ions in intense laser-matter interaction, with very high reproducibility.

1. Introduction

The recent progress in the field of ultrashort, intense laser-matter interaction has produced exciting results in the areas of high-energy-density science [1], extreme non-linear physics [2], ultrashort coherent x-ray sources [3] and compact high-energy particle accelerators [4]. Specifically, the interaction of intense laser pulse with micrometer thick solid foils have lead to acceleration of proton beams, with energy extending 10s of MeV [5,6]. The generation of proton beam in the 100 MeV energy range is essential for probing of transient electromagnetic fields in overdense plasmas [7,8], fast-ignition scheme of laser driven fusion [9,10], and for cancer therapy [11]. Recently, by using extreme laser intensities of the order of 10^{21} W cm^{-2}, numerical studies have demonstrated a possibility of accelerating ions with GeV energy [12], whereas experimentally maximum proton energy of 67.5 MeV was observed at intensity of 1.5×10^{20} W cm^{-2} by irradiating microcone targets [13]. In practice nowadays such extreme intensities have been realized by tight focussing of the laser pulses with a small f-number (or large numerical aperture) focussing elements [14,15]. However, tight focussing of light pulse lead to extreme shortening of confocal parameter and consequently results in drastic variation of the laser intensity over a distance of only few micrometers. This gives a very small range along the focus, limiting the effective interaction length with the target. Therefore, in order to avoid any substantial shot to shot fluctuations in the laser irradiance, a precise target positioning diagnostic is required. Beside determining the plane of interaction, some special targets, for instance - microstructured target [16], also demand precise laser pointing on the target surface. This translates into requirement of three dimensional positioning of the target with respect to the laser focus.

At present there are several alignment techniques for precise positioning of the target surface. For instance, transverse shadowgraphy imaging [17], where edge of a thin foil target is imaged by a backlight source. However in this technique the target surface cannot be seen and therefore any curling or crumpling in the foil edge will lead to mismatch between the edge plane and central part of the foil. Beside shadowgraphy, "retro-focusing" technique [18] has also been used for target alignment. This scheme uses the primary focusing optics itself to collect the back-scattered light from the target and then reflect it back along the laser beam path. Normally a small leak of back-scattered light is taken through one of dielectric mirror in the beam line, which is then focused on a camera. The camera is positioned relative to the focusing lens such that the backscattered light is tightly focused on the camera only when the target is at the tight focus position of the primary optics. However, due to absence of any target surface imaging, this technique is not very reliable, especially for the foils having very rough and modulated surface.

In order to overcome these limitation, we present a target position monitoring diagnostic, having a sensitivity of few micrometer. The alignment system consists of an objective, a broadband illuminating source, and a CCD camera. In this technique, the objective placed along the axis of incident laser pulse at first facilitates the optimization of the laser focus, followed by precise three dimensional positioning of

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the target surface. The effectiveness and reliability of the entire alignment system is demonstrated in acceleration of ions during intense laser matter interaction.

2. Experimental set up

The experiment was performed using CPA Ti:sapphire laser system (10 Hz, 30 fs, 100 TW) installed at the Center for Relativistic Laser Science (CoReLS), IBS, Gwangju. The experimental arrangement is schematically shown in the Fig. 1. A p-polarized, 30 fs, infrared laser pulse having central wavelength of 800 nm and energy of nearly 4 J was focused using an f/2 dielectric off-axis parabola on a 2 μm thick aluminium target at an angle of 45°. Nearly 50% of laser energy was confined in the 23 μm^2 area of the focal spot, resulting in the peak intensity of 2×10^{20} W cm^{-2}. A target position monitoring diagnostic, with accuracy of few micrometers was used to position the thin foil at the laser focus plane.

3. In-plane alignment of laser focus and target surface

The detailed schematic of the target alignment system is shown in the Fig. 2. Here, laser focal spot monitoring (FSM) system placed along the laser propagation axis is used at first for optimization of the off axis parabolic (OAP) mirror and characterization of laser intensity distribution at the focus and later on for positioning of the target at the smallest laser focus spot. The FSM system consist of a long working distance microscopic objective (20 × , Mitutoyo, numerical aperture = 0.28) controlled by three-axis motorized linear stages in vacuum. The working technique of alignments system is as following: nearly 120 times magnified image of the laser focus formed by FSM assembly, is captured on a 16 bit CCD camera (C150, CHROMA). After optimization of the OAP, which correspond to the smallest laser focus spot image on CCD, the target is positioned in a plane where target surface is sharply imaged on the CCD while FSM position is unchanged. This target position refers to the plane same as the laser beam focal plane and it serves as a “reference plane” for the target. During the course of experiment if any inconsistency arises between the best laser focus and the “reference plane”, one can always redefine the “reference plane” according to the smallest focus spot. In this way, rather than relying on any indirect reference, the best laser focus plane continues to be an absolute reference.

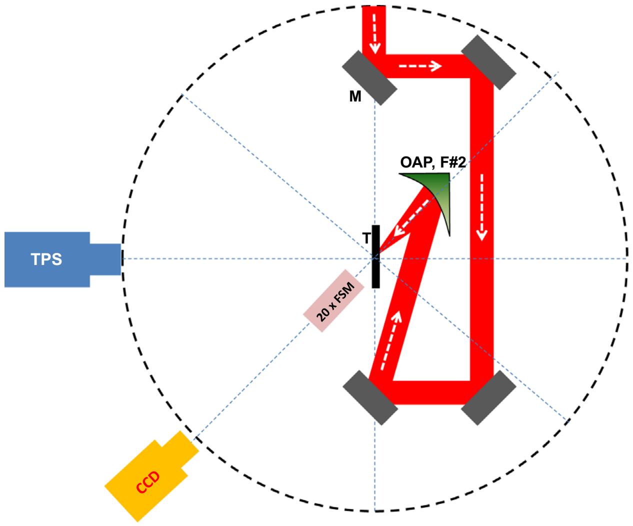

Fig. 1. Sketch of the experimental set up. An 800 nm, 30 fs laser pulse, focused by an F/2 dielectric off-axis-parabola (OAP) excites the target (T) at 45° of incidence. CCD, charge-coupled device; M, mirror; TPS, Thomson parabola spectrometer.

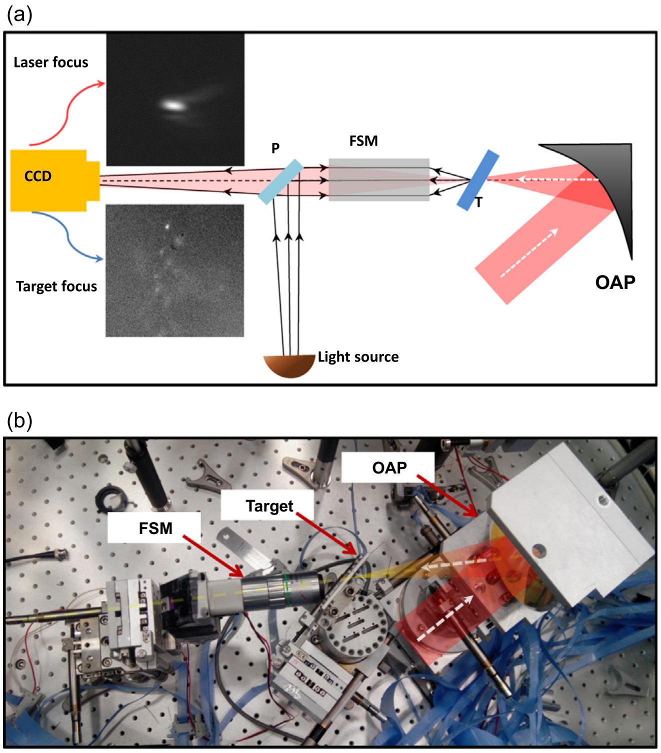

Fig. 2. In-plane alignment of laser focus and target surface. (a) Schematic of the working technique of target alignment. FSM, focal spot monitor; OAP, off-axis parabola; P, glass plate; T, target. (b) Real picture of the set up during experiment.

To locate the target surface a broadband white light source is used. The choice of light source is very essential in terms of the image clarity. For example, by employing a coherent source (650 nm, diode laser) for illumination, a strong distortion in the image is observed due to interference pattern formed by multiple reflections in the imaging optics system. The broadband white light, due to its incoherent nature, is free from any interference pattern. The target surface is illuminated by the light collected by FSM through a partial reflection from a polished glass plate (AR coated for 800 nm), as shown in Fig. 2(a). The scattered light from the target surface is captured back by the FSM. By placing the target surface at the “reference plane”, a sharp image of the foil is formed in the CCD. Thus the alignment technique ensures the precise positing of the target surface. The main source of uncertainty between laser focus and target surface is due to the depth of focus of the FSM, which is less than 5 μm for our objective. It should be noted that in this geometry the rear surface of the foil is getting placed at the laser focus. For foils of thickness less than the FSM depth of focus (as in the present case of 2 μm aluminium foil) it is not of concern, however for thick foils the target position need to be readjusted according to the thickness.

The efficiency of this imaging system also relies on the angle between the target surface and the laser beam. As the FSM axis is fixed along the laser propagation direction, the FSM and the laser beam carry the same angle to the target surface. For a non-zero angle, the illuminating white light, incident on the target surface, gets scattered away from the FSM and hence the collection efficiency of the FSM to see the target surface is drastically reduced. The low level of scattered light makes it difficult to distinguished the image from the background signal. The situation gets even harder for few nanometer thin targets, where most of the lights is transmitted. For example, during our experiment few micrometer thick metallic foils could be seen at an angle of 45°, however for nanometer thin targets, the widest angle was limited to mere 15°.

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