A novel in-situ dual channel alignment system for precision alignment of complex targetry

Contact *james.green@stfc.ac.uk*

J. S. Green, R. Heathcote, N. Booth

Central Laser Facility, STFC Rutherford Appleton Laboratory
Harwell Campus, Didcot, OX11 0QX, UK

K. L. Lancaster, D. Farley, C. D. Murphy, J. Pasley, W. Trickey, C. Baird, C. Underwood

York Plasma Institute, Department of Physics
University of York, Heslington, York, YO10 5DQ, UK

**at University of York during this project*

P. Koester

Intense Laser Irradiation Laboratory, INO-CNR
Pisa, 56124, Italy

A. Horne*, Z. Davidson, R. Gray

Department of Physics, University of Strathclyde
107 Rottenrow, Glasgow, G4 0NG, UK

Introduction

As targetry for High Energy Density Physics (HEDP) experiments has become more complex, methods to more accurately position the laser focal spot on the desired region of the target prior to the shot are needed. When the target feature sizes are similar in scale to the spatial jitter of the laser, a second requirement for on-shot laser positional information becomes important. This report details a novel dual channel system created to align targets with feature sizes of 20-50 μm. An IR channel (1053 nm) was used to align the target prior to the shot, and then a second-harmonic channel (527nm) was used to image the self-emission indicating on-shot position of the focal spot. This alignment system was deployed during a recent experiment using the VULCAN Petawatt system and was invaluable for categorising successful shots.

Background and system requirements

Previously there have been very few experiments that require transverse alignment accuracies (perpendicular to the focal direction) of a few laser spot widths. As targetry and experimental designs have become more sophisticated, the need for highly accurate spatial positioning of the focal spot on the surface of the target has increased. This is complicated somewhat by the intrinsic spatial jitter of the laser system; if the feature size to be irradiated is on the order of the spatial jitter then statistically there will be a number of unsuccessful shots.

Our experimental team have been performing experiments to test the resistive guiding technique for fast electrons based on methods proposed by A. Robinson et al [1,2]. This technique uses conical features clad in a material of lower atomic number to create a gradient in the material resistivity. This material boundary leads to generation of magnetic fields as fast electrons propagate in the vicinity of the boundary region. These magnetic fields can act to reduce the divergence of the electron beam. The guiding targets have conical tip sizes of 20-50 μm which are extremely challenging to align without a system of suitable magnification, spatial resolution and illumination.

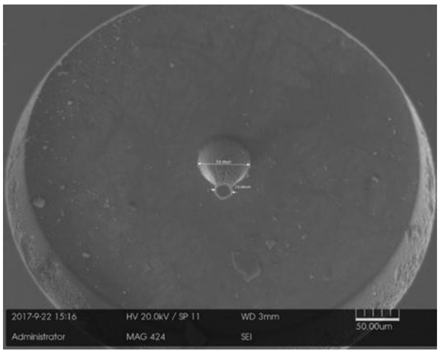

Fig. 1 – TEM image of Si conical target (courtesy of CLF target fabrication group and Scitech precision)

Since the main laser was 1053 nm, an alignment channel that was illuminated at this wavelength was required in order to observe the laser spot in focus on the conical feature.

In order to ascertain the actual position of the focal spot on-shot the second-harmonic (2ω), self-emission at a wavelength of 527 nm was chosen to be imaged. The most intense part of the signal should correlate to the position of the central focal spot which would allow the spatial position of the laser spot relative to the centre of the cone tip on shot to be determined. This is true for high contrast interactions where second harmonic production is predominantly via the relativistic oscillating mirror method (ROM) [3], the source size of which correlates strongly with the highest intensity part of the laser focal region. Imaging the target prior to the shot at a wavelength matching the 2ω, and overlaying the self-emission region on-shot, should provide a good measure of the spatial position of the full power focal spot, and hence yield valuable data on the success of the shot.

The magnitude of the spatial jitter of the laser on-shot was estimated to be ~17-20 μm from an experiment directly previous to the experiment in this report. Small (100 μm square), thin targets were irradiated at zero degrees, with the focal spot aligned directly in the centre of each target foil. The jitter in the position of the optical transition radiation (OTR) [4] observed at the rear surface was measured. Under these conditions, the position of the OTR would be expected to correspond to the position of the focal spot since the targets are thin and were accurately positioned using the target edges.

Design and deployment of the dual-channel system

The system was initially constructed off-line in order to optimise the design and layout. During this time, the limitations on position of optics and lighting levels, and achievable spatial resolution were determined. Off-line, the spatial resolution was found to be 2.2 μm using USAF resolution slides.

The alignment system was installed into the Vulcan Petawatt target chamber as part of an experiment in September 2017. As described earlier, this experiment involved Si targets with small conical features on to which the laser was positioned using this alignment system. The layout of the system is detailed in Fig 2. The system layout was mostly constrained by the laser beam path due to use of plasma mirrors.

Target illumination was achieved with two light sources - a white light source and an IR diode of wavelength 1050 nm - which were fed into the chamber via fibre optic cables. The IR source was collimated via a 1 inch lens to increase the brightness at the target position. The first optic in the system was an Edmund Optics 2x telecentric lens with a 75 mm working distance. Given the proximity of the telecentric lens to the interaction, thin Kodak Wratten filtering of ND 3 was required. This filter also acted to protect the objective from debris and laser damage. The filter was placed on a rotating filter wheel to allow maximum light levels for alignment prior to the shot. Mylar of equivalent thickness was rotated in to the beam to ensure the image position did not change between alignment and shot.

A 30 cm achromatic lens was used to further magnify and image the target on to two CCD cameras. The beam was split into two channels outside the interaction chamber, one IR (1053 nm) and one second harmonic (527 nm). The IR channel utilised a Xenics IR CCD camera and an RG1000 filter in front of the chip. The green channel utilised an Andor Neo CMOS camera with a 527 nm interference filter and an ND 2 filter.

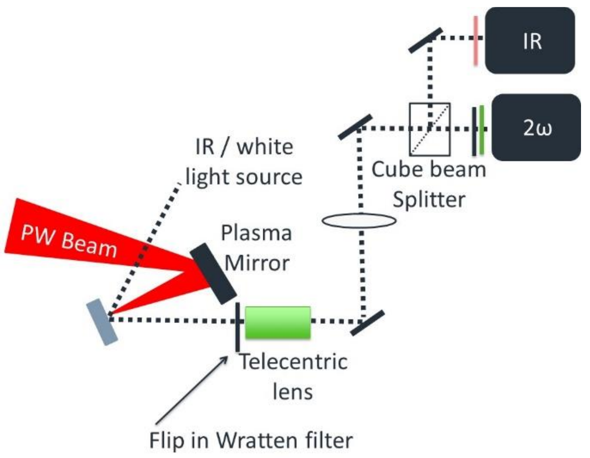

Fig. 2 – In-situ layout of the alignment system

The spatial resolution in-situ of the system was found to be 3 µm and the magnification was ~17.

The IR channel was used to roughly position the target along the x and y axes. Note - The exact focal position was determined using a separate process with a focal spot camera. It was possible to observe and position the focal spot on the target using this IR channel as a cross-reference. Once the target had been positioned, an image of the target was captured using the green channel. The green channel was then used to capture an on-shot image of the self-emission. This image could be overlaid on the pre-shot image to understand where the focal spot was relative to the cone tip. Figures 3a, b and c show examples of shots where the laser spot hit the cone tip, clipped the cone tip, and missed the cone tip. This enabled us to categorise the shots into successful and unsuccessful shots to help prioritise data analysis.

Summary and Conclusions

We have successfully designed, and deployed a novel in-situ front surface imaging diagnostic for both pre-shot target alignment and on-shot focal spot position determination. This diagnostic has been used to categorise a successful data set obtained from a VULCAN Petawatt experiment on resistive guiding techniques.

Without such a system, it would have been difficult to know if the cone tip had been hit successfully, making data analysis extremely challenging. This system has proved to be an invaluable source of knowledge in such demanding experimental conditions and could be applied in future for a range of HEDP experiments.

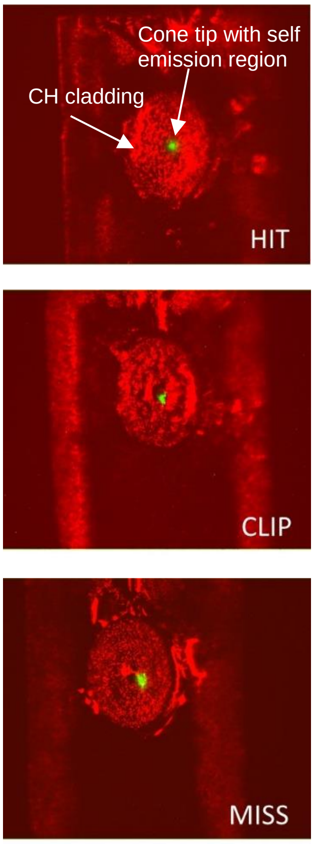

Fig. 3 – a) image of self-emission directly on cone tip, b) clipping the cone tip, and c) completely displaced from the cone tip

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