Spatial intensity mapping of Petawatt laser focus into fast electron transport

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Introduction

In understanding of fast electron transport through dense matter is of crucial importance for high power laser matter interaction physics and its associated applications [1,2].

Investigation of high energy electron transport through dense targets can be achieved by imaging the transition radiation emitted by coherent electron bunches from the target rear surface. This has proven to be an effective technique for measuring the divergence and size of the electron propagation [3]. Here we report on the use of this diagnostic in the observation of spatial intensity sub-structure, which indicates a mapping of the laser focus into the electron transport through thin foils.

Transition radiation

Radiation is emitted as charged particles and their electric fields propagate over a transition between two different mediums. The optical component of this transition radiation is termed OTR.

The total transition radiation emitted from a hot electron current, generated by a high intensity laser interacting with target foils, includes both incoherent (ITR) and coherent transition radiation (CTR). The former is the summation of the radiation spectra from individual electrons, and the latter is governed by the interference between the radiation waves from different electrons [4]. The number of electrons (N_e) determines the emitted power of both these mechanisms, with CTR having a much higher emission ($\sim N_e^2$) compared to ITR ($\sim N_e$).

Generation of bunched electrons can come about either due to the laser ponderomotive force or resonance absorption. While the oscillating component of the ponderomotive force will accelerate bunches of electrons twice every laser cycle ($2n\omega$), this would happen only once per cycle in the resonance absorption ($n\omega$), see figure 1. If the electrons remain bunched together after propagation to the target/vacuum boundary then the transition radiation will be coherent. Typically, at relativistic laser intensities the ponderomotive component will dominate the emission.

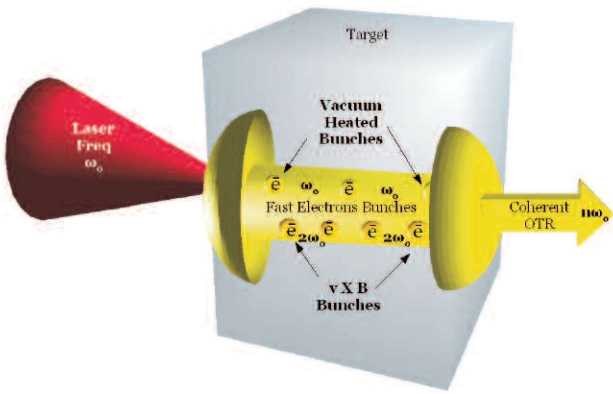

Figure 1. Coherent transition radiation emission mechanisms.

The imaging of the CTR enables the spatial and temporal structure and divergence of the fast electron beam transported through the target to be studied. However, this diagnostic is only sensitive to the highest energy electrons over a few MeV. The low energy electron population will not be subject to detection [5,6].

Experimental setup

The transition radiation was imaged from the rear of targets which had been irradiated on their front surface using the Vulcan Petawatt laser with a defocused focal spot. Targets consisted of planar aluminum foils, 2 µm and 25 µm in thickness. The laser operated at 1054 µm wavelength with a 700 fs pulse duration. A plasma mirror was used to achieve high contrast between the laser ASE pedestal and main pulse [7]. The defocusing of the laser, by shifting the target towards the plasma mirror, enabled laser spot sizes from 25 µm to 250 µm. The energy on target ranged from 60 J to 200 J. By varying the laser spot size, laser intensities from 4×10^{18} Wcm^{-2} to 3×10^{19} Wcm^{-2} were achieved. The main objective of the experiment was an investigation of the influence of laser spot size on proton acceleration. These results will be reported elsewhere. OTR imaging was one of a number of residual diagnostics employed to investigate the effects on electron transport.

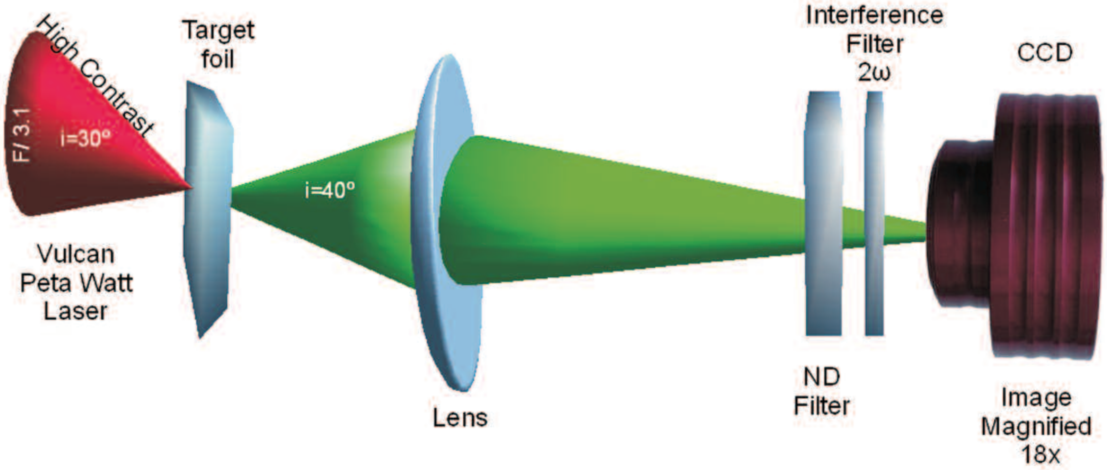

Figure 2. OTR diagnostic setup as used in the Vulcan experiment.

The rear surface emission was collected at a viewing angle of ~40° to target normal. As the laser light was incident at 30 ° onto target, within a cone of ~20°, the collection was within the CTR emission cone. The target rear surface was imaged onto an Artemis large format 16-bit CCD. The imaging system included an achromatic 7.5 cm doublet lens of 40 cm focal length giving a magnification of 18 and spatial resolution on target of ~3 μm. The camera was fitted with a 2ω interference filter and varying ND filters, see figure 2.

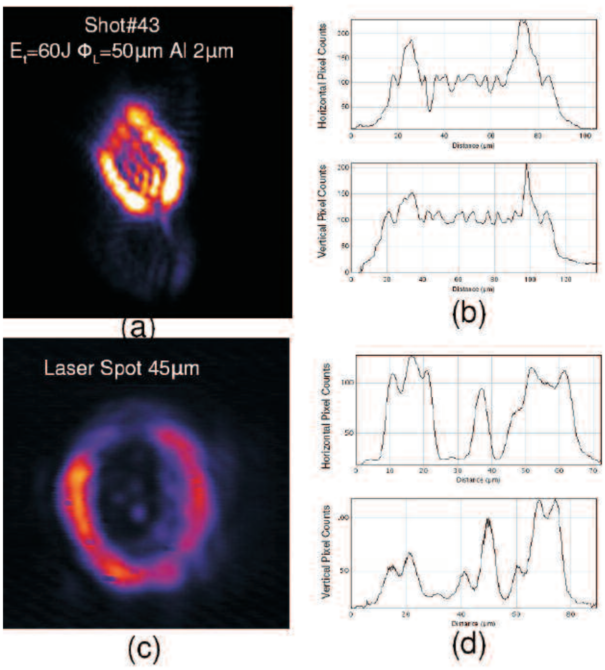

Figure 3. Comparison between CTR image (a) and laser spot spatial intensity distribution (b). The laser spot was imaged by an 8-bit Andor camera at normal incidence. Horizontal and vertical line-outs are shown alongside OTR image (c) and laser spot (d).

Results and conclusions

The variation of laser spot geometry, to study proton emission, also permitted the investigation of the effects on electron transport by imaging OTR emission. Due to a limited number of data shots, firm conclusions regarding changes to electron transport as a function of laser spot size cannot be drawn at this stage. However, we can highlight some initial observations from this work.

Firstly, there is strong evidence of substructure mapping from the spatial intensity distribution of the laser spot onto the CTR emission. An example is shown in figure 3. The intense ring-like rim of the laser spot is apparently driving fast electron propagation with according geometry. From the line-outs of the CTR image it appears that the centre of this ring emission contains structure of similar intensity and with similar geometry as the ring itself.

This suggests that the fast electron transport is being seeded from the ring-like spatial intensity distribution of the laser, an intensity correlation which propagates intact through the 2 μm target. Such a mapping of laser beam geometry to that of the particle acceleration has been shown to occur for proton beams [8].

There also appears to be a relationship correlating a response of CTR image size to the incident laser spot size. Larger laser spot sizes (Φ_L) produce larger regions of CTR emission. While complicated by changes in laser intensity and target thickness, and within the limits of the number of shots for which a usable OTR image was obtained, this appears to scale linearly, see figure 4.

We also observed that the axis ratio of the CTR images is changing as a function of target thickness. For the thinner targets the CTR image matches closely to the elliptical extent of the driving laser spot. As the laser beam is incident at an angle, the focal spot is therefore slightly elongated (axis ratio of ~1.2). For thicker 25 μm targets an elongation of the emission geometry is noted. The rear surface emission areas for these thicker foils doubled the original axis ratio of the laser focus. However, the reason for the change in emission pattern cannot be determined due to variations in other parameters such as laser

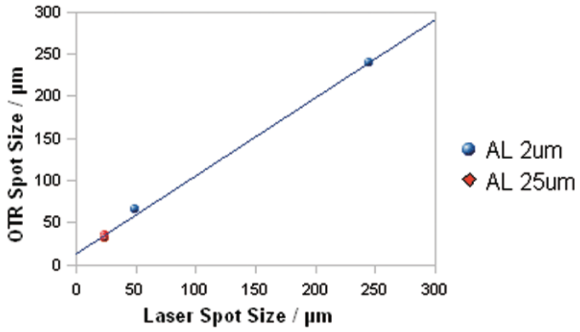

Figure 4. Correlations between 2ω OTR image geometry.

intensity. In principle, it should be possible, with relatively thick targets, to separate the OTR components produced by fast electrons generated by different laser absorption mechanisms. Electrons accelerated by resonance absorption of the laser pulse will be directed perpendicular to the target surface (due to the direction of the density gradient), while the laser ponderomotive force at high intensities accelerates electrons along the laser propagation[9]. This would lead to two sources of rear emission separated horizontally.

Summary

From a limited dataset, involving large laser spot irradiance of the Vulcan Petawatt laser on Al targets, a number of preliminary observations are reported.

The CTR measurements indicate direct imprinting of laser spatial intensity onto the rear surface optical emission. This points to a spatial intensity mapping of the laser focus onto the fast electron current within the target. Further investigations are required to extend these initial findings.

Acknowledgements

The authors wish to acknowledge the assistance throughout this work of the CLF staff at the Rutherford Appleton Laboratory in carrying out this work. This work was supported by the UK Engineering and Physical Science Research Council (EPSRC).

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