Optical emission from the rear side of solid targets irradiated with the Vulcan Petawatt laser

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Introduction

The study of electron transport through solid targets is an active area of research where there is still much to be fully understood. Although the energy to be deposited in the core of the pre-compressed pellet in the Fast Ignitor approach is well established, as given by Atzeni[1], the efficiency in the conversion of the laser energy into the fast electrons current, their transport through the overdense plasma and the energy coupling to the fuel are key issues that can significantly modify the required driver energy.

In this report, we present an experiment carried out in irradiating solid targets with the Vulcan Petawatt Laser, in which optical emission from the rear side of the targets, mainly due to transition radiation (TR) and synchrotron radiation (SR), was recorded.

Transition radiation is produced when a charged particle crosses the interface of two materials with different dielectric constants: the polarization field induced by the particle in its passage through the matter and the particle's driving fields coherently add in the vicinity of the interface and along the particle's path. In dealing with real cases, the physical picture of transition radiation from a single electron must be replaced by considering the contribution of many electrons to the final radiation field. This gives rise to an incoherent (ITR) and coherent (CTR) component of the emitted radiation. The information contained in the CTR is useful for characterizing the electrons produced in the interaction of high intensity lasers with solids[2,3].

In particular, the spectral properties of CTR are of interest in order to better understand the generation mechanism of the fast electrons, while the information on the electron transport can be deduced by analyzing the spatial properties of CTR, which will be the subject of this report.

Experimental set-up

The experiment was performed on the Vulcan Petawatt facility. The *p*-polarized laser pulse, capable of delivering up to 350 J on target at the wavelength λ_0=1054 nm (Nd:glass), was focused with an off-axis f/3 parabolic mirror onto solid targets, usually positioned at ~ 40° from laser axis (Figure 1). The focal spot contained about 35% of the total energy within a diameter of less than 6 µm (FWHM), giving an intensity largely above 10^{20} W/cm^2.

The targets consisted of different materials and thicknesses. Au and CH targets were mainly used, with a thickness of 10, 15, 20 and 50 µm. During part of the experiment a double plasma mirror was also used, with the laser pulse almost normally incident on target. This allowed for thinner CH targets, between 0.05 and 0.5 µm thick.

A two-lens imaging system viewed the rear of the target at 55°±5° from target normal and 15°±5° from laser axis (55°±5° when using the the plasma mirrors), in the plane of polarization of the laser field. The collected radiation was then split and imaged onto two 16-bit CCD cameras (Figure 1).

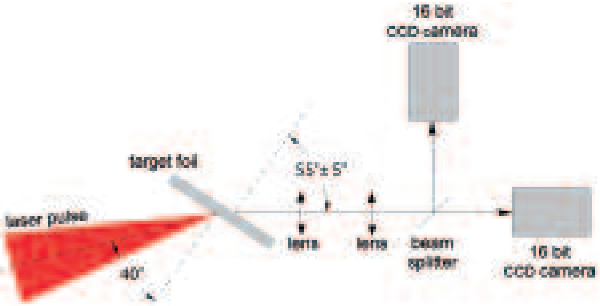

Figure 1. Layout of the experimental set-up.

Both cameras were normally equipped with $2\omega_0$ bandpass filters, with a spectral window of 10 nm (FWHM). Hence two images of the emitted radiation were recorded simultaneously, thus giving the possibility of comparing the structure of the optical emission at different wavelengths and polarization.

Results and Discussion

Transition radiation is generally observed looking at target normal. For a single electron, the angular distribution of the emitted radiation is well known[4] and, in the relativistic case, is confined within two narrow lobes around the electron propagation direction. When dealing with many electrons, this result can be significantly modified. Zheng *et al.*[4] showed that, if one can factorize the distribution function of the fast electron population as $f(t, \mathbf{x}, \mathbf{v})=f_1(t, \mathbf{x})f_2(\mathbf{v})$, then the angular emission of CTR from a beam directed perpendicularly to the boundary is mainly confined in a cone with half-angle $\theta=\lambda/(2\pi R)$, where λ is the radiation wavelength and R the radius of the electron beam.

We observed bright spots at $2\omega_0$ despite our viewing angle at ~55° from target normal, which would then imply that the radius of the filaments exiting the target was of the order of 10^{-2} µm. This is below the resolution of our imaging system (~10 µm). Indeed, it is also expected that transition radiation would be principally emitted towards the direction of propagation even for a beam exiting the target at some angle from normal. Moreover, as already pointed out in the same paper, the mathematical simplification of factorizing the distribution function is not necessarily justified, but a more general treatment makes the analysis more difficult.

It is noted that the $2\omega_0$ signal could be partly due to synchrotron radiation, produced when some (the majority) of the escaping electrons are pulled back towards the target by the space charge potential. The character of coherent radiation has been verified by putting different bandpass filters centred at the harmonics of the laser frequency; it was found that optical emission was essentially around $2\omega_0$, as also reported in previous experiments[5]. This is explained as an indication of the acceleration of ultrashort relativistic electron bunches by **j**x**B** heating.

Some of the images recorded during the campaign are presented in Figure 2. Multiple spots were usually obtained, a signature of the filamentary structure of the electron beam.

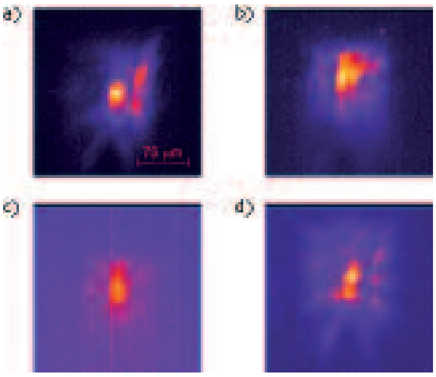

Figure 2. Spatially resolved optical emission filtered at $2\omega_0$ (in false colours and with different intensity scales) for the following targets and energies before compression: a) 15 µm Au, 556 J; b) 20 µm Au, 628 J; c) 25 µm Au, 615 J; d) 50 µm CH, 618 J.

In addition, two/three emission regions distinctly appear for some shots (see Figure 2a) and have been consistently reproduced for 15 µm Au targets. Two emission regions were also observed in previous experiments[5] and were interpreted as evidence of the acceleration of the electrons in the direction of the laser axis via the ponderomotive force and towards target normal via the Brunel-type heating. Unless a ballistic model of transport is discarded, this explanation does not apply to our case for the following reasons:

1. the distance between the two spots (~ 35 µm for the 15 µm Au targets) is not compatible with the geometry of the interaction and does not increase with target thickness, as expected;

2. the central, brighter, spot (corresponding in this view to the laser direction) is found to be vertically elongated by a factor 2.06±0.23, sensibly larger than the ~ cos(40°)/cos(55°) = 1.34 expected for a circular beam produced in the laser direction.

On the other hand, there is evidence of the role of the laser direction in respect to the orientation of the target. In fact, when the plasma mirrors were used the laser direction was changed at almost normal incidence, with the orientation of the target kept at ~55° from our viewing angle. In this case, a rounder emission region was found (Figures 3a and 3b).

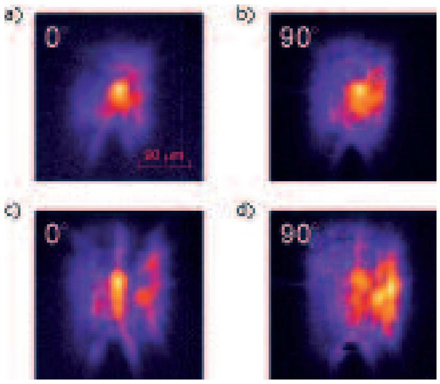

Figure 3. Comparison between the $2\omega_0$ radiated light for perpendicular polarizations (in false colours and with different intensity scales). Here 0° refers to the plane of polarization of the laser field. Parameters (energies given before compression): a) and b), 0.2 µm CH, 714 J, double plasma mirror, 0-5° laser incidence; c) and d), 5 µm Au, 551 J, 40° laser incidence.

Another interesting observation is presented in Figure 3. This concerns the degree of polarization of the emitted radiation: during part of the experiment the two cameras were equipped with two polarizers, besides the $2\omega_0$ bandpass filters; it was verified that the two cameras were giving consistent images in the same conditions (same spectral filters, same polarization). Two shots are presented showing a comparison at perpendicular polarization, with one polarizer in the direction of polarization of the laser field. The structure of the emitted radiation clearly presents some differences, though the overall structure is similar. Transition and synchrotron radiation from a single electron are expected to be linearly polarized. Comparing the relative intensity in the structure of each image, we notice that there is a preferential direction of polarization for some of the emitted radiation.

Summary

In summary, the propagation of the electrons through solid targets irradiated by the Vulcan Petawatt Laser was investigated. Optical emission from the rear side of the targets was collected mainly looking at ~15° from laser axis and ~55° from target normal. The emission shows strongly filamented behaviour, which exhibits a clear polarization dependence. Further studies are under way to determine the source of this optical emission, and its relevance to the energetic electron beams produced in these interactions.

Acknowledgments

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