Laser contrast diagnostic using target reflectivity

Contact **matthew.streeter@stfc.ac.uk**

M. J. V. Streeter, F. H. Cameron, E. Divall, P. S. Foster, J. S. Green, S. Hawkes, C. Hooker, P. P. Rajeev, C. Spindloe and D Neely
Central Laser Facility, STFC, Rutherford Appleton Laboratory, HSIC, Didcot, Oxon OX11 0QX, UK

C. Brenner, D. C. Carroll, P. Gallegos and P. McKenna
SUPA, Department of Physics, University of Strathclyde, Glasgow, G4 0NG, UK

R. Prasad, K. E. Quinn, L. Romagnani, S. Ter-Avetisyan, O. Tresca, M. Borghesi and M. Zepf
Department of Physics and Astronomy, Queens University, Belfast, BT7 1NN, UK

N. Dover, C. Palmer, J. Schreiber and Z. Najmudin
Blackett Laboratory, Imperial College London, SW7 2BZ, UK

Introduction

Ultra-short laser interactions enable the laser pulse to interact directly with a solid density target as the duration of the pulse is much shorter than the expansion time of the plasma. However, this requires that no pre-plasma or distortions of the target occur due to additional pulses or amplified spontaneous emission (A.S.E.) which are incident upon the target before the main pulse.

By monitoring the specular reflection of the laser pulse, information about the interaction of the main pulse with the target was obtained during an ion acceleration experiment. In particular specular reflectivity measurements were used to characterise the level of pre-plasma formation in low contrast, high intensity shots. Such data can then be used to give an estimate for the contrast of the laser [1].

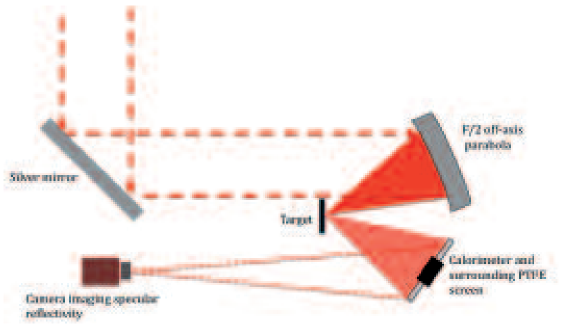

Figure 1. Schematic of the experimental setup showing the focusing geometry and the specular reflectivity monitor. The parabola was moved towards and away from the target which has the effect of changing the spot size on target and hence the intensity of the interaction.

Experiment

The experiment was carried out using the Astra Gemini laser which produces ~12 J pulses with a characteristic pulse length of 50 fs. The contrast of the laser (ratio of peak intensity to A.S.E) was measured to be around 10^6-10^7. A double plasma mirror system was used to improve the contrast by an estimated factor of 100 per mirror [2,3] so the anticipated final contrast after the plasma mirrors was 10^{10}-10^{11}. The throughput of the plasma mirrors was measured to be 48% (69% per mirror).

The laser was focused onto the target with an F/2 parabola, producing a focal spot with a FWHM of 2.5 μm (1.26 times the diffraction limit). Assuming ~30% of the energy lies within this area, a maximum intensity of 1.5×10^{21} W/cm^2 without plasma mirrors and 7.0×10^{20} W/cm^2 using double plasma mirrors is calculated.

The specular reflectivity was measured by means of a plastic sheet placed approximately 20 cm from the target such that it intercepted the specularly reflected laser beam. A lens imaged this screen onto a CCD with an 800 nm interference filter so that the reflected laser beam was captured for each shot. A central hole was cut in the plastic screen to allow calibration of the reflected energy using a calorimeter.

The intensity on target was varied during the experiment by defocusing with the parabola and by lowering the energy with a waveplate-polariser combination. This allowed the reflectivity to be plotted as a function of intensity for two different contrast levels.

Results

Target reflectivity was first measured for the low contrast case (no plasma mirrors) as a function of intensity (see figure 2).

These results show the reflectivity dropping for intensities greater than 10^{17} W/cm^2 which is consistent with previous experimental data [1] with a contrast of 10^7.

Using the double plasma mirror setup a second scan was taken to give the results shown in figure 3.

These show the specular reflectivity remaining high up to 5×10^{19} to 10^{20} W/cm^2 which implies a contrast of at least 2.5×10^9 from previous measurements [1].

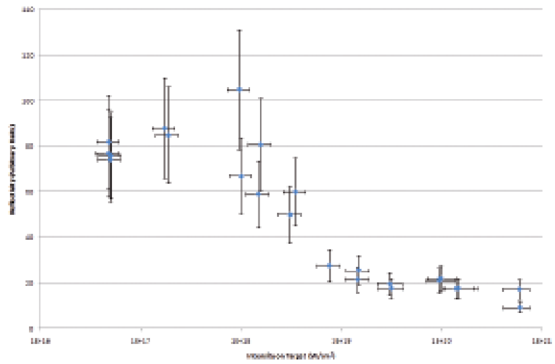

Figure 2. Specular reflectivity of copper foils at intensities in the range 10^{15} to 5×10^{20} W/cm^2 when using the Astra Gemini laser with no contrast enhancement. The targets were not perfectly flat. This added to the scatter of the data as well as making it difficult to obtain meaningful absolute values for the specular reflectivity.

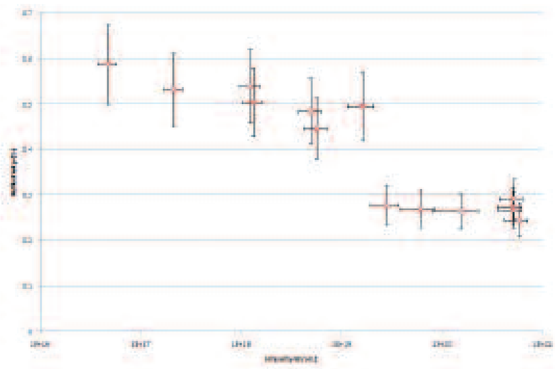

Figure 3. Specular reflectivity of 100 nm Aluminium foils for the intensity range 10^{17} to 10^{21} W/cm^2 using the double plasma mirror set up.

While the specular reflectivity at the highest intensities drops by 50% relative to the low intensity shots the beam profile is still clearly visible on our diagnostic. Figure 4 shows representative images from our specular reflectivity cameras which illustrate this point.

The image taken at 5.4×10^{20} W/cm^2 still shows much of same structure which is seen in the lower intensity image although the overall brightness has decreased. This suggests that there must still be a significant amount of specular reflection. This could be explained if only the central, most intense region of the focal spot created a pre-plasma. Everything outside this area would be reflected as normal due to the outer focal spot area experiencing a lower intensity and hence less pre-pulse formation. This process would be analogous a Schlieren type effect [4].

Conclusions

Imaging the specular reflection can be a very useful tool for characterising the interaction conditions for ultra-short pulse solid target experiments. As demonstrated in previous studies [1] it can be used to detect pre-plasma formation on the target and thereby infer the contrast ratio of the laser. Other information on the surface quality and orientation of the target can also be obtained which can help to explain observations from primary diagnostics such as ion spectrometers.

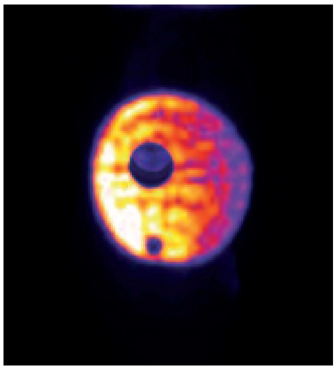

Figure 4a. Reflected beam profile at 1.3×10^{18} W/cm^2.

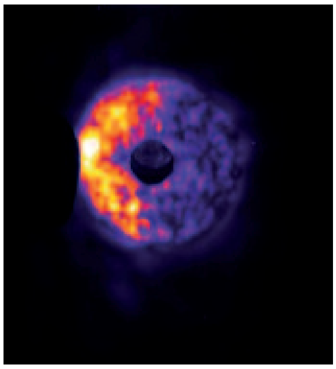

Figure 4b. Reflected beam profile at 5.4×10^{20} W/cm^2.

These results show the necessity of using plasma mirrors to enhance the contrast of ultra-short pulse lasers for intensities greater than 10^{17} W/cm^2 as most experiments using these conditions would require a solid density target. This is especially valid for thin targets as any significant pre-plasma would completely destroy the target before the peak of the pulse arrives.

Also there are indications that even with the double plasma mirrors the target may be modified prior to the peak of the pulse for intensities greater than 10^{20} W/cm^2. If this is the case then experiments using Astra-Gemini would greatly benefit if the contrast of the laser could be improved by an order of magnitude before the plasma mirrors. Otherwise an additional plasma mirror would be required for some experiments which would be undesirable in terms of practicability and the additional loss of energy that this would entail.

References

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4. *Hecht optics*. E Hecht - 1998 - Addison-Wesley.