Observation of Relativistic Electron Transport through Dense Preformed Plasmas

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Introduction

The Fast Ignitor scheme(1) for ICF relies on the transport of laser energy to the core of a compressed fuel pellet. It is necessary for an ultra intense laser pulse to propagate through plasma reaching many times critical density via hole boring and induced transparency. In the final stage of energy transport, the laser pulse is converted into relativistic electrons, which then must propagate to the core to ignite the fuel. Studies of propagation of laser pulses and relativistic electrons through hundreds of microns of overdense plasma are of great importance to the realisation of the Fast Ignitor Scheme.

An experimental campaign performed on the Vulcan Laser at the Rutherford Appleton Laboratory, UK has studied the interaction of ultra-intense laser pulses with plasmas several times critical. In previous experimental work(2), novel use was made of pre-ionised foam targets in an attempt to measure laser propagation through overdense plasma. Here, in an extension of this work, we present observations of the propagation of relativistic electrons through up to 200μm of overdense plasmas.

Experimental Arrangement

The set-up is shown in Figure 1. Overdense plasmas were preformed using soft x-ray heating of low-density foam targets. The target composition was triacrylate, doped 10% by weight with chlorine. Washer supported, parylene backed foams with density 20mg/cc and length 50 μm were used in addition to 200 μm long, freestanding foams with density 30 mg/cc. The Foams were placed 50 μm behind a pair of 700 Å gold burn-through foils. Two 600 ps heating beams of the Vulcan laser were frequency doubled to 527 nm and focused onto the foils with an intensity of 2×10^{14} W/cm^2. The soft x-ray emission from the rear of the foils caused volumetric ionisation of the foam within a nanosecond, producing a uniform, overdense plasma. A picosecond CPA pulse was subsequently focused into the plasma with an off-axis parabola producing an intensity on-target of 5×10^{19} W/cm^2.

Several diagnostics were employed in the experiment. Soft x-ray pinhole cameras, filtered for radiation below 500eV, were positioned at the front and rear of the target. The rear of the target was imaged at 1054 nm onto a CCD camera using a lens positioned behind the target. In addition, a picosecond UV probe pulse was used to produce a shadowgram of the target at

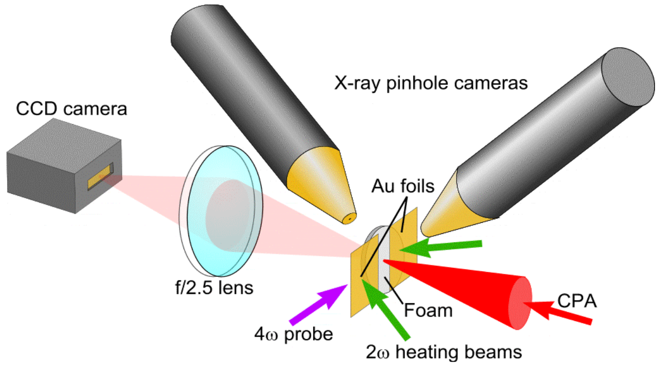

Figure 1. Beam and diagnostic arrangement.

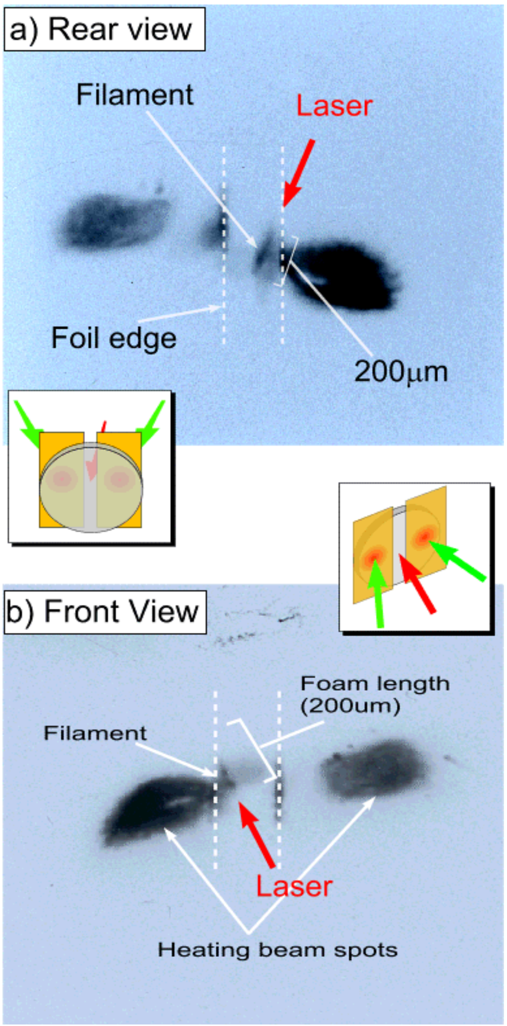

Figure 2. Soft x-ray images of a 30mg/cc, 200μm long foam.

varying stages following the interaction.

Results

Figure 2 presents x-ray images recorded by the front and rear pinhole cameras. The overlay shows the position of the inner edges of the two gold foils. The two large dark spots correspond to the x-ray emission from the laser heating of the foils. Between the foils, a dark feature can be seen. This corresponds to the laser direction and appears to extend throughout the target.

Figure 3 presents images from the CCD camera behind the target. In the case of the thinner foams, a compact, bright spot is seen. This corresponds to the position of the laser focal spot when no target is present and is of similar size being less than 20µm in diameter. The energy from this emissive spot is very low, representing less than 10^{-5} of the incident laser energy. Figure 3 b) shows an image of the rear of a 200 µm foam. On this longer foam the spot is broken up and spread over an area roughly 50µm in diameter. This breaking-up was not seen in earlier experiments when only the compact emission spot was observed from thinner foams.

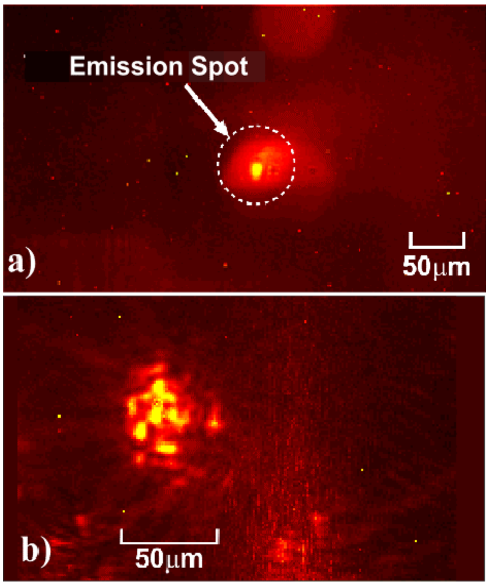

Figure 3. Emission from the rear of a) a 20 mg/cc, 50 µm long foam and b) a 30 mg/cc, 200 µm long foam.

Plasma Simulations

The plasma conditions were simulated with the 1D Lagrangian hydrocode, MEDUSA. Figure 4 presents the simulated density profiles at the time of interaction from foams of density 20mg/cc and 30mg/cc. The plasma density is similar for the two targets, reaching 6-8 times the critical density. The 0.1 µm plastic foil on the rear of the 20 mg/cc foam leads to higher density than would otherwise be the case. This suggests that the CPA interacts with plasmas of similar density when the two target types are used.

Discussion

The emission from the target rear is unlikely to be due to direct laser propagation. In order to propagate, the laser intensity must remain above the threshold for induced transparency throughout the target. This would have resulted in a significant amount of the incident energy being transmitted. It is more likely therefore, that the laser energy is converted into relativistic electrons, which propagate through the target. As the electrons pass through the rear surface, they emit visible radiation, either as transition radiation as they leave the plasma or via synchrotron emission as charge separation accelerates them back onto the target. These processes have been introduced to explain similar observations in other experiments with solid density targets3).

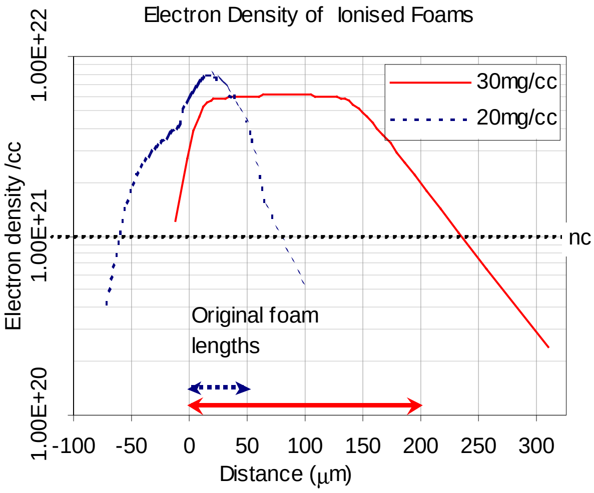

Figure 4. 1D simulation results showing electron density at the time of CPA interaction for two target types.

In thinner foams, 50 µm long, the electron transport appears to be collimated whilst filamentation takes place over longer propagation distances, up to 200 µm. This lends support to computational studies that predict that the electron stream is unstable as it interacts with the opposing cold return current4, 5). This return current of background electrons is highly collisional, unlike the relativistic current, which it balances, and it is likely that this produces the x-ray signal on the pinhole cameras.

In addition, previous work2) presented shadowgraphs showing localised expansion of the rear of the target attributable to a hot electron current propagating to the rear side6).

Conclusion

These observations represent the first measurements of electron transport in a plasma below solid density and as such are of great relevance to fast ignition studies. We have observed filamentation and break-up of a relativistic electron beam over a 200 µm length in plasma with 6 to 8 times the critical density for 1 µm radiation. This effect may have significant impact on the Fast Ignitor where it is desirable for highly collimated electron beams to propagate through high-density plasma. PIC simulations are underway to investigate the electron transport parameters in this density regime.

Acknowledgements

We extend our thanks to the staff of the Central Laser Facility for their invaluable assistance and support. This work was funded with an EPSRC grant.

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