# Investigation of ultra-intense laser interaction with overdense preformed plasma

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## Introduction

The interaction of ultra-high intensity laser pulses with overdense plasmas is of particular relevance to the Fast Ignitor scheme[1)] for Inertial Confinement Fusion. This scheme requires the deposition of energy of an ultra-intense laser pulse as close as possible to the core of a compressed fuel pellet. It is necessary for the pulse to propagate and channel through a long scale-length plasma which reaches densities many times critical. Investigation of propagation in well characterised overdense plasmas has thus far been limited to computational modeling [2)] and interaction with thin solid targets [3,4)].

Here we present results of experimental investigations of the interaction of an ultra-intense laser pulse with overdense preformed plasmas. The plasmas were preformed using soft x-ray preheating of low-density foam targets of various thicknesses. Simulations indicate interaction with an overdense region 50-200 μm in length. X-ray pinhole camera images reveal emitting filaments along the laser path extending through the plasma. Localised expanding plasma was observed on the rear of the target, in line with the laser direction. In addition, observations suggest possible marginal transmission of laser energy through shorter plasmas.

## Experimental Set-up

The experiment was performed using the Vulcan laser operating in the Chirped Pulse Amplification (CPA) mode. The experimental arrangement is shown in Figure 1.

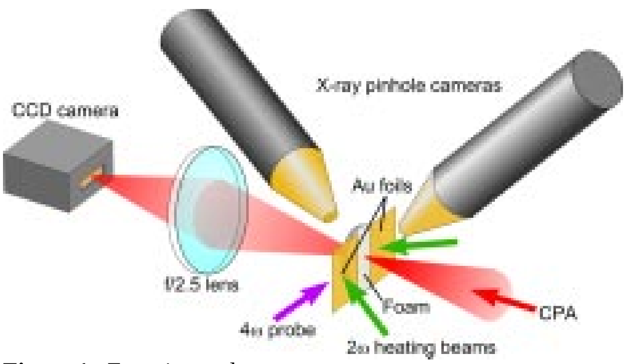


**Figure 1.** Experimental set-up.

Triacrylate and CH foams of different densities and lengths were used as targets. The triacrylate foams were 50 μm thick with density 10 or 20 mg/cc and were mounted in washers with a parylene backing. The CH foams were free-standing and had density 30 or 50 mg/cc and lengths from 100 to 250 μm. Two gold burn-through foils (700 Å of Au on 1 μm formvar) were positioned 50 μm in front of the foam, 200 μm apart. Two 600 ps beams were used to preheat the target. These were frequency doubled to 527 nm using KDP crystals. The two heating beams were focused onto the gold foils using f/10 lenses. This produced intensity of the order of $2\times10^{14}$ $Wcm^{-2}$ at the foils. The x-rays emitted by the foils [5)] were used to heat and ionise the foam target [6)] to produce the required plasma conditions. The CPA beam, operating at 1054 nm with a pulse length of 1 ps FWHM, was focused onto the preheated foam plasma with a f/3.5 off-axis parabola producing an intensity on target in excess of $10^{19}$ $Wcm^{-2}$. The delay between the plasma preforming pulses and the CPA pulse was between 800 and 1500 ps to allow the radiation wave to propagate through the foam.

Several diagnostics were used during each shot to provide information on the plasma formation and laser interaction. X-ray pinhole cameras with 25 μm pinholes were placed in front of and behind the target (Figure 1). The cameras were loaded with Kodak Industrex x-ray film. A 25 μm Be foil was used as a filter, transmitting radiation above 1 keV. Transmitted laser light was collected with an f/2.5 lens behind the target. The lens imaged the focal plane of the parabola onto an optical CCD camera to record transmission of the main laser pulse.

A 4ω pulse, 1 ps FWHM was used as a transverse optical probe. Delay relative to the main pulse was controlled to within a few picoseconds. An UV f/4 objective was used to image the target onto photographic film.

## Experimental Results

Figure 2 presents a typical CCD image of the rear of one of the thinner targets showing transmitted radiation. This is observed only through foams 50 μm thick with density of 20 or 10 mg/cc.

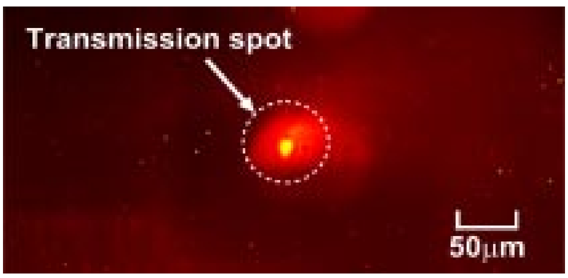


**Figure 2.** CCD image of target rear, transmission observed through a 20 mg/cc, 50 μm long foam target.

A bright spot is seen corresponding to the size, shape and position of the laser focal spot, suggesting that the energy transmission takes place during the CPA interaction.

The optical CCD was calibrated with a low energy shot (0.1 J). From this it is estimated that less than $10^{-5}$ of the initial laser energy was transmitted.

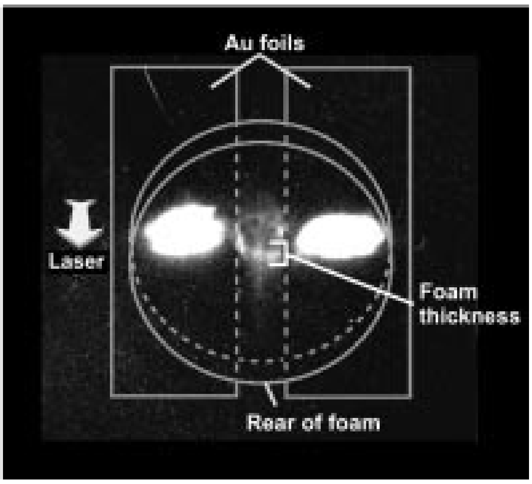


**Figure 3.** Soft x-ray image from rear pinhole camera with overlay showing the position of the surfaces of the foam and the gold foils.

X-ray images from the rear pinhole camera (Figure 3) show bright filaments extending through the foam and some distance beyond. The film shows the bright spots of the heating beams on the foils with a vertical filament in the centre. Such filaments are observed on several shots for different foam densities and lengths. In rare cases, breaking up of the filaments at the rear of the foam was observed.

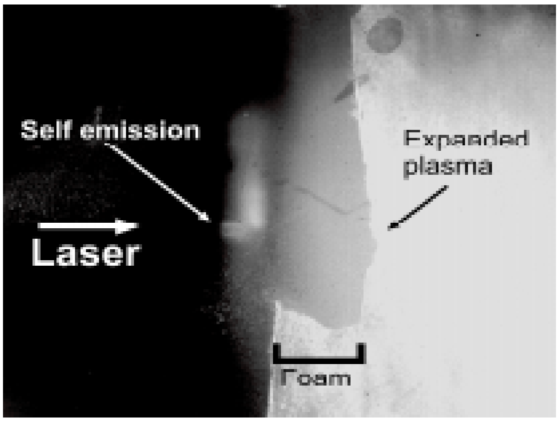


**Figure 4.** Shadowgram of a 150 μm freestanding foam showing expansion of the rear side.

Figure 4 presents a shadowgram produced by transverse optical probing. The image displays a profile of the target 50 ps after the CPA pulse. A localised region of expanding plasma is visible on the rear of the foam which lines up with the self-emission from the CPA interaction at the front. This localised expansion implies a collimated transport of energy through the foam.

**Modelling and discussion**

Plasma simulations have been carried out using the 1D Lagrangian hydrocode MEDUSA to determine the electron density of the plasma at the time of laser interaction. Simulated CH and triacrylate foams were heated with x-rays with temperature 60 or 120 eV (corresponding to one or two heating beams). Typical results (Figure 5) show a uniform ionisation with an electron density profile peaking for all target types at around $8n_c$. The electron density remains above critical density for length similar to the unexploded foam length. PIC simulations are planned to discriminate between the various mechanisms that could be responsible for the observed results.

The x-ray filaments within the plasma could be produced by heating of the plasma by the laser as it propagates through the overdense plasma. This is possible in the high intensity regime due to either induced transparency[7)] caused by relativistic modification of critical density or hole boring[8)] due to the ponderomotive pressure. Alternatively, the filaments could be produced by a stream of fast electrons, accelerated by the laser. As a matter of fact, localized expansion at the rear of the target has been attributed, in the past [9)], to fast electrons emerging from the target. The set of results seems to indicate that overdense laser propagation takes place, but in order to confirm this, further observations, analysis and modelling are required.

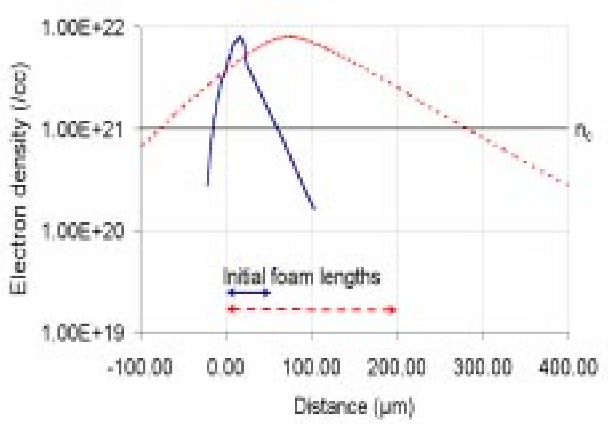


**Figure 5.** Simulated electron density profiles for 20 mg/cc, 50 μm long (solid line) and 30 mg/cc, 200 μm long (dashed line) foams at the time of CPA interaction.

**Acknowledgements**

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