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The front cover shows the view through the Titania laser cell into the multiplexing area.

The back cover shows part of the Titania pulsed power area in R2.

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PRODUCTION AND CHARACTERISATION OF UNDERDENSE PLASMAS FOR INTERACTION STUDIES

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INTRODUCTION

The study of laser interaction with long scale, underdense plasmas, crucial for ICF applications, requires suitable plasmas to be produced in a controllable way. A well established and flexible method consists in exploding a thin target by irradiating it with laser pulses. By appropriately choosing the pulse and target parameters, plasmas in a wide range of densities and temperature can be obtained with this technique. Both diagnostic development and target design are fundamental issues, in view of a detailed characterisation of these plasmas. In particular, due to the growing interest in short pulse interaction, the development of diagnostics able to resolve physical phenomena on picosecond and subpicosecond temporal scale is strongly required.

The production and characterisation of plasmas produced by symmetrical laser irradiation of thin targets was the object of a previous experimental study by our group [1] performed at the Rutherford Appleton Laboratory in 1992. In that experiment, plasmas were produced by uniform laser irradiation from opposite sides of Al disks coated on thin, narrow stripes. Time resolved X-ray spectroscopy was used to infer the electron temperature, while 2-D electron density maps of the plasma were obtained with an interferometric technique. The resolution available in the interferometric measurements was 100 ps. This limited the readability of the interferograms, since the visibility of the fringes vanished in the inner region of the plasma, where the density variation during 100 ps was large enough to smear out the fringe pattern. A complete density map could be obtained only at late stages of the plasma evolution (typically after 4 ns from the peak of the pulse). An additional problem encountered was the deviation of the plasma from cylindrical symmetry, with the adopted target design.

We report about the progress in the production and characterisation of underdense plasmas achieved in a recent experiment, carried out with the Vulcan laser at the Central Laser Facility.

EXPERIMENTAL ARRANGEMENT

The plasma was produced by four 600 ps, 1.053 μm heating beams of the Vulcan laser, in the configuration reported in [1]. The heating beams were superimposed on target in two opposite pairs in a 650 μm FWHM focal spot for an irradiance on each side below 10^{14} W/cm^2. Each pair was composed of two beams at angles of +13 and -13 degrees to the target plane, respectively. The targets used were Al disks, alternatively coated onto 0.1 μm thick plastic foil support, or held by four tiny Al arms in the shape of a X. This second type of targets was obtained by etching of an Al thin deposit on a plastic foil. The diameter of the dots was 800 μm and their thickness 0.4 μm. A 1 ps Chirped-Pulse Amplified (CPA) beam, frequency doubled to 0.53 μm, was used as an optical probe for interferometric measurements in a line of view parallel to the target plane (see [1]).

A modified Nomarski interferometer [2] allowed to detect the phase changes undergone by the probe beam and thus measure the electron density profiles. The probe line set-up was modified with respect to the configuration of the previous experiment. A confocal optical system (composed of a microscope objective and a f/10 lens) imaged the plasma and recollimated the probe beam. A third lens was used in order to relay the image plane, so that

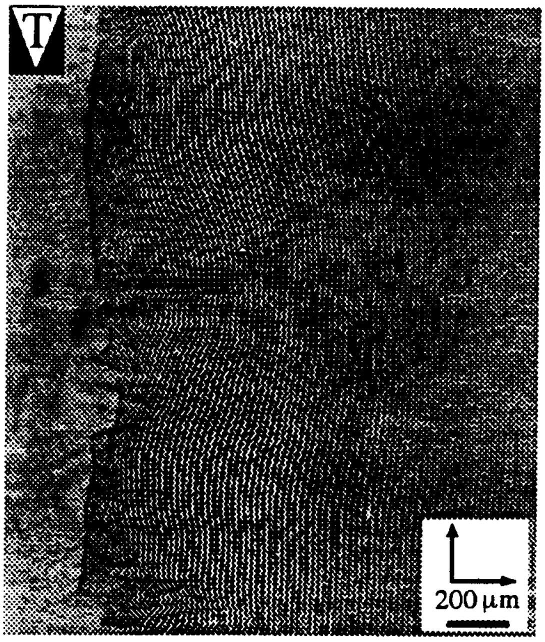

Fig. 1. Interferogram taken 2.2 ns after the peak of the heating pulses. The heating irradiance was 7.2 10^{13} W/cm^2, the duration of the probe pulse about 1 ps. The original target position is indicated by the "T" wedge.

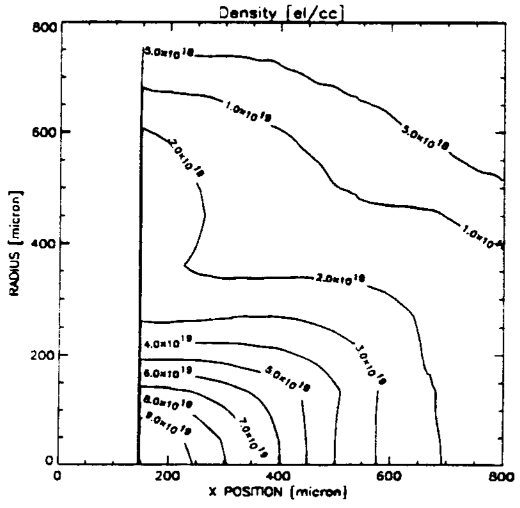

Fig. 2. Density profile obtained from the interferogram of fig. 1. The x position is measured from the original target position, the radius from the main symmetry axis.

spatial filtering could be performed in the Fourier plane of this lens. The Wollanston prism was located close to this plane.

INTERFEROMETRIC CHARACTERISATION

The use of a short pulse optical probe marked a notable progress in the interferometric characterisation of the plasma. An interferogram taken 2.2 ns after the peak of the heating beams is shown in Fig. 1. The target was an Al disk coated on a large plastic foil. The irradiance on target was 7.2 10^{13} W/cm^2 on each side.

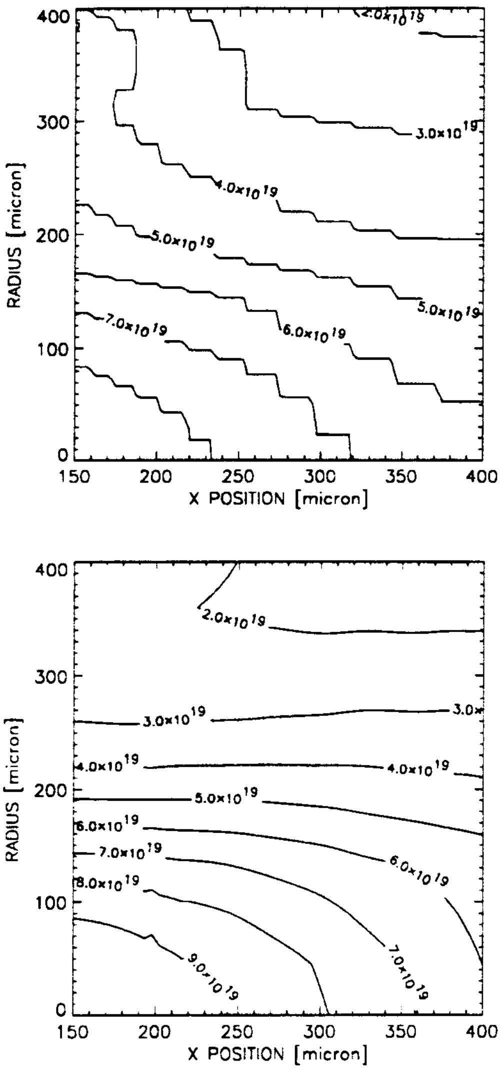

Fig. 3. 2-D predictions for the situation of fig. 2 (above), compared with the experimental profile (below).

The progress achieved is evident from comparison with interferograms obtained with the 100 ps probe [1]. In that case, even at later times, the visibility of the fringes was lost over a considerably wider region: in interferograms taken 3 ns after the plasma production, the region over which the density was not measurable extended longitudinally for 400 μm. With the picosecond probe, it was possible to measure the density profile almost over the length of the whole plasma as early as 2 ns. The density map of fig 2 was obtained from the interferogram using a Fourier transform method for the phase extraction [3], and subsequent Abel inversion [4] of the phase distribution. The Barr algorithm [5] was used to invert the Abel integral.

The hydrodynamic expansion of the plasma was simulated using the 2-D hydro-code POLLUX [6]. In fig. 3 the code prediction for the density profile in the same conditions of the interferogram of Fig. 1 is shown, together with the experimental profile. The substantial agreement with the experimental data gives confidence in 2-D simulations as a reliable and useful tool in designing experiments in this configuration.

TARGET DESIGN

The targets used in the 1992 experiment consisted in Al disks coated on plastic stripes, as wide as the disk diameter. This target design was chosen in order to avoid plasma to be produced outside the Al disks on the line of sight of the probe, since this could result in shadowing of part of the field of view. The drawback of this design was that the plasma produced from this type of targets considerably deviated from cylindrical symmetry. In fact, a plasma was created on the plastic support above and below the Al disk, that confined the Al plasma in the vertical direction. Consequently, the symmetry of the plasma was ellipsoidal rather than cylindrical, with the longer axis along the probe line.

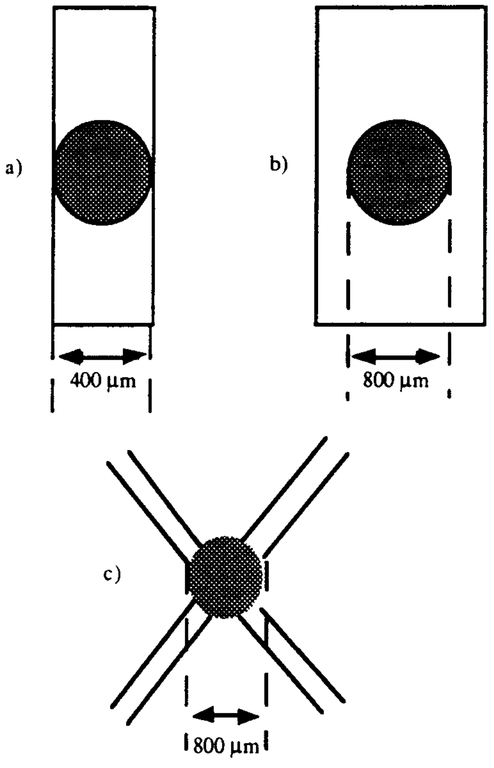

Fig. 4. The different target designs experimented: a) Al disks coated on narrow plastic foils, as used in the 1992 experiments; b) Al disk coated on large plastic foils; c) X-shaped targets.

Since Abel inversion techniques are based on the assumption of cylindrical symmetry, a systematic overevaluation resulted in the density measurements, that led to discrepancies with the numerical predictions [1].

Different target designs were experimented this time. In first place, targets in which Al dots were coated on large plastic foils were used. Plasmas produced from these targets expand with cylindrical symmetry, since a plasma is generated on the plastic support all around the Al disk.

It is not unexpected, then, that the experimental density profile was much closer to the hydrocode predictions, as seen above (fig. 3). Residual, though unsubstantial, discrepancies can be explained keeping in mind that a certain ellipticity of the plasma is however intrinsical, since in the adopted configuration the laser spots are elliptical, rather than circular. However, when using these targets, the shadow of the dense, slowly expanding plasma created on the plastic support obscures the central part of the interferogram. In the interferogram of fig. 1 the shadow extends longitudinally for 150 µm from the original target position.

In interaction studies this limitation can be highly undesirable, since, in order to follow the propagation of an interaction pulse, it may be necessary to visualize the interference fringes over the length of the whole plasma [7]. *X-shaped* targets, in which the Al disk is held by four Al arms, showed to be more suitable for this purpose. Since no plastic is present on the line of sight of the probe, the field of view is not limited by any shadow when using these targets. An interferogram of a plasma obtained from one of these targets is shown in fig. 4. As it can be seen, this particular target design, together with the short duration of the probe pulse, ensured excellent fringe visibility virtually throughout the whole plasma.

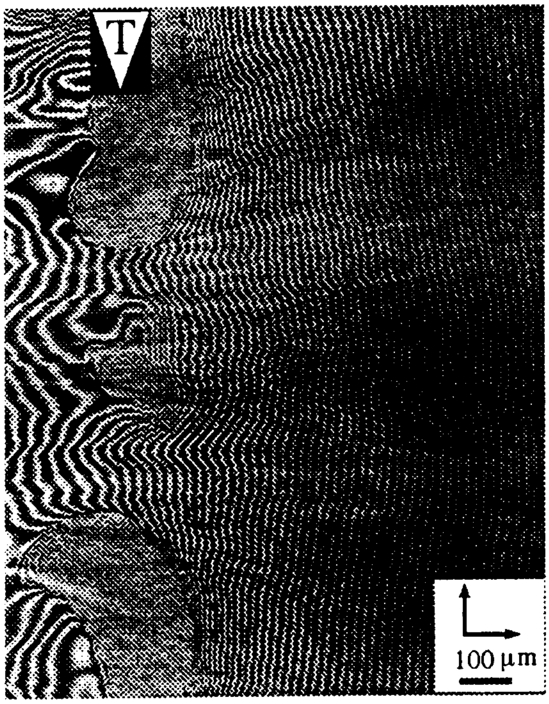

Fig. 5. Intereferogram of a plasma produced from an X-shaped target, taken 2.2 ns after the peak of the heating pulses.

Unfortunately the width of the Al arms could not be reduced below 200 µm, due to technical constraints in the target preparation. As a consequence, the plasma produced on the arms by the outer edges of the laser spot introduced a non negligible perturbation to the symmetry of the whole plasma in the region closer to the original target position.

In the interferogram of fig. 5 the longitudinal extent of this region is about 300 µm. An approximate value for the electron density could anyway be obtained in that region, while the deconvolution of the interferogram at distances further away from the original target position did not present any problem.

CONCLUSION

Long scale, underdense plasmas suitable for interaction studies were produced by uniform laser irradiation from opposite sides of thin targets. The plasmas were characterised via optical interferometry with picosecond resolution. The use of a picosecond pulse probe led to relevant progresses in the plasma characterisation with respect to previous results obtained with a lower temporal resolution. Different target design were experimented and their relatives merits compared.

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