Ablation loading of solid target through foam absorber on ABC laser at ENEA-Frascati

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Abstract. This work reports an experimental characterization of the efficiency of energy transmission of porous laser absorbers as a function of their density and thickness. In this campaign the foams were deposited on different metal substrates, which finally absorbed the energy deposited by the laser on the bulk of the porous material. The dimensions of the craters produced on the substrate can be related to the energy transmitted through the foams.

Introduction

The stability of acceleration of targets irradiated by high intensity lasers is a main concern in inertial confinement fusion (ICF) research. The highest degree of both irradiation homogeneity and target surface finish will be required in ICF devices to achieve high performance implosions. The uniformity of the pressure exerted by the ablating plasma on the underlying target can be enhanced further by an even absorption of the laser light. Volume structured materials, such as foams with supercritical average density, have been proposed as random absorbers of the radiation [1,2] to mediate the interaction of the laser light with the target. In order not to limit the overall energy transfer to the target, optimization of the absorber characteristics is of primary importance. We report here a study of the energy transmitted through laser-irradiated porous absorbers in the ABC facility in Frascati at intensities ~10ⁱ³-¹⁴ W/cm². Previous experiments in similar conditions reported low levels of reflected and transmitted light [3]. The purpose of this work was to measure the energy transmitted by the absorber to a metallic holder opposite the laser beam. This energy is deduced from the volume of the craters imprinted on the substrate, knowing the properties of the substrate material. In our experiment, the dimensions and shapes of the craters were measured with a high-resolution confocal microscope. The foams used had densities in the 10 - 60 mg/cm³ range and varying thickness. The experimental dependence of crater characteristics vs. the interaction parameters, the foam thickness and the foam density, are investigated. The plasma produced on the foam was characterized by 2nd harmonic interferometry and imaging, time resolved soft X ray.

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emission and ion-collectors measurements [4]. Density profiles of the plasma were deduced from the analysis of the complex interferometry data.

Smoothing of laser radiation

The absorbers used in our experiments were polystyrene foams with average densities in the range 10 - 60 mg/cm³, a few times higher than the critical density \( \rho_c = 3 \text{ mg/cm}^3 \) at the fundamental laser wavelength (1054 nm). These can be regarded as composed of empty cells delimited by solid plastic walls a few \( \mu \text{m} \) thick. Laser absorption on such materials relies on a 2-stage mechanism as described in [1, 2]: in the initial phase (\( \sim 1 \text{ ns} \)) the radiation absorbed on the cell walls creates the plasma, which rapidly expands in the vacuum regions. In the following stage, extended hot plasma is created by collisional interaction of the small plasma zones. During this process the absorber’s transparency length decreases and part of the laser energy is converted to the motion of a high-pressure front propagating in the plasma [5]. To optimize the efficiency of this process, the foam characteristics should be chosen in relation to the laser pulse duration, so that energy is delivered during the extended plasma phase and full absorption occurs inside the absorber thickness. In ABC for a foam of density \( \rho_{\text{foam}} = 20 \text{ mg/cm}^3 \) and typical sizes of the pores \( \delta_0 \sim 50 - 100 \mu \text{m} \) with wall thickness \( b_0 \sim 2 \mu \text{m} \) [5], typical initial transparency lengths are \( \sim 400 \mu \text{m} \), reduced by a factor \( \sim 2 \) in the second phase.

Experimental setup

ABC is a Nd-glass laser, wavelength 1054 nm, delivering 2 beams with energies \( \leq 100 \text{ J} \) each, which can be focused on opposite sides of a planar target to spots of \( \phi_{\text{min}} \approx 40 \mu \text{m} \) by F/1 lenses. By the use of ISI plates (Induced Spatial Incoherence) [6], intensity profiles with amplitude modulations < 1 % can be achieved on 500 \( \mu \text{m} \times 500 \mu \text{m} \) spots. The measurements reported in this paper were obtained with a single heating beam with \( E_0 \sim 50 \text{ J} \), pulse duration 3 ns. The laser intensity varied between \( I_0 \sim 10^{13} \text{ W/cm}^2 \) with ISI beam smoothing plates and \( \sim 2.5 \times 10^{14} \text{ W/cm}^2 \) focusing on 100 \( \mu \text{m} \) spots. Multichannel ion-collectors and soft-X ray pin diodes were used for time resolved measurements of particles and radiation emission. Shadowgraphy and interferometry of the plasma were obtained by means of a 2nd harmonic beam, originated from the main pulse; this beam has a \( \approx 0.6 \text{ ns} \) duration and is split and delayed to probe the plasma at 4 different times. Spatial resolutions of the images are better than 50 \( \mu \text{m} \). The interferometer configuration is of Nomarsky type and uses Wollaston prisms; electron density profiles are obtained by analysis of complex interferograms and Abel inversion with the ‘cplxifer’ code [7]. Polystyrene foams of \( \sim 10 \text{ mm}^2 \) area and thicknesses 200 - 800 \( \mu \text{m} \) were put in close contact to metal substrates (Al, Sn), which absorbed the energy of the shock wave produced by the laser [8]. The metal substrates were previously polished with 15 \( \mu \text{m} \) grain size.

Experimental results

Experimental data were collected at approximately constant laser energy. Reference shots on pure Al target were used for comparison with the foam plasma behaviour and to correct the crater volumes against shot to shot variations of the laser output. Figure 1 reports the time evolutions of the optical border of the plasma originated on pure Al targets and on a 320 \( \mu \text{m} \) thick foam. The pictures where obtained by transverse illumination of the target with 2nd harmonic probe beams delayed respectively by \( t = 0.3; 4 \) and 6 ns with respect to the heating beam. The absorption of the laser energy on the foam is accompanied by small-scale non-uniformities in the plasma, compatible with the pore sizes, and by an enhanced transvers expansion leading to profiles more flat than in pure Al targets. This is also shown in the density reconstructions obtained by complex analysis [7] of the interferograms (see Figures 2-4); marked enlargements of the density profiles have been observed in
two conditions of laser intensity: the first using an ISI smoothing plate and a 500µm*500µm focal area, the second with a sharper focus (SF) on a 100µm focal spot. Large tranverse energy propagation in the foam plasma appears as an evidence of the property of the foam of redistributing the absorbed energy.

**Fig. 1** Images illustrating the plasma evolution.

- Top - Al target
- Bottom – Foam-coated Al target

\(\rho_{\text{Foam}} = 10\text{mg/cm}^3, \delta_{\text{Foam}} = 320\mu\text{m}\)

The dense plasma appears dark.

(The first 2 columns are shadowgraphies, the last column is a portion of interferograms obtained with a Wollaston prism).

(The ‘wings’ on the plasma periphery are disregarded since they are know to be due to the laser profile in the focal spot).

**Fig. 2** - Image produced by the Nomarsky interferometer and density reconstruction for shot #1117 at t=4ns

**Fig. 3** Example of a radial electron density profile (shot #1117 at t=4ns)

**Fig. 4** - Density vs. distance from the target at t=4ns with foam (shot #1117, #1123) and on pure metal (#1093, #1095)

**Crater analysis**

The analysis of craters was done with a confocal microscope LEICA DCM 3D which allowed measurements of their surface with an accuracy of ~ 1.7 µm on the planar dimensions and ~ 45 nm on the depth, an example is shown in Figure 5. The dependence of the crater volumes on foam thickness is shown in Figure 6 for various densities of the absorber. The data show a clear maximum for \(\delta_{\text{Foam}} \sim 250\mu\text{m}\) while for \(\delta_{\text{Foam}} \sim 800\mu\text{m}\) the crater volume reduces to about a factor 10 of the maximum.
Crater formation

The ablation of material from the target substrates is caused by the high-pressure shock wave traveling in the laser produced plasma. The amount of matter, which is melted and evaporated by the shock wave hitting the metal, can be related to the energy transmitted by the plasma. The volume of the crater $V_{\text{crater}}$ [cm$^3$] depends on the laser energy $E_L$, on the laser-plasma energy coupling $K_p$ and on the efficiency of conversion to shock wave $\sigma$:

$$V_{\text{crater}} = \frac{\sigma K_p E_L}{\alpha w_0 \rho_0}$$

where $\alpha$ is the thermal/kinetic ratio in the shock adiabat, $w_0$ the specific vaporisation heat, $\rho_0$ the solid metal density. It is well known, for strong shock waves, under the approximation of negligible elastic energy, $\alpha=2$. The main part of the crater is created by the shock wave damped during several tens of nanoseconds, longer than laser pulse. So, the average factor $\alpha$ is less 2 and varies in the region 1.2-1.5 (see, for example, [9]). For $E_L = 50$ J, the efficiency of energy transformation to shock wave for pure Aluminum ($w_0=10^3$ J/g $\rho_0=2.7$g/cm$^3$) is $\sigma K_p V_{\text{crater}} \sim 10^2$ cm$^{-3}$. Experimental data show that the value at the optimum thickness is $\sigma K_p \approx 8 \times 10^{-3}$ which is comparable with the pure Al values (for which $\sigma K_p \approx 6 \times 10^{-3}$). The experimental data above indicate that choosing the optimal thickness of the foam the efficiency of energy transfer to the target can be similar or even better than in the case of direct irradiation, with the advantage of reduced non-uniformities.

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