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Impact of Foam Structure and Composition on Laser Absorption and Energy Transfer

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1. Introduction

Target design using low-density foam layers may significantly facilitate various applications of high power lasers. Foam layers may be used in inertial fusion targets to improve implosion symmetry [1,2]. Alternatively, transparent underdense foam may be applied as a dynamic phase plate in order to randomize and partly wash out inhomogeneity patterns inside laser beams [3].

According to our previous experiments [4,5] laser interactions with underdense foams (homogenized, fully ionized foam has electron density n_{eh} less than the critical density n_c) depends on foam pore size D_p significantly. Namely, rear frontier of region emitting X-rays with photon energies ≥1 keV reached the depths of 400 μm during 320 ps laser pulse (λ = 439 nm) for fine pore ($D_p \approx 0.5 - 3$ μm) foam of density 4.5 mg/cm^3 ($n_{eh} \approx 0.5\, n_c$), while it stayed confined to surface 150 μm deep layer of coarse ($D_p \approx 30 - 100$ μm) foam of the same density. The frontier speed also decreases with foam den sity.

Present experiment is devoted to measurement of laser transmission through foams with fine pores. It can enlighten laser-foam interaction physics and it is also important for possible foam application as a dynamic random phase plate. The presented one- and two-dimensional simulations study laser penetration into foam.

2. Experimental setup

Third harmonics (λ = 439 nm) of PALS iodine laser was incident normally on the target surface placed 500 μm behind the best focus, and thus, the laser spot diameter on target surface was 300 μm and laser irradiances were in the range of $I \approx 10^{14} - 10^{15}$ W/cm^2. The

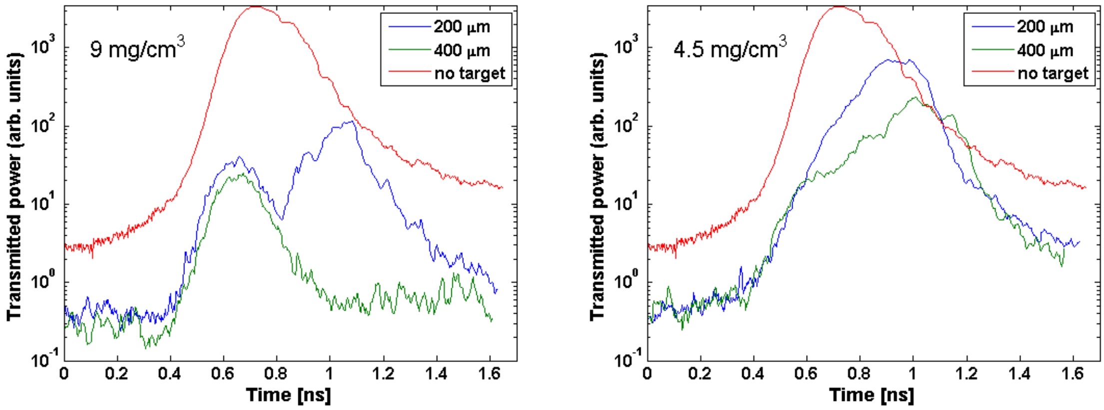

Figure 1: *Laser transmission through foam layer compared to vacuum transmission. Laser pulse of energy in range 150 – 170 J, wavelength 439 nm and duration 320 ps is incident normally on TAC foam layer of thickness 200 or 400 µm. Foam density is 9 and 4.5 mg/cm^3 in the left and right graph, respectively.*

targets 100, 200 and 400 µm thick were made of fine-structured TAC (cellulose triacetate, $C_{12}H_{16}O_8$) foam [6] of density 2.25, 4.5 and 9 mg/cm^3 with pore diameters $D_p \approx 0.5 - 3$ µm. Optical streak camera was used together with a calorimeter for measurement of laser transmission through foam targets. Measurements with foams were related to the transmission of laser pulse of the same through detection channel when target is absent.

3. Measurements of laser transmission through foam layers

Temporal shapes of laser pulses transmitted through foams are presented in Fig. 1. In all shots, leading edge of the laser pulse penetrated through transparent foam up to intensity 3×10^{12} W/cm^2, which was ≈ 0.5 – 1% of the maximum. At this intensity level, pore walls were ionized and laser was absorbed in the foam. For higher foam density 9 mg/cm^3 ($n_{eh} \approx 0.5\, n_c$), laser penetration stopped after foam ionization and it was restored at the end of laser pulse for foam thickness 200 µm, but not for thickness 400 µm. Laser penetration was not completely interrupted for foam densities 4.5 mg/cm^3 and below, however, the transmittance dropped at this moment and it increased with a certain delay.

Penetration of the laser pulse leading edge through the foam layer may be important disadvantage for foam application for ablation pressure smoothing, as laser imprint on the foil may be formed by the leading edge of the laser pulse. It can be also deduced that the measured fast propagation of X-ray emitting region into the TAC foam of density 4.5 mg/cm^3 is associated with laser penetration deep into the foam layer.

Laser transmission (ratio of transmitted to incident laser energy) is plotted versus foam density and thickness in Fig. 2. Transmitted energy decreases with foam density and thickness. It increases with laser energy, as foam homogenization is faster for higher laser intensities.

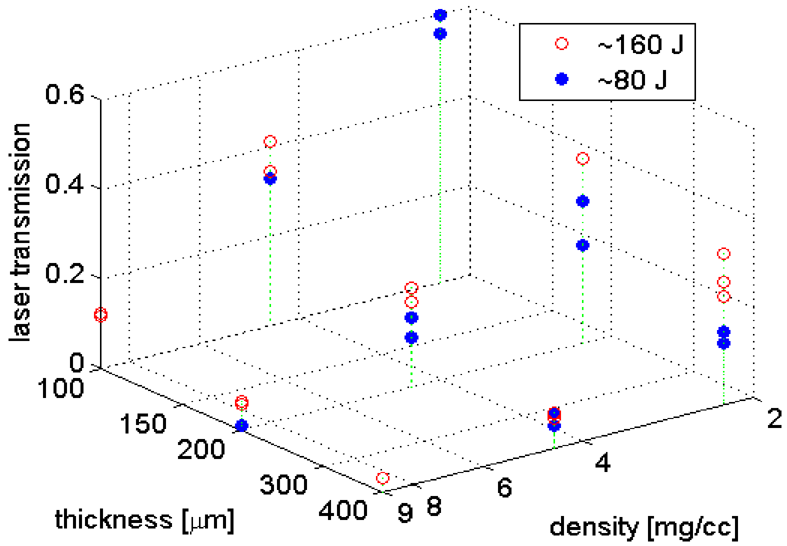

Figure 2: *Laser transmission through foams of various densities and thicknesses. Laser pulse of energy in the range of 153 – 183 J (open circles) and of 74 – 88 J (filled circles), of wavelength 439 nm and of duration 320 ps was incident normally on the foam target, best focus was 500 μm ahead of target and laser spot diameter on the target was 300 μm.*

4. Numerical simulations

Laser foam interactions are simulated by one-dimensional (1D) staggered Lagrangian fluid code and newly developed two-dimensional (2D) arbitrary Lagrangian-Eulerian (ALE) code [7]. One temperature hydrodynamics uses QEOS equation of state and Spitzer-Harm heat conductivity with heat flux limitation (flux limiter $f = 0.03$). Radiation energy transport has not been taken into account yet though it may be important even for low Z foams. While 75% of incident laser energy is damped at the first critical surface in 2D code, detailed laser absorption may be calculated in 1D via solution of stationary wave equation. Foam is modelled as a sequence of slabs separated by void space.

Simulations show that laser penetration into the foam is controlled by the areal mass of pore walls (slabs). For light slabs (Fig. 3 left up), laser skins through several slabs at once, uniformly heated slabs expand symmetrically to both sides (exploding foil regime). For heavy slabs (Fig. 3 left down and right), laser heats separate foam layers successively, the slab front expands rapidly and the rear side is ablatively accelerated, laser penetration into the foam is considerably slower. In this regime, heat wave propagation far ahead of laser penetration was observed in numerical simulations. Speed of laser penetration into the target depends on laser absorption model, simulations including detailed absorption predict slower laser penetration into foam with heavy pore walls. Laser penetration in 2D simulations is even faster than for 1D simulation with laser absorption at critical surface

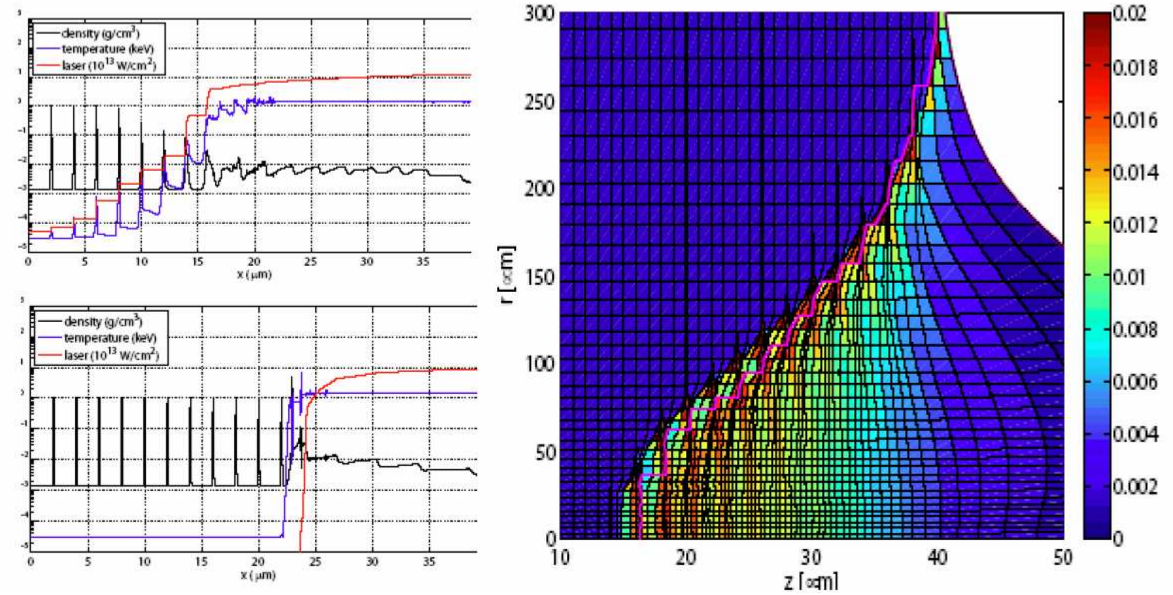

Figure 3: *Density, temperature and laser intensity profiles at time 20 ps for foam target with pore wall width 10 nm (up), and 20 nm (down); density profile in 2D simulation for 20 nm walls (right). The width of each slab-void pair was set to 2 μm, the slab and void initial densities were 1 g/cm^3 and 1.43 mg/cm^3, respectively. Laser is incident from right, laser pulse rises in 1 ps to constant maximum intensity 3.7×10^{14} W/cm^2, λ = 439 nm. Gaussian laser beam with spot radius 125 μm is assumed in 2D and spot averaged intensity is equal to 1D simulations. Detailed laser absorption model is used in 1D while 75% of laser energy is damped at the first critical surface in 2D simulation.*

due to higher intensity in the laser beam centre. Lateral heat transport does not slow down laser penetration into the foam. Qualitative explanation of heat wave speed dependence on foam structure was found and reasonably quantitative agreement with experiment is observed.

Acknowledgements

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