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AEROGEL FOIL PLASMA: FORWARD-, BACKSCATTERING AND TRANSMISSION OF LASER RADIATION

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AEROGEL FOIL PLASMA: FORWARD-, BACKSCATTERING AND TRANSMISSION OF LASER RADIATION*

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Abstract

Experimental results obtained with "Kanal-2" facility under the study of powerful laser pulse interaction with the polymer low density microstructured media are presented and discussed in the report. The polymer low density microstructure media are considered as promising materials for ICF.

In the experiments the laser radiation parameters were as follows: pulse duration, 2,5 ns; radiation wavelength 1,06 μm, spectral radiation width, 17 to 42 Å; output laser energy, 30 to 100 J; power flux density of heating radiation on the target, 10^{13}-10^{14} *W/cm*^{2}.

The polymer aerogel of triacetate cellulose (TAC) with the density changing within the range of 2-10 mg/cm^3 *with the thickness 100-500 μm was used as the target. The interaction with the targets of both the critical and under critical density was investigated.*

The temporal, spectral, and energy characteristics of both the radiation scattering in the direction of heating radiation beam and the backscattering radiation were studied; the directional diagrams of forward and backscattering radiation were obtained. Analysis of intensity redistribution on the beam cross-section after passing through a polymer microstructure target was carried out.

The energy balance measurements have shown that the energy transmitted through the target is comparable with that of the incident radiation. The radiation scattered into the aperture of a focusing lens does not exceed 1%. The value of the energy passed through the TAC target depends on the aerogel density, its thickness, and may achieve 70% even when the density proves higher than the critical one. It is found that the spectrum of transmitted radiation is considerably broadened up to 200 Å. The second harmonic generation and other nonlinear effects were also experimentally registered under TAC targets irradiation.

Laser radiation transmission through aerogel is considered as nonlinear transparency of a plasma layer arising from the laser radiation interaction with the low-density target. The observed broadening of the radiation line is connected with the stimulated scattering processes, such as SBS and SRS.

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Volume-structured materials are considered as different functional elements in the ICF targets [1-6]. First of all, the smoothing of a heating inhomogeneity and production of a steady compression of the ICF targets are possible applications of these materials. Therefore, investigation of the specific features of laser radiation absorption and scattering by such a media, as well as the energy transfer, plasma formation and plasma dynamics are the topical problems.

The report presents recent results obtained from studying the laser interaction with volume-structured media. The attention is focused on studying the backscattering, forward scattering and the propagation of laser radiation through such media, including the spatial distribution of the transited radiation and its spectral and energy characteristics. The analysis of intensity redistribution on the beam cross-section after passing through a polymer microstructure target has been performed.

The experiments have been made with a Nd-glass laser facility "KANAL-2" with controllable coherence of radiation [7] with the following parameters: laser pulse duration, 2.5 ns; pulse energy, 50 – 150 J; output aperture, 45 mm; degree of spatial coherence, ~ 0.05 – 0.015; degree of temporal coherence, ~ $5x10^{-4}$ – $5x10^{-3}$; degree of radiation polarization, ~ 0.5; pulse radiation contrast > 10^6.

As the targets, the triacetate cellulose aerogels of the density changing within the range of 2-10 mg/cm^3 and the thickness of 100-500 μm have been used. In several experiments up to 10 weight percent of copper nanoparticles of the average diameter of 40 nm have been introduced into the polymer, but for all that the electron concentration and average density did not change. 3D polymer nets do not change their structure under the change of density from 50 mg/cm^3 to 1 mg/cm^3. The distance between the filaments is 0.6 to 1.7 μm, and the filament diameter is 70 to 40 nm. The aerogel density fluctuations at volume averaging 0.3x0.3x0.3 mm^3 do not exceed 0.5%

at the aerogel average density higher than 4 mg/cm^3, and grow up to 3% for the aerogel density of 1 mg/cm^3.

The dependence of the radiation scattering angle on the target linear mass has been revealed for the polymer TAC targets at studying the backscattering on fundamental frequency. The diagrams of backscattering on the fundamental frequency for the TAC targets 4.5/400 (density/thickness) and 10/200 are similar. The increase of scattering angle in which the scattering of the main part of energy (80-90%) occurs has been observed for TAC target at changing of the linear mass from 0.09 to 0.36 mg/cm^2 (Fig. 1 a). According to Fig. 1 b, the radiation transited through the aerogel target propagates practically along the axis of the heating laser radiation beam.

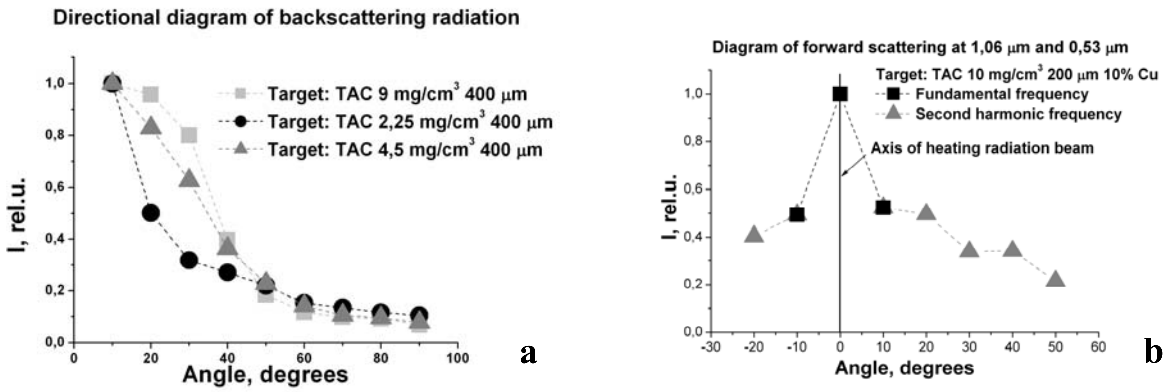

Fig. 1. a. Directional diagram of backscattering radiation on the fundamental frequency. b. Directional diagram of the radiation on the fundamental and second harmonic frequency transited through the aerogel target.

The energy of the radiation scattered into the focusing aperture lens is less than 1% of the heating laser energy and, in particular, it is 0.2% for TAC target 9/400. This means that the nonlinear scattering processes such as back-SMBS and back-SRS are non-essential from the energy viewpoint, and may affect the scattered radiation linewidth only. From this one may also conclude that the nonlinear processes of forward scattering due to SMBS and SRS are not energy essential. However, one can observe (see Fig. 2) an essential (up to 200 Å) spectrum broadening of the transited radiation.

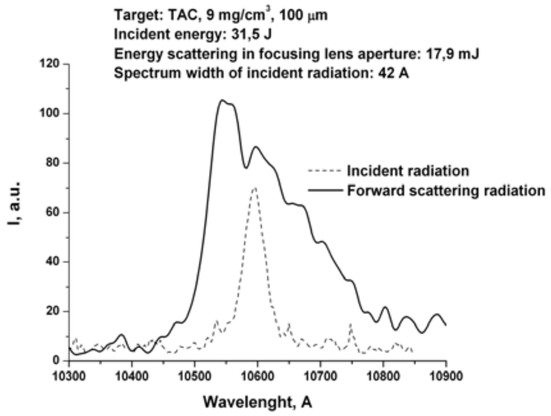

Fig. 2. Spectra of the heating laser radiation and the radiation transited through the aerogel target.

It was found, that the energy E_{tr} transiting through the target is comparable to the energy E_{inc} of the incident radiation and the value of energy E_{tr} can run up to 70% from the incident energy. In particular, it is 72.7% for TAC target with the density of 2.25 mg/cm^3 and thickness 180 µm at the power flux density $9 \cdot 10^{13}$ W/cm^2.

The energy transited through the aerogel decreases with the increase in the aerogel thickness, the increase in the target density, and the increase in the target linear mass (Fig. 3).

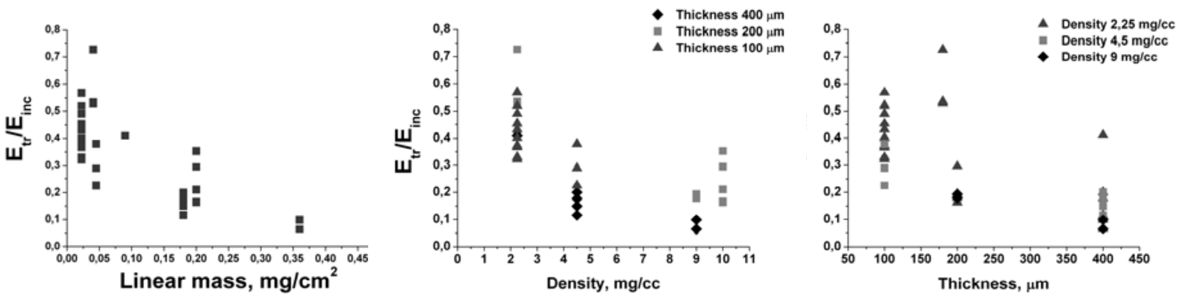

Fig. 3. Dependences of the energy transited through the target on the target linear mass, density, and target thickness.

In TAC target irradiation experiments the plasma electron temperature value was 0.4-1.4 keV. The electron temperature dependences on the power flux density, target thickness and energy *ΔE* was revealed (Fig. 4). Here

$$\Delta E = E_l - E_{bs} - E_{fs+tr}$$

and E_l - the energy of incident laser radiation; E_{bs} - the backscattering radiation energy; E_{fs+tr} - energy of the radiation transited through the target and forward scattering. It was found that plasma electron temperature is in direct proportion to ΔE.

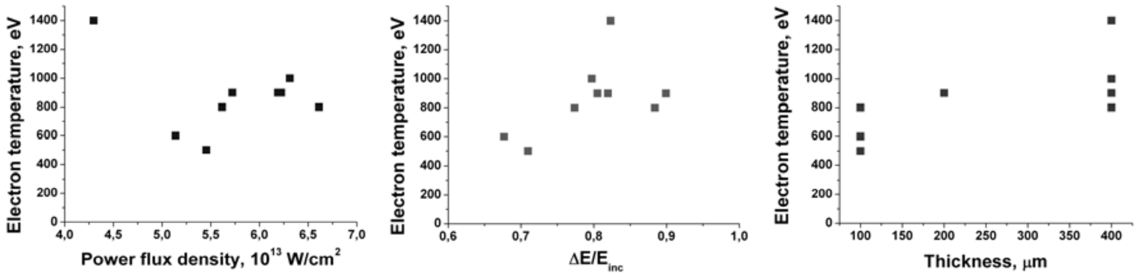

Fig. 4. Electron temperature dependences on power flux density, ΔE, target thickness.

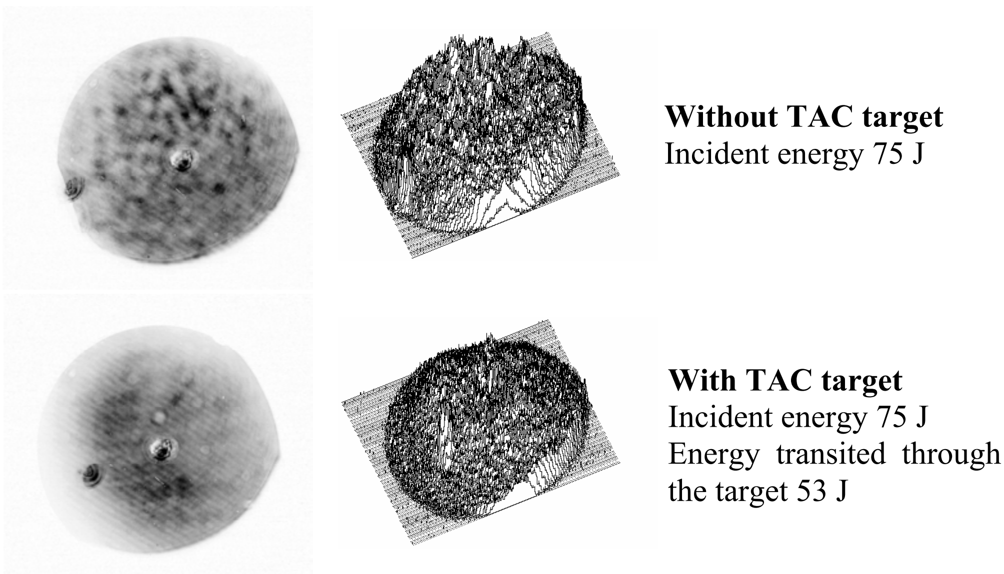

Fig. 5. Distribution of radiation intensity in the near-field zone.

The distribution of radiation intensity in the near-field zone was obtained at the investigation of radiation transited through the target. As seen from Fig. 5, the intensity redistribution on the beam cross-section can be achieved. The intensity smoothing after passing through a polymer aerogel takes place at optimum correlation between the laser and target parameters. In our case TAC target had the density of 2.25 mg/cm^3 and the thickness 400 μm.

As one can see from Fig. 6a, the energy comparable with the target incident energy transits through a target at the pulse beginning when the size of plasma is not large. As the plasma develops the absorption grows, and the pulse passing ceases. As seen from X-ray measurements, the X-ray radiation intensity grows, and this corresponds to a going-on plasma heating. Pulse duration of a transited energy is comparable with the duration of the incident laser pulse.

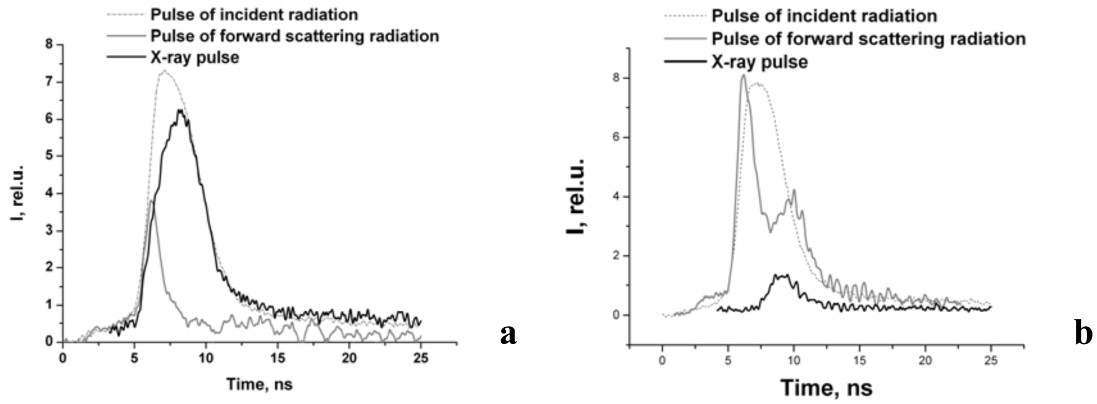

Fig. 6. Temporal behavior of the heating laser radiation pulse, the radiation pulse transited through the aerogel target, and the X-ray pulse for TAC target of the density 9 mg/cm^3, the thickness 500 μm (a) for TAC target of the density 10 mg/cm^3, the thickness 200 μm μm, and 10% of copper nanoparticales (b).

The interpretation in frames of the target geometrical transparency [2, 4] is not capable to explain the observed duration of a transited energy pulse, and the value of that energy.

This seems to suppose that nonlinear transparency of plasma produced under aerogel irradiation may be responsible for the observed effect.

Such a transparency arises due to the plasma density modulation in the laser field. As shown in [8-11], due to such modulation there may arise even a full transparency of a plasma layer under certain relationship between the laser intensity, plasma layer size, and the radiation wavelength.

The second harmonic registration shows that such density modulation actually takes place. The registration of harmonics $(3/2)\omega_0$ and $(5/2)\omega_0$ indicates that such modulation is deep enough.

Another reason for nonlinear transparency of the aerogel target may be connected with anomalous burning considered in [12].

It should be noted that the real picture of nonlinear transparency of the arising plasma (compare Fig. 6a and 6b) is more complicated and is defined by the conditions of energy absorption and transfer, plasma formation and plasma dynamics. This means that the temporal behavior of the pulse transmitted through the aerogel target may change from shot to shot.

It is suggested that the TAC target could be used for the laser radiation conversion to optimize the light absorption and to obtain a broad linewidth of the incident radiation. As a result, the efficiency of energy yield from the active elements may be higher, and the laser efficiency may increase.

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