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INVESTIGATION OF LASER-PLASMA INTERACTION WITH HIGH SPATIAL RESOLUTION IN A WIDE SPECTRAL RANGE

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INVESTIGATION OF LASER-PLASMA INTERACTION WITH HIGH SPATIAL RESOLUTION IN A WIDE SPECTRAL RANGE*

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Abstract

The recent experimental results of laser radiation interaction with different targets and their qualitative description are reported. The spectral distribution and the directional diagrams of backscattering radiation on the fundamental and second harmonic frequencies are investigated. The plasma images in visible and near infrared spectral range, in particular, on $2\omega_0$, $3/2\omega_0$, $5/2\omega_0$ and ω_0 harmonic frequencies, are registered by means four-frequency polarized microscope. Also the plasma images in the intrinsic X–ray radiation are obtained.

These investigations were carried out with powerful laser installation "Kanal-2", which consists of a neodymium glass laser with controllable function of mutual coherence and an interaction chamber with a complex of diagnostic devices, and allowed to register the parameters of laser radiation and plasma with temporal, spectral and spatial resolution.

An analysis of the experimental data shown, that the reflected energy makes ≤ 1% from the incident radiation energy for all types of the used targets; the plasma electron temperature is ~ 0.5-1.2 keV. Under graphed spatial diagrams of scattered radiation on the frequencies ω_o and $2\omega_o$ it was concluded, that the scattering radiation on the frequency ω_o concentrates practically in the heating radiation aperture of the laser beam, the scattering radiation on frequency $2\omega_o$ spreads more diffusely in space. Intricate structure of plasma radiation spectra on the fundamental frequency and the harmonic frequencies indicate the plasma oscillation excitation in the area of electron density $n_e<n_c$, that points out the existence of different types of nonlinear processes under laser-matter interaction.

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The efficiency of laser radiation energy transmission to plasma remains a particular problem in the experiments on high power laser interaction with matter. In order to determine the absorption efficiency, the nonlinear interaction of powerful radiation with plasma, and the occurrence and behavior mechanisms of these processes one needs detailed information about the laser plasma parameters.

The investigation was carried out on a powerful laser installation "Kanal-2", consisting of a neodymium glass laser with controllable function of mutual coherence [1] (pulse duration, 2.5 ns; 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) and the interaction chamber. In order to study spectral, temporal, spatial, and energy parameters of plasma we used a diagnostic complex consisting of several channels:

- a channel intended for investigation of the plasma radiation spectral characteristics within the range of 0.4 – 1.1 μm;

- a four-frequency polarized microscope, to register the laser plasma image in the optical wavelength region of 0.4 – 1.1 μm at spatial resolution 12 μm;

- an optical system to record the direction of plasma expansion and laser radiation scattering in the given section with in a wide registration angle region ($\Delta\alpha \sim 90^0$) and a wide spectral range (0.4 – 1.1 μm);

- a calorimetric system for plasma and laser energy characteristics measurement;

- a system for studying the temporal behavior of the heating radiation pulse, the backscattering radiation pulse, and the radiation transmitted through the target.

Metal foils and polymer aerogels produced of triacetate cellulose (TAC) have been used as the targets. The density of TAC targets varied within the range of 2 to 10 mg/cm^3, at thickness from 100 to 500 μm.

The diagrams of backscattering on the fundamental frequency for the TAC targets 10/200 and for solid state Fe, Be targets are similar (Fig. 1). The diagrams of backscattering radiation demonstrate that the scattering on fundamental frequency takes place in spatial angle close to spatial angle of laser beam, while the scattering on second harmonic radiation is distributed more diffusely in space [2].

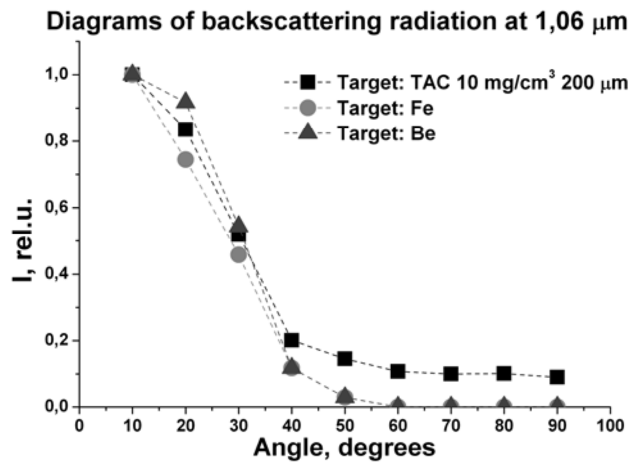
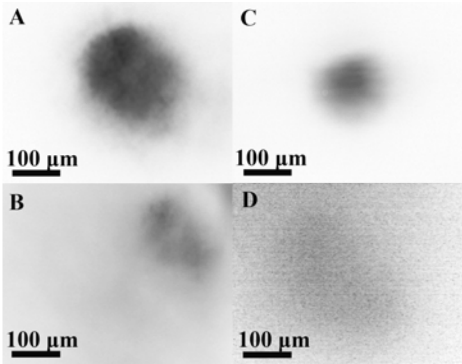
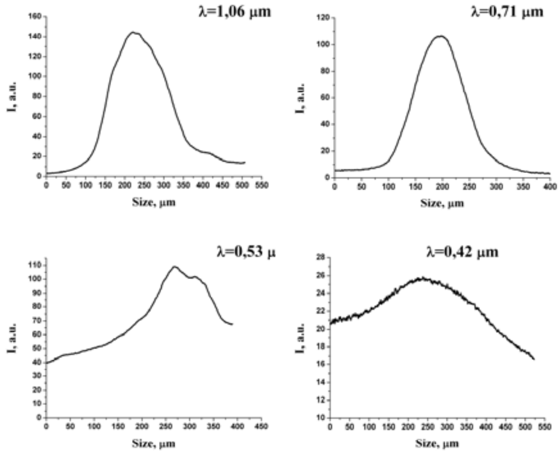


Fig. 1. Directional diagrams of backscattering radiation on fundamental frequency for the TAC and Fe, Be targets.

The plasma radiation registration with high spatial resolution in visible spectral range enables one to obtain information about the plasma luminescence area size, and the radiation intensity distribution in this area. The plasma images on harmonic frequencies $2\omega_0$, $3/2\omega_0$, $5/2\omega_0$ and ω_0 were obtained with a four-frequency polarized microscope (Fig. 2). Harmonic generation at $2\omega_0$, $3/2\omega_0$, $5/2\omega_0$ and ω_0 demonstrates strong nonlinear interaction of heating laser radiation with plasmas, which takes place near the critical and quarter critical density. Scattering of radiation on frequencies $2\omega_0$, $3/2\omega_0$, $5/2\omega_0$ and ω_0 occurs in a spatial region corresponding to the size of focal spot for all types of the targets used.

Solid state target Cu

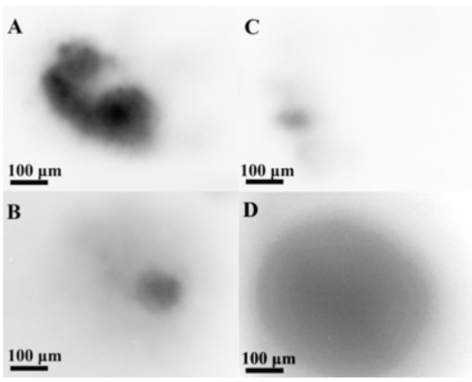




A – 1.06 μm (w_0)
B – 0.53 μm ($2w_0$)
C – 0.71 μm ($3/2w_0$)
D – 0.42 μm ($5/2w_0$)

Spatial distribution of plasma radiation intensity on frequencies $2\omega_0$, $3/2\omega_0$, $5/2\omega_0$ and on ω_0

TAC target



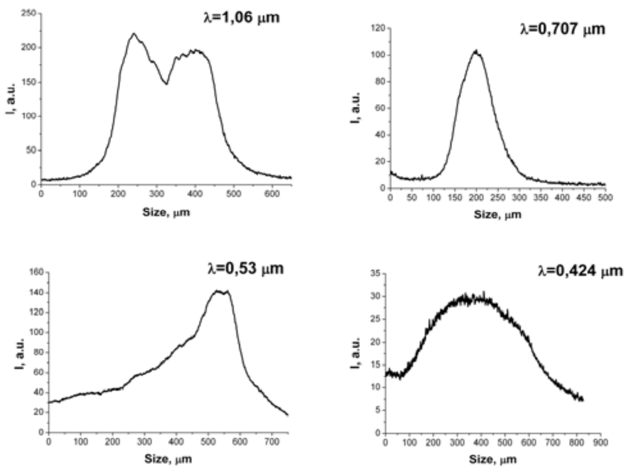


Fig. 2. Photographies of plasma obtained with four-frequency polarized microscope in visible and near infrared spectral range.

The energy emitted in spatial angle of registration channel at the investigated frequency was estimated using the photo of plasma image: i.e. the plasma luminescence area size, absolute spectral sensitivity, and signal value. Thus transformation coefficient of heating radiation into the harmonics in plasma was calculated for a foam target with density 9 mg/cm^3 and thickness 400 μm, and for a copper target, the incident energy was 17.8 J and 71 J, respectively (see Table 1).

Table 1

	Copper target	**Foam target**
	Energy (J) scattered into the spatial angle of diagnostic channel	Energy (J) scattered into the spatial angle of diagnostic channel
ω_o	$1.8 \cdot 10^{-5}$	$2.8 \cdot 10^{-6}$
$2\omega_o$	$1.8 \cdot 10^{-10}$	$3.1 \cdot 10^{-11}$
$3/2\omega_o$	$6.6 \cdot 10^{-9}$	$1.5 \cdot 10^{-9}$
$5/2\omega_o$	$2.6 \cdot 10^{-10}$	$2.6 \cdot 10^{-10}$
	Coefficient of transformation of heating radiation into the harmonics in spatial angle of diagnostic channel	Coefficient of transformation of heating radiation into the harmonics in spatial angle of diagnostic channel
ω_o	$2.5 \cdot 10^{-7}$	$1.6 \cdot 10^{-7}$
$2\omega_o$	$2.5 \cdot 10^{-12}$	$1.7 \cdot 10^{-12}$
$3/2\omega_o$	$9.3 \cdot 10^{-11}$	$8 \cdot 10^{-11}$
$5/2\omega_o$	$3.7 \cdot 10^{-12}$	$1.5 \cdot 10^{-11}$

Diagnostic channel with four-frequency polarized microscope is situated on-the-mitre to the axis of the heating radiation beam. If the data obtained with the microscope are compared to the data of radiative pattern for $2\omega_0$, it is possible to estimate the energy emitted by plasma in spatial angle 2π (in a hemisphere located on side of the plane of target where the heating radiation falls).

Because of the radiation scattering on the second harmonic frequency occurs diffusely in space [3], it is the energy scattered at frequency $2\omega_0$ in the spatial angle 2π ~ $1.1 \cdot 10^{-8}$ J for foam target and ~ $6.4 \cdot 10^{-8}$ J for copper target. The transformation coefficient of heating radiation into the second harmonic in plasma at spatial angle 2π is ~ $6 \cdot 10^{-10}$ for foam target and ~ $9 \cdot 10^{-10}$ for copper target. Thus the radiation energy scattered by plasma is greater for solid state target than for foam target.

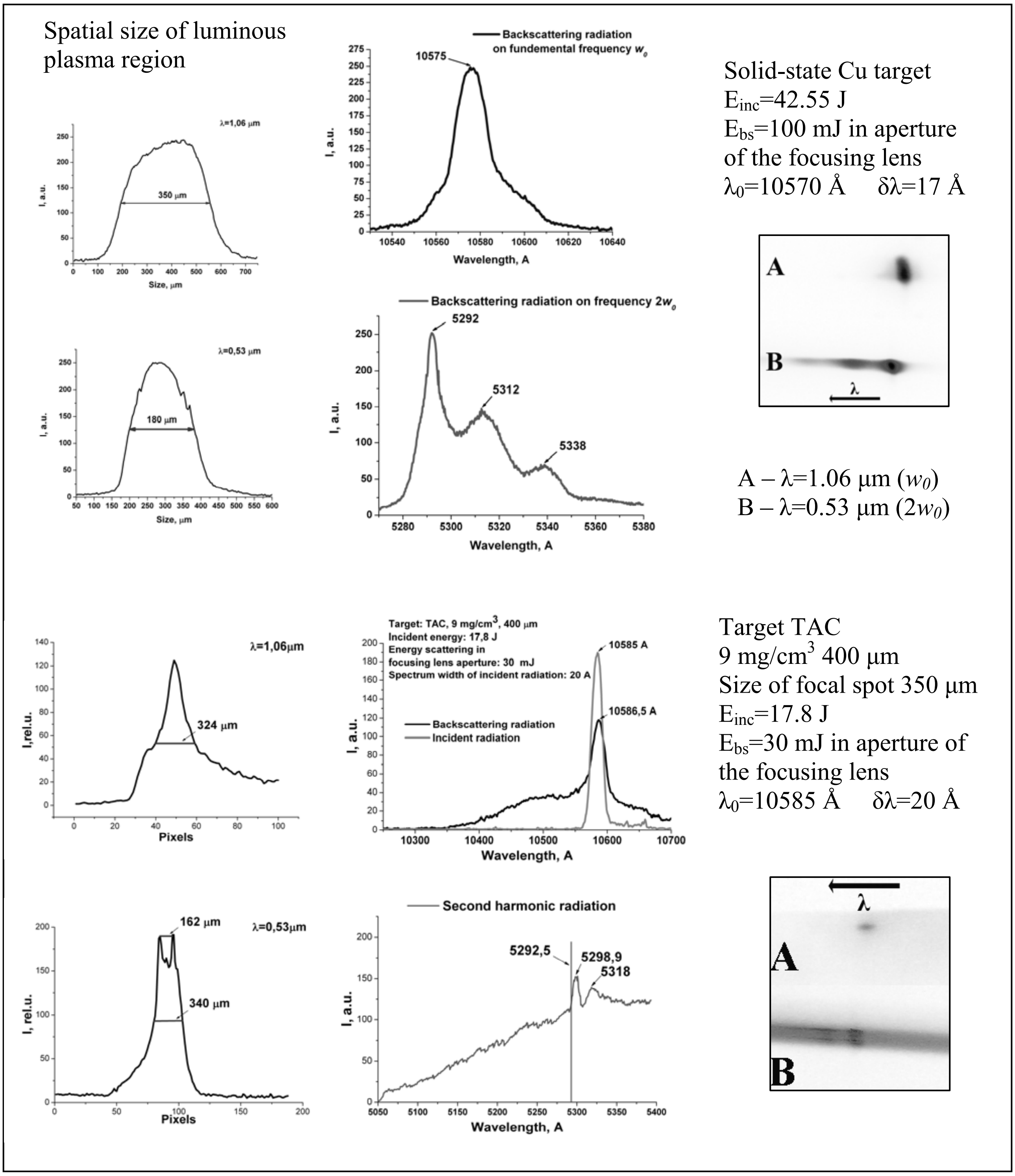
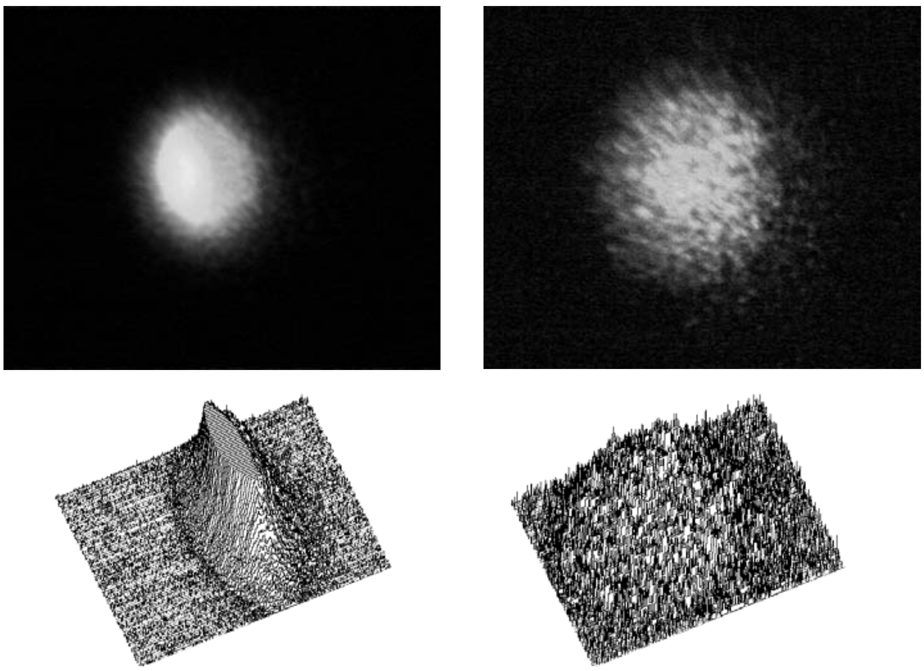


Fig. 3. Spectrum of backscattering radiation on fundamental and second harmonic frequencies.

Some features in spectral characteristics of scattering radiation at the fundamental and second harmonic frequencies were revealed for foam and solid state targets (Fig. 3). Near the fundamental frequency the asymmetric broadening of scattering radiation spectral lines occurs. It was found that there is broadening in blue spectral range for a foam target, and in red spectral range for copper target. Spatial distribution of radiation on fundamental frequency corresponds to focal spot size.

Near the second harmonic frequency there are several strongly pronounced spectral maximums against the background of continuum. Presence of such spectral structure indicates that two types of processes reduced to generation of second harmonic occur in plasma. There are linear transformation of laser radiation and parametric instability [4]. For the foam, a two-component spectral structure was found and for the copper target, a three-component spectral structure. In addition, a difference in spatial distributions of radiation on the second harmonic frequency was observed for foam and copper targets. Spatial distribution of intensity is smoothed for copper target, and inhomogeneity in spatial distribution of intensity was registered for foam target.



Incident energy 29.5 J
Solid-state target Cu
Size of focal spot 170 μm

Incident energy 94 J
TAC target 2.25 mg/cm^3 200 μm
Size of focal spot 170 μm

Fig. 4. Images of plasma obtained with pinhole camera in X-ray spectral range.

The plasma images in the intrinsic X-ray radiation were obtained by means X-ray pinhole camera. The radiation with wavelength ≤9Å (with quantum energy ≥1500 eV) was registered. From Fig. 4 one can see that for the copper target the X-ray radiation is emitted from more narrow area ~ 180 μm, while for the foam target the size of such area is bigger ~ 450 μm.

Analysis of the experimental data, in particular the energy data, have shown that the part of reflected energy makes ≤1% of the incident radiation energy in the focusing lens aperture for all types of the targets used. In particular, it is 0.4% for Cu target and 0.2% for TAC target with the density of 9 mg/cm^3 and thickness 400 μm.

Intricate structure of plasma radiation spectra at the fundamental frequency and the harmonic frequencies indicates the plasma oscillation excitation in the area of electron density $n_e < n_c$, which points out the existence of different types of nonlinear processes under laser-matter interaction.

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