

Laser plasma influence on the space-time structure of powerful laser radiation

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Abstract. This paper deals with the influence of laser plasma on the structure of the radiation field of a powerful Nd-glass laser with pulse energy up to 30 J and with the diameter of the output beam 45 mm. Laser plasma is generated by focusing the laser radiation on a low-density target such as nylon mesh and teflon or mylar films. Temporal profile of the laser pulse with a total duration of 25 ns consists of a several short pulse train. Duration of each pulse is about 2 ns. Notable smoothing of spatially non-uniform radiation structure was observed in the middle of the laser pulse.

1. Introduction

Laser fusion studies face a number of problems. One of them is elimination of instabilities, which are formed during the compression of a thermonuclear target for its non-uniform irradiation with laser light. This heterogeneity is typically caused by the laser pulse generation process and remains in its further amplification and transmission through the channels of a powerful laser system. Currently, to smooth the profile of the laser beam intensity the passage of a laser beam through a phase plate is widely used. These plates are an optically inhomogeneous medium with a refractive index that varies quite rapidly in space and time. A desired structure of the medium in the form of dynamic plasma phase plate (DPPP) can be obtained based on a laser plasma, which is formed on a low-density target in the area of focus of the laser beam [1].

During the experiments on a powerful laser facility [2] the DPPP in a form of laser plasma was created with using a preliminary pulse (~ 50 J, ~ 1 ns). Diagnostic laser pulse (~ 15 J, ~ 1 ns), for which the smoothing was conducted, passed through the plasma with a delay Δt . The maximum smoothing effect was observed at a delay of $\Delta t \sim 150$ ps. Furthermore, the smoothing efficiency has been changing significantly during the laser pulse. The modulation of the laser radiation intensity was significantly smoothed only in the time interval corresponding to the central area of the laser pulse. In this paper, we consider the smoothing feature of the spatial structure of powerful laser radiation, when it consists of several short (~ 2 ns) pulses.

2. Experimental installation

The studies were conducted on an experimental installation "MISHEN" ("Target"), the scheme for which is shown in figure 1. During the experiments the initial laser radiation characteristics were

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recorded, as well as the radiation transmitted through the DPPP target: energy, duration and the shape of the laser pulse, the spatial structure of a cross-section of the beam.

Laser system consists of the Q-switched pulse generator (1) on the active element of Nd: phosphate glass (GLS-22) and two amplifier modules (3 and 4) based on the solid-state laser GUK-4507 (GLS-21). Module (3) is made under the scheme of seven-pass telescopic amplifier with phototropic shutter LiF. Module (4) is single-pass. The output of the laser beam (~ 45 mm) had a pulse energy up to 30 J for the wavelength $\lambda = 1.055$ nm and total duration of the laser train ~ 25 ns, the power density on the DPPP target was $I \sim 10^{16}$ W/m². For visualization of the spatial structure of a cross-section of the laser beam we used a partial conversion (about 1%) of infrared radiation into the second harmonic using the DKDP crystal (5).

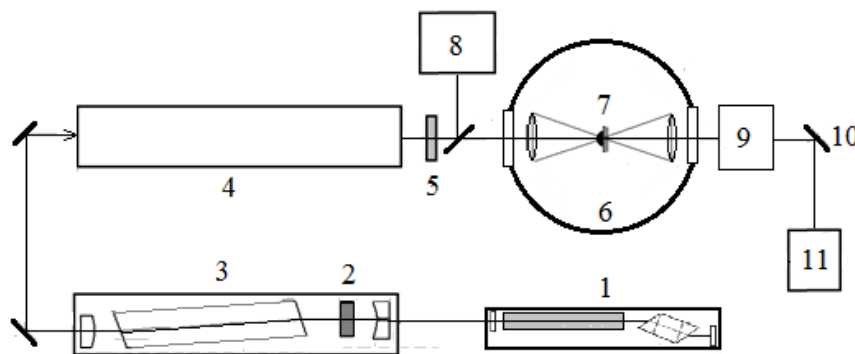


Figure 1. Experimental laser installation “MISHEN” (“Target”).

Laser plasma was produced in the vacuum chamber (6) at a pressure of 10^{-3} Pa, and a laser beam was focused onto the DPPP target (7). The focal lengths of the input and output lenses were equal to 120 mm. To control the energy and temporal characteristics of the laser pulse we used standard measuring tools, combined into a diagnostic module (8). The laser radiation that has passed through the laser target, is gathered back into a parallel beam (~ 40 mm) and attenuated into the optic module (9). Next, after a strong attenuation ($I_{in}/I_{out} = 1.5 \cdot 10^4$) the beam is further compressed by 3 times to match the height of the entrance slit of a digital camera «BIFO» K-008 (11). To suppress the infrared radiation the interference mirror (10) was used with a maximum reflection coefficient at the wavelength $\lambda \sim 530$ nm. The second harmonic radiation was recorded with using the K-008 camera, operating in the linear sweep mode with a coefficient of 30 ns/cm («streak» mode) and the height of the slit is 20 mm.

3. Experiment and results

Figure 2 shows the temporal profiles of the initial radiation recorded by a variety of diagnostic tools: 1 – laser pulse (digital streak frame camera K-008, BIFO); 2 – laser pulse (*pin*-photodiode FDUK); 3 – X-ray pulse (*pin*-photodiode, 9 micron Al foil). Comparison of the *pin*-diode signals has shown that the laser plasma emits the X-rays during the entire duration of the laser pulse, about $20 \div 25$ ns. A more detailed study of the laser pulse was conducted using the high-speed digital camera K-008 having a high time resolution (≤ 1 ns). In this experiment, it was found that the laser pulse is a train of individual short (~ 2 ns) pulses with intervals between the individual pulses of ~ 4 ns (figure 3).

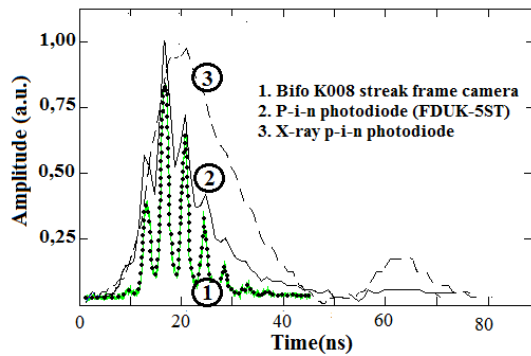


Figure 2. Laser and X-ray pulses.

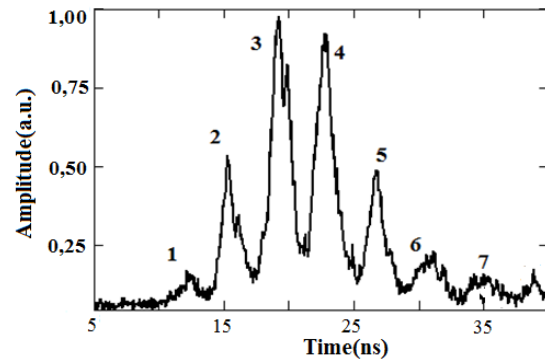


Figure 3. Typical view of laser pulse train.

In a series of comparative experiments using the K-008 camera, an initial space-time structure of the laser radiation was studied along with its variation as a result of passing through the laser plasma. To produce a plasma we used the DPPP targets of different types: 30 micron nylon mesh ($\rho \sim 0.65 \text{ g/cm}^3$), 15 micron films of teflon ($\rho \sim 2.2 \text{ g/cm}^3$), and 3 micron film of mylar ($\rho \sim 1.4 \text{ g/cm}^3$). Intensity profiles for different time moments within the laser pulse train were restored using the initial data.

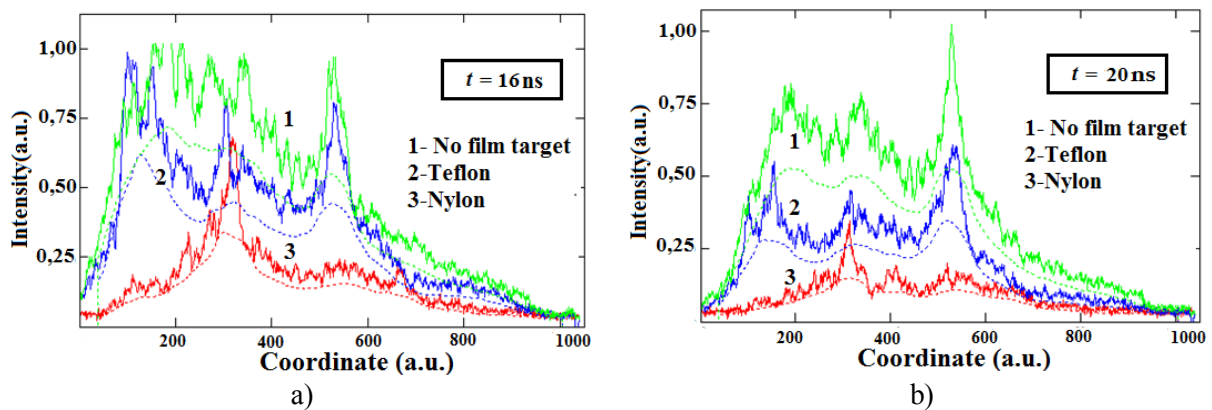


Figure 4. Intensity profiles for the teflon film and nylon mesh targets: a) $t = 16 \text{ ns}$; b) $t = 20 \text{ ns}$ (solid line – experiment; dashed line – estimated smoothing).

As an illustration, figure 4 shows the laser radiation intensity profiles for the three experimental cases (without plasma, plasma on a teflon film, and plasma on a nylon mesh) for instants $t = 16 \text{ ns}$ and $t = 20 \text{ ns}$, which correspond to the second and third pulses in figure 3. The spatial coordinate in the beam cross-section is presented in the relative units (1000 relative units correspond to the diameter of the laser beam, which is 40 mm). Attenuation of radiation intensity of the laser beam passing through the plasma is clearly seen. The experimental data (solid lines) is smoothed by mathematical methods (dashed lines).

To analyze the effect of laser plasma on the space-time structure of the radiation the following processing algorithm was used. The area under the curve corresponding to experimental profile of intensity was calculated along with the area under the curve corresponding to mathematical procedure of smoothing (figure 4). Their difference allows to assess the level of speckle modulation of the laser beam, which determines the noise component in the intensity profiles. Applying the same procedure throughout the duration of the laser train provides an integral noise characteristic.

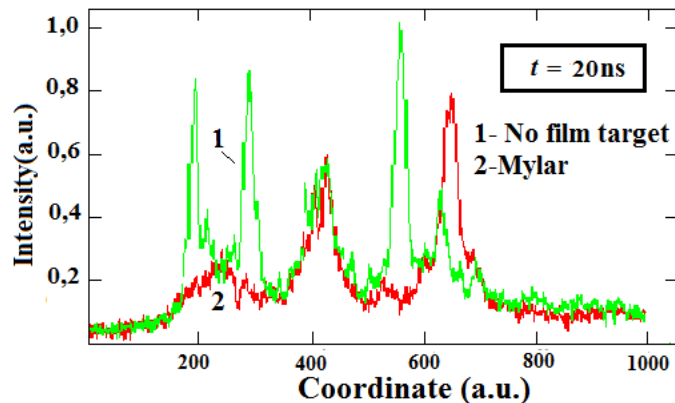


Figure 5. Intensity profiles of the initial radiation (without plasma) and radiation passing the laser plasma obtained with mylar film.

Comparison of the results obtained by this method shows that the integral noise characteristics for the selected laser targets are not very different from similar characteristics of the initial radiation. This indicates the absence or bad quality of smoothing across the entire train of laser pulses. However, in the case of a thin film of mylar (3 microns) for some time moments and some areas of space profile we can see quite good suppression of the speckle modulation (figure 5). Moreover, the smoothing effect is getting stronger in the middle of the laser train.

4. Conclusion

The technique was developed and the preliminary results were obtained for the effect of laser plasma on the spatial and temporal characteristics of high-power laser radiation. Thus for the moment it is not clear how the material, thickness and density of the irradiated sample affect the ability of plasma to locally weaken the separate elements of the speckle pattern. The mechanism of attenuation of the individual speckle is obviously connected with the local plasma parameters. It would be helpful to combine the use of the streak camera with the use of the X-ray diagnostic and laser interferometry.

References

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