Focusing of a laser beam on a target using the effect of wave-front inversion (WFI) produced as a result of stimulated Mandel'shtam-Brillouin scattering (SMBS)

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The effect of WFI produced as a result of SMBS is used for sharp focusing on a target of a 5- and 10-nsec pulse with energy of up to 20 J from a neodymium laser. The distribution of the intensity in the focal spot is estimated; 50% of the energy is contained in a circle with an area of $\sim 2\times 10^{-5}$ cm^2. The x-ray spectra of multiply charged Mg and Fe ions were recorded as a result of irradiation of flat targets in a vacuum.

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Lately, the prospect of using the effect of wave-front inversion (WFI) (Ref. 1) to compensate for the phase distortions of the light signal in the active medium and for aberration of the elements of high-power laser systems has been discussed.[2-4] In this paper, we use the WFI effect produced as a result of stimulated Mandel'shtam-Brillouin scattering (SMBS) to sharply focus on a target a 5- and 10-nsec radiation pulse from a 20-J neodymium laser; the focusing lens is included in the elements whose aberrations are compensated.

The experimental setup is shown in Fig. 1. The radiation pulse from a single-mode master oscillator 1 was directed to the electro-optical valve 2, which yielded the 5- or 10-nsec beam. The beam was then expanded by a negative lens 3 and transmitted to the diaphragm 4, which separated the central part of the beam. A diffraction pattern from the diaphragm 4 with a 30-μm diameter of the first dark ring was formed in

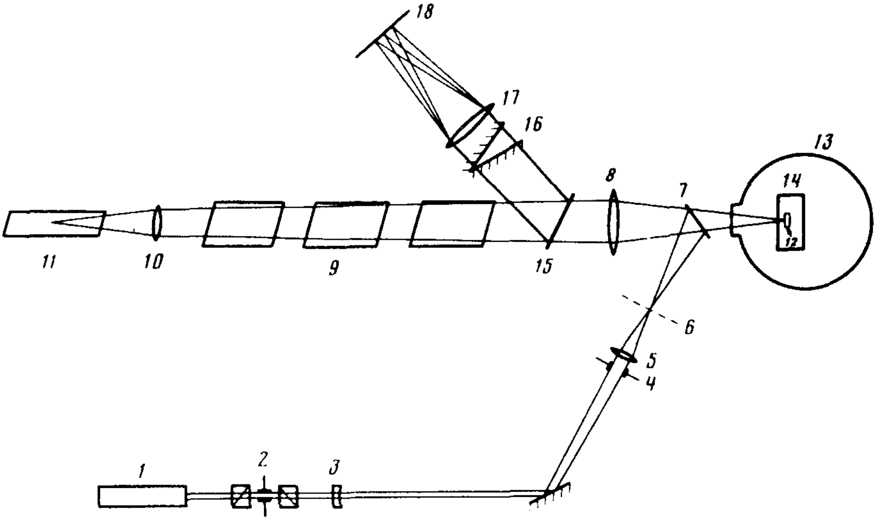

FIG. 1. Experimental setup: 1, Master oscillator; 2, electro-optical valve; 3, negative lens; 4, diaphragm; 5, injector lens; 6, focal plane of the lens 5 coupled to the surface of the target 12; 7 and 15, beam dividers; 8 and 17, identical lenses; 9, three ϕ 45-mm amplification stages; 10, lens; 11, container with CCl_4; 13, vacuum chamber; 14, x-ray spectrograph, 16, mirror wedge; 18 focal plane of the lens 17.

the focal plane 6 of the injection lens 5. The spherical aberration of the lens 5 was 20 μm. The diverging beam was then focused on the working lens 8 with the help of a divider 7. The energy of the beam injected into the amplification channel was $\leqslant 1$ mJ. After transmission through the lens 8, the weakly converging beam passed through three amplification stages 9 with $\phi\, 45 \times 680$-mm active elements made of GLS-1 glass with a total amplification factor of the weak signal of $\sim 10^3$, after which it was focused by lens 10 into a container 11 filled with carbon tetrachloride. The radiation reflected from the container as a result of SMBS was again amplified in the chain of the active elements and focused by the working lens of the target 12 in the vacuum chamber 13, which contained an x-ray spectrograph 14. A fraction of the beam was returned through divider 7 to the injection channel; an air breakdown occurring at the focal point 6 suppressed more than 90% of the radiation and protected the optical elements in the injection channel. The plane of the target 12 and plane 6 were coupled with an accuracy of 50 μm in depth using an auxiliary light emitting optical system, which enabled us to simultaneously observe the target and the injected image of the continuous He-Ne laser.

An auto-calibration method described in Ref. 5 was used to record the distortion of the intensity in the focal spot of the working lens. This was accomplished by diverting a fraction of the beam (4%) through the divider 15 to the mirror wedge 16 behind which a lens 17 identical to the working lens 8 was situated. The sequence of burnt images of the focal spot, each of which differ in exposure from the preceding image by a factor of 2, was recorded on the photographic plate 18.

Moreover, the energy of the beam injected into the amplifiers was recorded at the

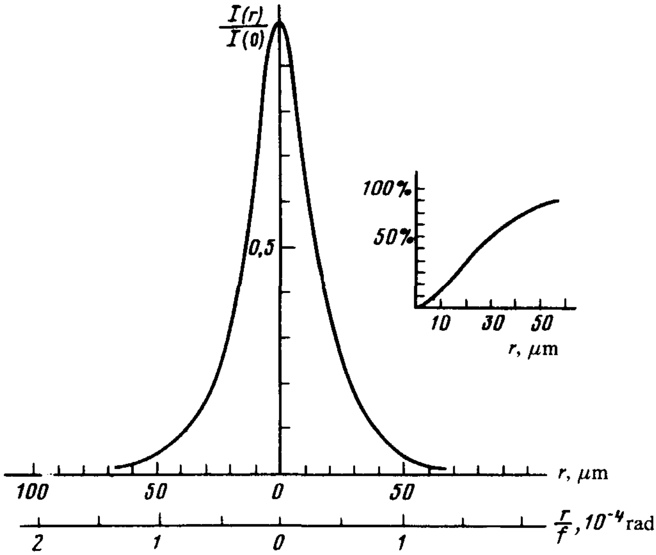

FIG. 2. Distribution of the intensity in the focal spot of the recording lens. The plot in the upper right-hand side gives the fraction of energy contained in the circle of a given radius.

inlet and the outlet of the container with CCl_4 and at the outlet of the beam of amplifiers; the shape and duration of the pulse were also recorded.

Figure 2 shows the distribution of the intensity in the focal spot of the lens 17. The distribution of the intensity, which was the same for $\tau_L = 5$ nsec and for $\tau_L = 10$ nsec, was characterized by a factor-of-two decrease of the intensity as a result of increasing by 10 μm the distance (r) from the center of the focal spot $[I(r) = I_0 2^{-r/10\ \mu m}]$. The distribution is almost independent of the energy of the beam up to 20 J the working energy level of the laser.

The dependence of the fraction of the total energy of the beam within the circle of radius r is plotted on the upper right-hand side of Fig. 2. The circle of 25 μm radius contained 50% of the energy of the beam.

We note that, in addition to other functions, the SMBS effect in this apparatus produces a nonlinear optical decoupling, which effectively suppresses the enhanced luminescence of the active medium and the initial pulse of the master oscillator. Because of this, the system was not self excited without additional optical insulators (brightening filters, etc.) and the signal power was amplified significantly (10^4–10^5).

In this experimental setup we obtained x-ray spectra of multiply charged magnesium and iron ions with a spatial resolution normal to the target. The crystal spectrograph was used to record the spectra according the Johan's scheme described in Ref. 6. Figure 3 shows part of the spectrogram for magnesium in which the spectral lines are indicated. The characteristic feature of the spectra is the ratio of the intensities of the fine-structure of the components of the resonance line of the hydrogenlike ion.

The observed ratio indicates that the optical thickness of the plasma in the given spectral lines is smaller than that usually observed by focusing the lens (this problem is examined, for example, in Ref. 7). This fact indicates indirectly that the transverse dimension of the laser jet is small.

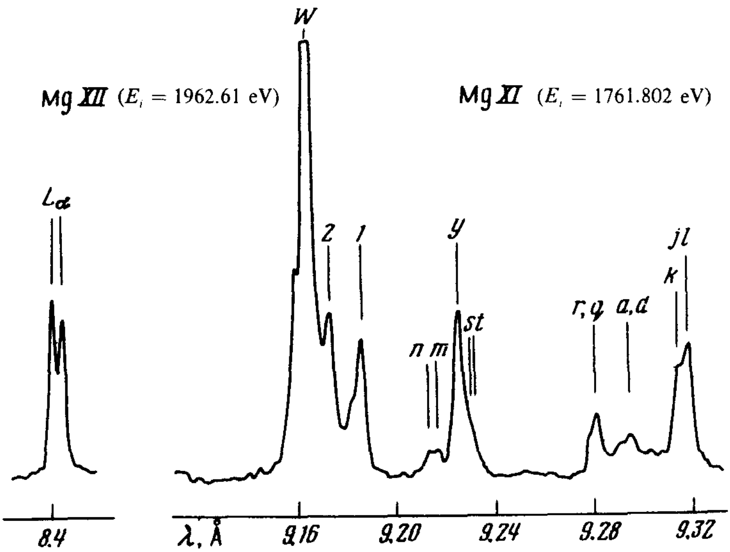

FIG. 3. The part of the magnesium spectrogram in the second-order reflection of the crystal. *W* is the resonance line and *y* is the intercombination line of the MgXI ion; *m*, *n*, *s*, *t*, *r*, *q*, *a*, *d*, *k*, *j*, *l*, 1 and 2 are the satellites of the resonance line, which begin at the autoionization levels of the MgX ion; L_α is the resonance doublet of the MgXII ion.

A high-power laser, which uses the WFI effect produced by SMBS, is a useful tool for different areas of physical research.

The special feature of this method is that it can produce the specified illumination profile at the target when it is irradiated by a pulse from a high-power laser. Such a problem occurs, for example, in experiments on amplification of generation of light in a laser plasma when there is a need for a nearly aberration-free focusing of radaition into a narrow band with a large ratio of the longitudinal dimension to the transverse dimension.[8]

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