Ultrashort pulses from a neodymium-glass laser with a rapidly switched plasma mirror

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Laser pulses with a length of about 20 ps have been observed in a neodymium-glass laser with a plasma mirror. The pulses were photographed in the near and far radiation zones. Streak photographs have been taken of the plasma motion. The position of the plasma mirror at the resonator axis has been determined.

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The single-channel laser of these experiments consists of four GOS-1000B illuminators, the first of which is inside the telescopic resonator. The plasma mirror is formed at the surface of a flat graphite target in air at the focus of a lens ($F = 50$ cm) positioned beyond the forth illuminator.[1] The rapid production of the reflecting plasma at the target leads to Q-switched operation and to the emission of a Q-switching pulse with a mode-locking structure.[1,2] In the present case, this pulse consists[2] of two or three trains of short pulses (Fig. 1 shows an oscilloscope trace of one of these trains). The length found for the short pulses in Ref. 2, $t_0 \approx 2$ ns, was determined by the time resolution of the detector system.1) In the present experiments, in contrast, the short output pulses from the neodymium-glass laser were studied at a time resolution in the picosecond range, with the help of an Agat-SF image-converter camera.

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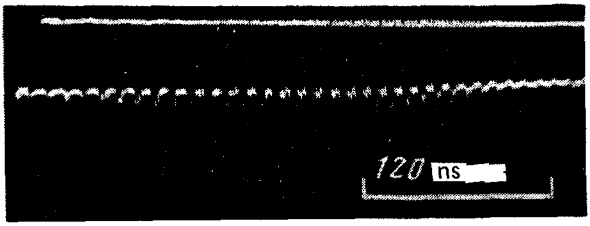

FIG. 1. Temporal structure of the Q-switching pulse (the first emission train; time runs from left to right).

To determine the lengths of the short pulses, we used an optical wedge to take the direct and reflected beams from the resonator, and we used a lens ($F = 1$ m) to focus them onto the slit of the image-converter camera. One beam was displaced along the slit from the other beam. The camera objective formed an image of the slit on the photocathode for subsequent enlargement and photography. The optical path lengths of the direct and reflected beams were equalized with the help of an LTI-PCh-8 garnet laser, whose output was directed along the axis of the neodymium-glass laser. The picosecond modulation of the Q-switching pulse from the garnet laser for the direct beam was brought into coincidence with that for the reflected beam, within ~2 mm, on the converter screen. The converter camera was triggered with an FK-20 coaxial photocell, which detected the output pulse. The sweep was begun 60–80 ns after the beginning of the train of short pulses (Fig. 1). Since the converter sweep time was 1.5 ns, much shorter than the 12-ns interval between successive emission pulses (Fig. 1), a pulse "multiplication" was performed with the help of a Fabry–Perot etalon (with mirror reflectances of 0.95 and 0.997) to eliminate the fluctuations in the time at which the converter sweep was triggered. The base length of the etalon (31 mm) was also used to calibrate the duration of the sweep.

Figure 2a shows a typical time sweep. The pulse incident on the target lags behind the reflected pulse by a time equal to the time required for a back-and-forth transit of a cell holding an aqueous solution of copper sulfate (used to equalize the intensities of the direct and reflected beams at the entrance to the converter). The length of the ultrashort pulse in Fig. 2a at the half-intensity level is $t_0 \approx 20$ ps. The instrumental width of the slit, determined with a slow (5-ns) sweep, is 0.15 mm on the converter screen; at the 370-ps/cm sweep rate used here (Fig. 2a), this width corresponds to a time of 5 ps. Some of the measurements revealed pulses only twice as long as the instrumental time width. It also follows from Fig. 2a that the position of the plasma mirror at the axis of the focusing lens corresponds within 3 mm to the focal spot.

Figures 2b and 2c show the results of a study of the far and near zones of the output for picosecond pulses. The waists of the incident and reflected beams lie in the focal plane of the auxiliary lens with $F = 1$ mm. The reflection from the target occurs at the focus of the main lens ($F = 0.5$ m), near the 3-mm caustic of the incident beam. The spot corresponding to the reflected beam is noticeably smaller than that corresponding to the incident beam. The reflection direction could change with-

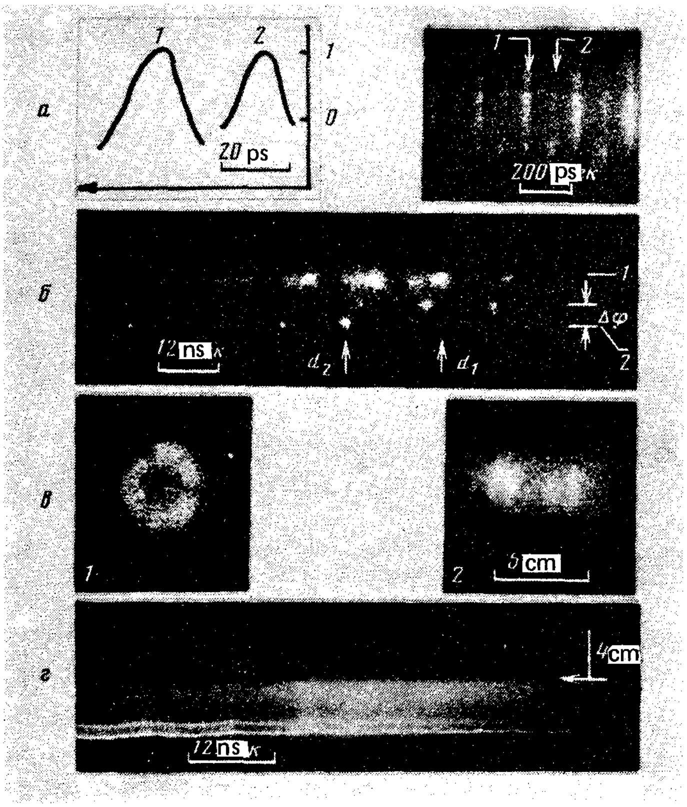

FIG. 2. Spatial and temporal characteristics of the output from the neodymium-glass laser with a rapidly switched plasma mirror. Subscripts 1 and 2 indicate the beam incident on the plasma mirror and the beam reflected from it, respectively. The time runs from right to left on all the time sweeps. a–Streak photograph of one ultrashort pulse (from the train in Fig. 1) after "multiplication" in the Fabry-Perot etalon and time evolution of the height of this pulse; b–framing photographs of the beam waist during focusing of a deflected train of picosecond pulses by an auxiliary lens with $F = 1$ m; c–shape of the beam incident on the focusing lens and shape of the beam reflected from the plasma mirror back into the aperture of the lens in a single ultrashort pulse; d–streak photograph ("photochronogram") of the plasma motion corresponding to the central part of the train in Fig. 1 (the arrow shows the position of the target; the laser beam is propagating from top to bottom; an area ~1 mm in size in front of the target is covered to reduce the brightness of the target on the photograph).

in $\Delta\phi \lesssim 0.4$ mrad from pulse to pulse (Fig. 2b). No reflection was observed in some of the short pulses. The near-zone pattern for the beam reflected from the plasma mirror (Fig. 2c) reproduces the annular shape of the incident beam (a consequence of the telescopic stage of the laser), with significant distortion. The cross-sectional shape of the reflected beam and the position of the cross section on the converter screen can vary from experiment to experiment. A photometric study of the focal spots in Fig. 2b yields $d_1 \approx 0.2$ to 0.4 mm and $d_2 \approx 0.1$ mm (at the half-intensity level). The corresponding angular divergences of the beam incident on the plasma mirror and of the reflected beam are $\phi_1 \approx 0.2$-0.4 mrad and $\phi_2 \approx 0.1$ mrad. Integration of the measured light distribution in the spots in Fig. 2b yields $r(d_2/d_1)^2 \approx (3\text{-}5) \times 10^{-3}$ for the reflection of the beam from the plasma mirror back into the laser aperture for a single picosecond pulse; this result agrees with the results of Ref. 2. Since $(d_2/d_1)^2 \sim 0.1$, the reflectance of the plasma mirror itself is $r \approx 0.03\text{-}0.05$. Actually, r may be even higher, since the plasma mirror of aperture d_2 may be at the edge of a spot with $d_1 > d_2$, where the intensity is much lower than at the center of the spot.

A streak photograph was taken of the plasma motion away from the target (Fig. 2d) at the time corresponding to the central part of the train in Fig. 1. The plasma expansion seems to be in a steady state. An ionization front can be seen ~1.5 cm from the target, and ~5 cm from the target there is an emitting zone, moving at $v \lesssim 10^6$ cm/s. The intense emission by the plasma at the target surface indicates that most of the absorption of the laser energy by the plasma occurs near the target.

Using these results, and estimating the average energy of one picosecond pulse to be 0.1-1 J from the results of Ref. 2, we can calculate the typical power levels and intensities of the electromagnetic radiation at the plasma mirror in the individual ultrashort pulses ($t_0 \approx 20$ ps): $10^{10}\text{-}10^{11}$ W and $10^{14}\text{-}10^{15}$ W/cm^2, respectively.

[1)] Mode locking and trains of short pulses ($t_0 \approx 1\text{-}2$ ns) have been observed previously in CO_2 lasers with plasma mirrors.[3,4]

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