Absorption in neodymium glasses during the passage of an intense laser pulse

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A jump in the absorption at the wavelength 0.66 μm and 1.053 μm has been observed during the self-focusing of a subnanosecond laser pulse in neodymium glasses. The jump stems from the filling of the $^4I_{11/2}$ lower level of the working transition of the Nd^{3+} ion. The absorption relaxation has a time constant $\tau_r \gtrsim 10^{-8}$ s.

1. We have observed a selective absorption in neodymium glasses during the passage of an intense light pulse at the wavelength $\lambda_0 = 1.064$ μm with a length of 0.5–0.7 ns and an energy density of 2–5 J/cm^2. A single intense pulse is taken from the packet of pulses from an Nd:YAG laser oscillator with periodic Q switching. This pulse is amplified by three amplifier stages using Nd:YAG and GLS-9P glass. The beam at the exit from the final amplifier, 7 mm in diameter, is collimated by a filter-retranslator (2) with threefold reduction and coupled into the test sample (sample 1 in Fig. 1). The experimental geometry eliminates a possible effect of breakdown at the ends of the sample on the weak probing pulse (pp) (with an energy < 1 mJ), which is synchronized with the intense pulse (ip). The probing pulse illuminates the channel through which the intense pulse passes in the glass, ~ 2 mm in diameter, at an angle of 3–5°. The absorption in the sample is determined from the change over two transits in the intensity and profile of the probing pulse at one of the wavelengths $\lambda_1 = 0.66$ μm (with a length $t_{pp} \approx 70$ ns), $\lambda_2 = 1.053$ μm ($t_{pp} \approx 130$ ns), $\lambda_3 = 0.56$ μm ($t_{pp} \approx$ ns). These wavelengths fall in the transparency "window" of the neodymium glasses. The probing pulses are generated by auxiliary laser oscillators using Nd:YAG and KNFS glass, by means of a nonlinear conversion of the light. The probing pulses of the signal channel, S (transmitted through the sample), and the control channel, C, of the same intensity and at the same time delay, are focused by cylindrical lenses in the direction perpendicular to the slit of an Agat-SF-3 streak camera (6). The temporal coincidence of the intense pulse and the probing pulse is also monitored on an I2-7 oscilloscope with the help of an FK-20 coaxial photocell (5). The energies of the intense pulse at the entrance to the sample and at the exit from it are measured with calorimeters 4 (the exit energy is measured through a diaphragm 3, which is 2 mm in diameter; this diameter corresponds to a divergence angle $\sim 10^{-2}$ rad).

2. In the phosphate and silicate glasses we observe a jump in the absorption at $\lambda_1 = 0.66$ μm (Fig. 2) as a result of the intense pulse. Specifically, these are the glasses KNFS (neodymium ion concentration of 8×10^{20} cm^{-3}; the length of the sample is $l = 7$ cm), LGS-55 (5×10^{20} cm^{-3}; $l = 13$ cm), GLS-1 (2×10^{20} cm^{-3}; $l = 26$ cm), LGS-60 (5×10^{20} cm^{-3}; $l = 13$ cm), and GLS-4 (2×10^{20} cm^{-3}; $l = 16$ cm). An

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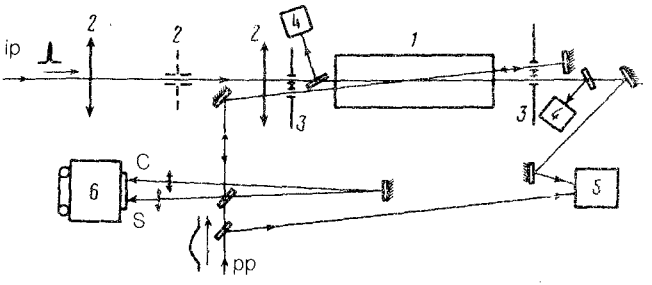

FIG. 1. Experimental layout.

induced absorption arises at power densities $\gtrsim 3.6$ GW/cm^2 in the phosphate glasses and at $\gtrsim 5.2$ GW/cm^2 in the silicate glasses upon the intense formation of filaments of a fine-scale self-focusing. The scattering loss of the intense pulse due to the self-focusing amounts to 20–40%. We studied the correlation between the induced absorption and the fine-scale self-focusing filaments in the following way. In a single shot, at a low energy, filaments appear near the entrance end of the sample. As the energy is raised, they stretch out toward the entrance end, filling the channel of the intense pulse. When they intersect the track of the probing pulse, we observe an induced absorption (we used four transits of the probing pulse across the sample to increase the sensitivity of the apparatus in these experiments). The scattering of the probing pulse directly by the fine-scale, self-focusing filaments is negligible, so that the relationship between the

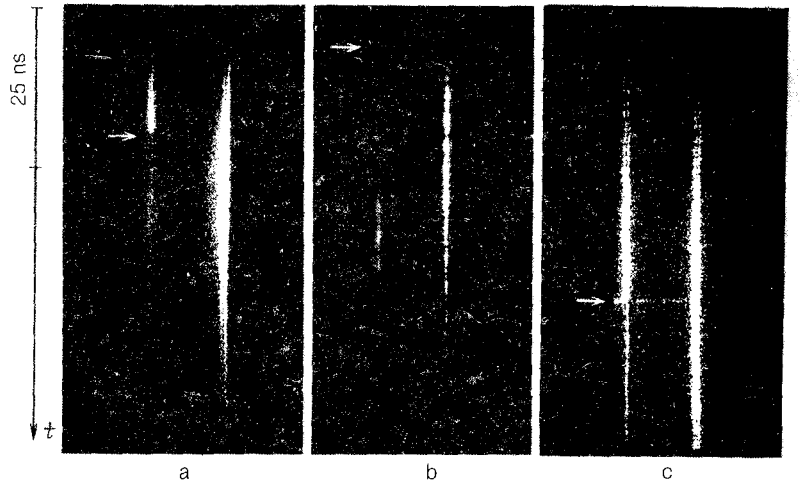

FIG. 2. The probing pulse ($\lambda_1 = 0.66\,\mu$m) of the signal channel (at the left) and that of the control channel (at the right) at the exit from the streak camera. a—KNFS glass; b—LGS-55 glass; c—GLS-4 glass (in a illuminator with the pump; the gain at $\lambda_0 = 1.064$ μm is $\alpha = 0.1$ cm^{-1}). The arrows show the temporal position of the intense pulse.

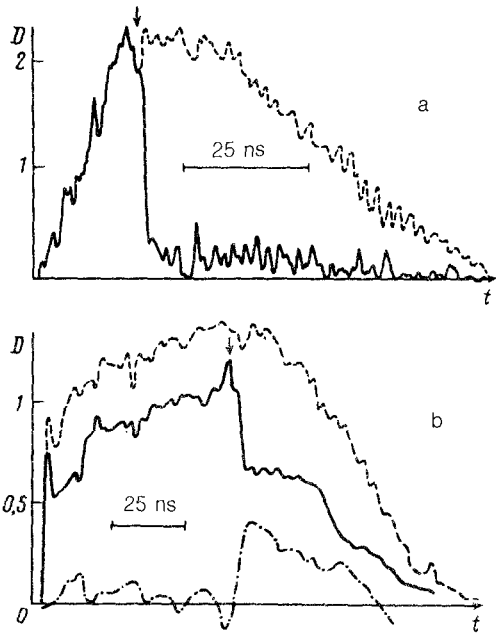

FIG. 3. Densitometer traces of probing pulses at $\lambda_1 = 0.66$ μm (part a; these results correspond to Fig. 2a) and $\lambda_2 = 1.053$ μm (b) in KNFS glass. Solid line—signal-channel pulse; dashed line—control-channel pulse; dot-dashed line—difference between the normalized densitometer traces of these pulses.

induced absorption and the filaments is a consequence of the existence around the filaments of a zone of larger diameter, in which an induced absorption arises. The absorption (κ), averaged over the length of the sample, is determined from densitometer traces of the probing pulse; for λ_1 it reaches $\kappa_1 = 0.1$–0.2 cm^{-1} in the phosphate glasses and $\kappa_1 = 0.01$–0.03 cm^{-1} in the silicate glasses. An induced absorption of the same order of magnitude is observed during the pumping of the test samples (Fig. 2c). A lower absorption, $\kappa_2 = 0.03$–0.1 cm^{-1}, is measured for probing pulses with $\lambda_2 = 1.053$ μm (Fig. 3b).

The temporal width of the induced-absorption front is 1–3 ns (Fig. 3), apparently determined by the time resolution of the experimental apparatus—by the length of the intense pulse and by the time required for a double transit of the sample by the probing pulse. The relaxation of the induced absorption (Figs. 2 and 3) occurs with a time constant $\tau_r = 15 \pm 8$ ns in the LGS-55 glass and 35 ± 15 ns in the KNFS glass; for the silicate glasses we find a lower limit $\tau_r > 5$ ns.

Under the same experimental conditions, we did not detect an induced absorption for probing pulses with $\lambda_3 = 0.56$ μm. Furthermore, we did not observe an induced absorption in the samples of K-8 glass ($l = 13$ cm), TF-3 glass ($l = 12$ cm), or GLS-1 and LGS-60 glasses (without neodymium; $l = 26$ cm and 12 cm). These results indicate that the induced absorption is associated with Nd^{3+} ions.

3. The selective absorption at the wavelength 0.66 μm and 1.053 μm can be linked with the transitions $^4I_{11/2} \rightarrow {}^2G_{7/2}$, $^4G_{5/2}$ and $^4I_{11/2} \rightarrow {}^4F_{3/2}$ of the neodymium ion during the filling, as a result of nonlinear processes in the glass, of the $^4I_{11/2}$ level, which is separated from the $^4I_{9/2}$ ground level by an energy ~ 1400 cm^{-1}. These transitions

were observed during a thermal filling of the $^4I_{11/2}$ level in ED-2 silicate glass by Fisher and James[1]; the cross section for the transition which they measured at 1.06 μm turned out to be half that at 0.66 μm. The ratio of the levels of the induced absorption at these wavelengths in our experiments and the absence of this absorption at $\lambda_3 = 0.56$ μm, which is not at resonance with the $^4I_{11/2}$ level, confirmed the suggestion regarding the nature of the induced absorption. The value found for the induced absorption corresponds to a value $\sim 2 \times 10^{18}$ cm^{-3} for the concentration of Nd^{3+} ions excited to the $^4I_{11/2}$ level, on the average over the volume. We estimate that up to 10% of the energy of the intense pulse must be expended on this excitation.

4. These experiments show that the induced absorption is related to the appearance of a fine-scale self-focusing. Various nonlinear processes can occur in the medium under these conditions, at a power density of tens of gigawatts per square centimeter. An identification of the particular mechanism for the excitation of the Nd^{3+} ions requires further research. At this point, we would simply like to point out that the induced absorption may, along with the fine-scale self-focusing,[2] limit the energy and distort the shape of the pulses in high-power neodymium-glass lasers. Furthermore, the relaxation time of the induced absorption, τ_r, may also set a limit on the recovery of the gain of a neodymium laser during the passage of an intense pulse.

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