Suppression of nonlinear processes of stimulated scattering, beam collapse, and breakdown of the medium during beam scanning: Self-focusing of "strolling beams"

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It is shown experimentally that the scanning of powerful laser beams can eliminate in many cases undesirable nonlinear processes such as stimulated scattering, breakdown and damage of the medium, inertial self-focusing processes, etc., if the time of scanning of the beam over its diameter is less than the time of formation or growth of the stimulated processes. This suppression of the stimulated processes was investigated with a setup with self-triggered scanning of the beam. It is noted that such a setup can be used also to investigate rapid processes and can replace in some cases devices of the image converter and photoelectric recorder type.

It is known that stimulated nonlinear processes such as Mandel'shtam-Brillouin, Raman, and other types of scattering, self-focusing, breakdown and destruction of the media, can occur in high-power laser beams. All these processes have definite time durations of formation or growth. One should therefore expect the development of these processes to be suppressed by transverse scanning of the beam, if the time necessary to displace the beam by an amount equal to its diameter, $t_{\text{scan}} \approx a_\perp/v_\perp$ (which is equal to the ratio of the beam dimension $a_\perp$ to the scanning velocity $v_\perp$), is shorter than the time of formation of the nonlinear process, $t_{\text{scan}} < \tau$. For example, at beam transverse dimensions $a_\perp \lesssim 10^{-2}$–10^{-3} cm and scanning velocities $v \gtrsim 10^{7}$ cm/sec we obtain $t_{\text{scan}} \lesssim 10^{-9}$–$10^{-10}$ sec, which is close to the growth times of the nonlinear processes. We note that almost all nonlinear processes begin or take place in the most concentrated regions of the beam, and this facilitates their interruption by transverse scanning.

We have investigated experimentally the suppression of nonlinear processes by beam scanning. We constructed for this purpose a simple setup to effect self-triggered scanning of the beam and observation of the effects.

1. SCANNING OF LASER BEAM

The experimental setup was based on a scanning device triggered by the laser pulse itself, whereby the front of the laser beam caused operation of a discharge gap, which applied to a scanning cell a voltage that increases linearly for 40 nsec. A refractive-index gradient that deflected the beam was produced in nitrobenzene between the electrodes of this cell.

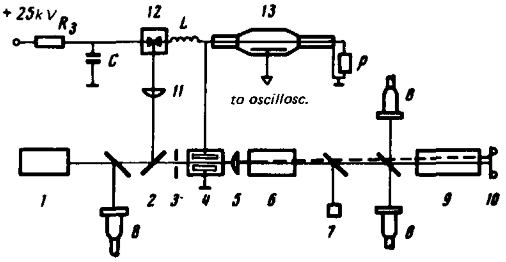

FIG. 1. Diagram of setup: 1-laser (generator), 2-beam-splitting glass plate, 3-diaphragm, 4-scanning cell, 5-focusing lens, 6-laser amplifier, 7-calorimeter, 8-photoelectric recorders (FEK-09), 9-cuvette with nitrobenzene or carbon disulfide, 10-photographic camera, 11-lens, 12-discharge gap triggered by the laser, 13-high-voltage voltage divider.

The experimental setup is shown in Fig. 1. The beam from neodymium laser 1 was diverted by glass plate 2 to a discharge gap 12, which discharged a capacitor C ($\approx 3\times10^{3}$ pF) through a tank circuit of inductance L (≈ 0.3 μH). This produced during the time interval of interest to us a linearly growing potential across the scanning cell 4. The voltage across the cell was applied through a high-voltage divider 13 to an oscilloscope. The main part of the laser beam passed through the cell and was deflected there by an angle that depended on the potential of the scanning cell and then passed through laser amplifier 6 and entered a

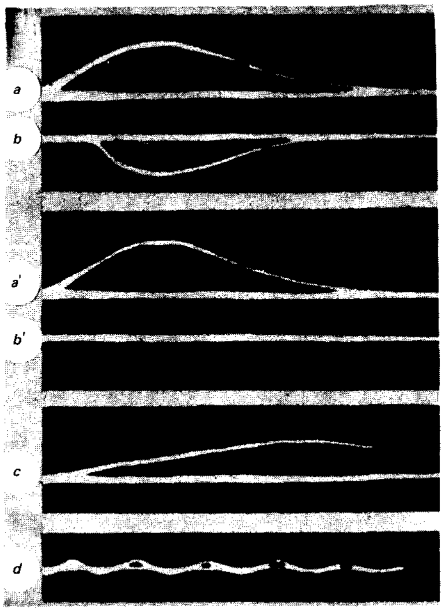

FIG. 2. Oscillograms of the radiation pulse and of the scanning-voltage pulse: a-laser pulse without scanning, b-pulse due to nonlinear stimulated backward scattering without scanning, a' and b'-the same with scanning (it is seen that there is no reflected pulse b'); c-rise of voltage on the scanning cell; d- time markers of frequency 100 MHz.

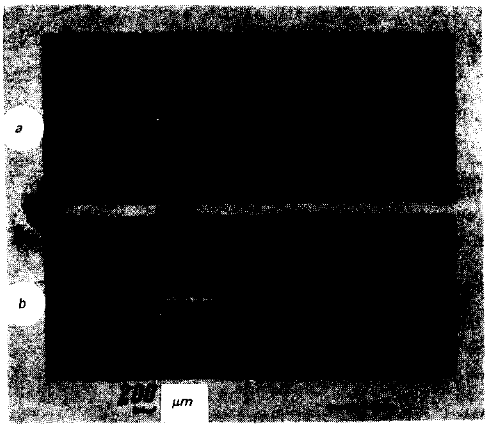

FIG. 3. Photographs of self-focusing sweeps: a) sweep on the end face of the cuvette when scanning a beam of 1 MW power. The minimum compression dimension is 40 μm. An elongated section lasting 10 nsec is seen, demonstrating waveguide propagation of 10 cm beyond the focus; (At this power and without scanning, the Kelly length is 10 cm in the interior of the cell. b) the same at a power 1.5 times larger.

cuvette of 30 cm length, with a nonlinear medium (9), or was incident on a screen. The cuvette was located either 3 or 6 meters away from the generator, in order to be able to vary the conditions and time of incidence of the reflected pulse on the generator. When the base was 6 meters, the laser pulse was not distorted by the reflected pulse and it was possible to observe the pure laser pulse and the pure reflected pulse not amplified in the laser system. A glass plate was placed in front of the medium to direct the incident and reflected radiation to two FED-09 coaxial photocells, the signals from which were fed to a fast multiple-beam oscilloscope 6-LOR-02-M (Fig. 2).

The laser operated in the single-frequency regime. The beam power on entering the cuvette was $\approx$1 MW. The laser pulse duration was 20 nsec at half-width, and the linear rise time of the voltage on the scanning cell was $\approx$40 nsec, i.e., the entire laser pulse occurred during the linear part of the sweep-voltage rise.

Since the scanning angle depends on the square of the field intensity in the scanning cell, the angular and linear displacements of the beam varied quadratically in time; this was specially verified to be able to mark the time of displacement by observing the trace of the beam on a film or on a screen (we investigated also the scan of the beam over a ridge lattice and registered the beam scanned and modulated by the ridge with the aid of a coaxial photocell). At the maximum voltage on the cell we obtained a scan amounting to an angle $\theta = 10^{-2}$ rad in 30 nsec, thus readily realizing a linear scanning velocity 3×10^7 cm/sec. The scanning cell was 10 cm long and the distance between its cylindrical and needle electrodes[1)] was 2 mm, thus ensuring a small change in the beam gradient over the beam diameter (1 mm). To decrease the dimension of the beam as it entered the nonlinear medium, we used a lens of great focal length, $\approx$60 cm, which focused the beam without changing the scanning angle. When the base was 6 meters, we used also a telescope to decrease the dimension and the shift of the beam during the scan.

2. RESULTS

a) *Suppression of nonlinear induced processes.* Turning on the scanning eliminated the stimulated Mandel'shtam-Brillouin scattering and the stimulated Raman scattering in carbon disulfide and nitrobenzene even at low scanning voltages. Figure 2 shows typical oscillograms of the laser-pulse signal (a), of the pulse reflected due to nonlinear scattering in the absence of scanning (b), the same in the case of scanning (a',b'), the rise of the scanning-cell voltage (c) and time markers of 100 MHz frequency (d). We see that the scanning eliminates the reflection completely (b'). At a distance of 6 meters from the nonlinear medium to the laser, the laser pulse is not deformed by the reflected pulse and is not altered by the scanning. (The oscillograms are shown for this distance.) At a distance of 3 meters, the reflected pulse is superimposed on the laser pulse and the scanning rids the latter of the reflection. Complete supression of the reflection was observed already at voltages smaller by a factor 2—3 than the maximum value. The growth time of the reflection signal in the absence of the scan was compared with the time required for the beam to move a distance equal to the diameter. It turned out that suppression of the SMBS takes place even at scan velocities insufficient to stop the process at a dimension on the order of the initial beam dimension (1 mm). The initiation and development of the stimulated processes is apparently connected with the regions of compression and focusing of the beam.

No breakdowns occurred in the media when the beam was scanned. In particular, the scanning eliminated the sparks produced in nitrobenzene at the beam-collapse points where the foci were stopped. The scanning of a focused beam smeared out the concentration of the action, broadened the damage region in glasses, and the damage became weaker and weaker when the scanning was made stronger.

b) *Scanning of self-focusing beam.* We investigated self-focusing in the course of scanning. We chose a regime in which the focus in the absence of scanning was located inside the cuvette (Kelly length $\approx$10 cm at the maximum of the pulse) and crossed the end face of the cuvette at a speed 10^9 cm/sec. Figure 3 shows the trace of the scanned beam. One can see a contraction to a minimum dimension 40 μm, lasting 10 nsec, thus indicating the existence of a waveguide extending 10 cm beyond the focus. (We note that the dimension of the beam spot on the end face of the cuvette without the self-focusing was 0.5 mm, as checked by using filters ahead of the cell to decrease the power.[2)] The influence of the scan on the self-focusing is manifest not only in the elimination of the stimulated scattering, but also in attenuation of the action of mechanisms of self-focusing with relaxation.

The foregoing suppression of the induced processes by beam scanning can be used extensively in practice in those cases when these processes are undesirable. Similar suppression of instability and collapse is possible for a scanned electron beam.

We can indicate several practical applications of the

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suppression by scanning: 1) Introduction of large power into a nonlinear medium. 2) Transmission of large power through a medium. 3) Suppression of some nonlinearities while retaining others having a shorter formation time (e.g., the study of self-focusing or stimulated Raman scattering after elimination of SMBS, etc.). Investigation of the development time of the nonlinearities. 4) Elimination of instabilities in the forward and backward currents to permit transmission of high-power electron current through a plasma.

For many nonlinear effects, the scanning of a concentrated beam is preferable to its defocusing, which decreases the instantaneous concentration of the action that decreases the self-contraction of the beam.

The employed simple system of triggered scanning can also replace in certain cases much more complicated and more expensive electron-optical converters and recorders for rapidly alternating processes (photocells, image converters, etc.) both in the case of continuous sweep and in frame-by-frame photography, by applying a stepwise growing voltage on the scanning cell.

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[1] See, e.g., V.K. Arkhipov, E.I. Ershov, Z.L. Ryzhkova, and R.P. Tarasov, Radiotekhnika i elektronika, No. 12, 2278, 1969. The use of electrodes of this shape decreased the inhomogeneity of the refractive-index gradient. The change of divergence as a result of scanning was monitored. It was small and exerted practically no influence on the Kelly length or on the investigated processes.

[2] The motion of the focus was observed in both the forward and backward directions, since the focus moved backward in an unperturbed medium. In the case of a nonmonochromatic (time-chopped) laser pulse, which permitted multiple crossing of the end plane by the focus, or in the case when interference beats appeared, we observed a multifocus end-face picture.