GIANT PULSE STRUCTURE IN A LASER WITH INSTANTANEOUS Q-SWITCHING

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The transverse component of the development of a giant pulse generation region after the restoration of the cavity Q is investigated experimentally in a ruby laser. It is shown that generation begins in the center of the crystal and spreads to the entire crystal in a time on the order of 3–10 nanoseconds. The effect of the resonator properties on the spatial development of generation is studied. The experimental results are in qualitative agreement with theory.

1. INTRODUCTION

An instantaneously Q-switched laser can emit a light pulse in 10^{-8} nsec.[1, 2] This time interval is comparable to the development time of the generation region in the transverse direction in the crystal after the Q of the cavity has been restored. This follows from theoretical considerations[3] and from the fact that pulses generated by individual regions of the crystal end face can be shorter than the giant pulse emitted by the entire crystal end face.[4] A second maximum may sometimes be observed[1, 2] in the trailing edge of the giant pulse.[1)] Furthermore, generation of several axial modes complicates the pulse shape; periodic fluctuations of the radiation are observed (see Fig. 1, and also [6]). The present paper is limited to the consideration of the pulse structure associated with the "spilling" of generation in the transverse direction of the crystal.

We shall note that the theories of a Q-switched laser (see, for example, [7-9], etc.) do not account for the transverse development of the generation region and therefore predict depressed values of duration and elevated values of power of the emission pulse. A paper by one of the present authors in collaboration with Suchkov[10] presented a Q-switched laser theory which held that generation begins in the maximum gain region and then proceeds in the transverse direction in step with the decay of the active medium during a time period of the order of the pulse length. This theory provides a natural explanation for the observed short pulses emitted by small regions of the rod end face,[4] and also for the structural drop of the giant pulse.[1, 2]

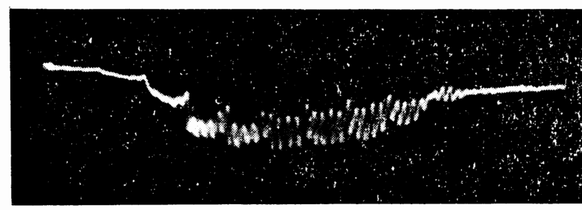

FIG. 1. Oscilloscopic trace of a giant pulse with intensity oscillations. Sweep, 300 nsec.

The present paper reports on the experimental investigation of the spatial development of a laser pulse assuming instantaneous Q-switching. We show that generation begins in the center of the crystal and spreads over the entire crystal in a time on the order of 3–10 nsec. The effect of the resonator properties on the spatial development of generation has been investigated. The experimental results are in qualitative agreement with theory.[10]

2. EXPERIMENTAL PROCEDURE

A study of the fine structure of the giant pulse calls for a simultaneous observation of emissions from small regions of the laser crystal face and a comparison of their time-dependent characteristics. The experimental setup assembled for this purpose is shown in Fig. 2.

The setup consisted of a laser with an instantaneous Q-switch, based on a ruby crystal,[2] and a recording circuit. The ruby crystal, 9 mm in diameter and 120 mm long, with an unpolished lateral surface, was placed in a reflector with an IFK-15000 helical pump lamp. Gain per pass amounted to about 12 for a pump energy of about 8 kilojoules.

[1)] This phenomenon has nothing in common with the generation of several pulses, obtained by slow Q-switching.[5]

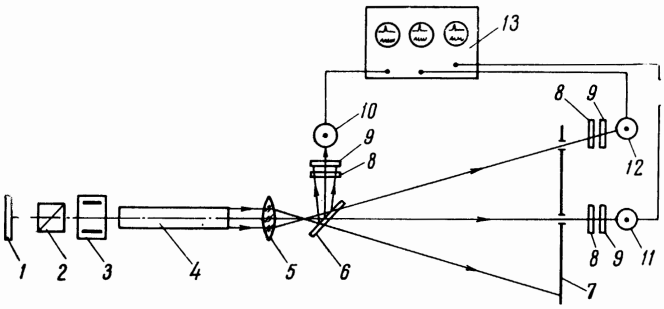

FIG. 2. The experimental setup. 1–99% reflection mirror; 2–polarizer; 3–Kerr cell; 4–crystal; 5–lens; 6–semitransparent plate; 7–screen with diaphragms; 8–interference filter; 9–ground glass; 10-12–coaxial photocells; 13–multibeam oscilloscope.

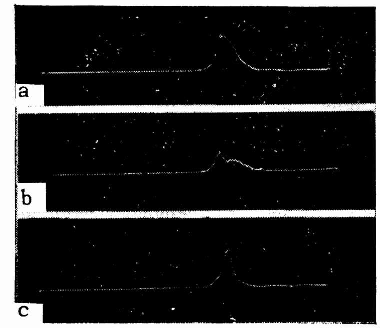

FIG. 3. Oscilloscopic traces of pulses from various regions of crystal end face, for various distances between the diaphragm and center of crystal. a–x/a = 0, b–x/a = 0.4, c–x/a = 0.8.

The laser emitted a single pulse of about 1.5 joules at 10–15 nsec half-power length.

Long-focus lens 5 projected the image of the crystal face, magnified 14 times, on screen 7 provided with holes which acted as diaphragms. The light beams passed through the diaphragms onto coaxial photocells (FÉK)[11] 11 and 12, having a time resolution of 0.5 nsec. To ensure uniform illumination of the photocathode, each photocell was screened by ground glass 9 and an interference filter 8. The integral pulse emitted by the entire crystal end face was recorded simultaneously with signals from two regions of the end face. For this purpose, a portion of the laser emission was deflected by plate 6 to coaxial photocell 10. The signals from each photocell were fed to high-speed multi-beam oscilloscope 13. To compensate for the nonlinear sweep of the oscilloscope, 100 mc timebase marks from a quartz oscillator were photographed simultaneously with the photocell signals.

The oscillographic traces were processed in a comparator. The relative time shifts between pulse peaks and half-power pulse lengths were measured. The resulting shift data were corrected by subtracting "constant shifts" between pulses of various rays, due to differences in the distance from the laser to the photocells and in the cable lengths. As a result, true shifts were determined between the pulses emitted from various regions of the crystal face and the integral pulse. The accuracy of measuring the shifts and pulse lengths was about 1 nsec.

3. STUDY OF THE GIANT PULSE STRUCTURE

The first experiments were performed using a single diaphragm 1.5 mm in diameter in screen 7, which was free to move from the center of the crystal end face image (x = 0) to x = a (a is the crystal radius). The ruby crystal used in these experiments had an index of refraction characterized by axially symmetric inhomogeneities (lens crystal). It was found that pulses emitted by small regions of the end face had shapes considerably different from the simple and always recurring shape of the integral pulse emitted by the entire end face. The half-power length of the integral pulse was 10 nsec.

Figure 3 shows oscilloscopic traces obtained at various distances of the diaphragm from the center of the crystal. The sweep interval of the oscilloscopic trace is 100 nsec. The most significant feature is the generation of a shorter pulse by the edge region of the crystal end face. Trace (c) shows a pulse whose half-power length is merely 5.8 nsec, while the integral pulse length is 10 nsec. The complex pulse structure (Fig. 3b) is due to beats produced by the addition of oscillations of the neighboring modes. As the diaphragm size increases, the pulse intensity oscillations disappear, because of the averaging of beats from various regions of the crystal end face.

The transverse development of the generation region was studied in another experiment in which a diaphragm, 1.5 mm in diameter, was placed within the resonator between a mirror and the Kerr cell. When the diaphragm was on the resonator axis (Fig. 4 a, b), the pulse had an expanded trailing edge which could be explained as follows. After the Q is turned on, generation occurs in the axial region of the crystal limited by the internal diaphragm. When the particles in the thin "thread" in the center of the crystal have been expended, the field penetrates into the neighboring regions with a higher population inversion of active particles. A shift of the internal diaphragm away from the crystal axis gives rise to a short pulse (Fig. 4c for x = 0.5 a).

Both experiments described above involved a

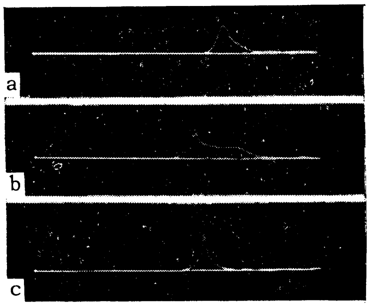

FIG. 4. Oscilloscopic traces of pulses from a laser with a diaphragm inserted in the resonator. Traces a and b pertain to diaphragm on the resonator axis; trace c pertains to diaphragm shifted by a/2 off the resonator axis. Sweep, 100 nsec.

laser with a Kerr cell used as a shutter. Similar experiments were carried out with a shutter made of bleachable solution of vanadium phthalocyacin. Figure 5a shows an oscilloscopic trace of a giant pulse emitted by the entire crystal end face, and Fig. 5b a trace of a pulse emitted by the central end-face region of 1.5 mm diameter. The sweep was 100 nsec. The presence of a steep leading edge 1 nsec long is typical. This was followed by experiments with several diaphragms (Fig. 2), designed for the observation of the consecutive development of the generation region in a laser after an instantaneous actuation of the Q-switch.

4. SPACE-TIME DEVELOPMENT OF GENERATION

Figure 6 shows the shapes of pulses emitted simultaneously by various regions of the crystal face, and the shape of the integral pulse. The pulse diagrams are the result of processing the oscilloscopic traces of simultaneous signals from the coaxial photocells. The integral pulse has the highest amplitude in all diagrams. Distances from the crystal center (the crystal center is at the point $x = 0$, a is the crystal radius) are given for pulses emitted by individual regions of the crystal end

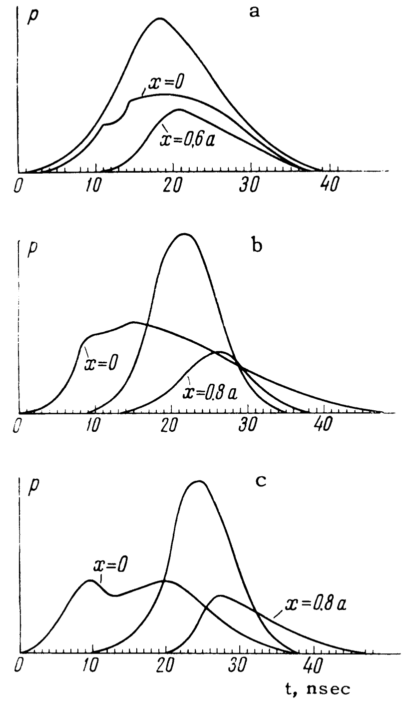

FIG. 6. Oscilloscopic traces of pulses from the entire crystal end face (pulse with the highest amplitude), from the center of end face, $x = 0$, and from a shifted regions of crystal end face; a–$x = 0.6$ a; b,c–$x = 0.8$ a (different experiments).

face. The amplitude of the integral pulse is estimated as 10^2 times larger than that of the pulse from the central diaphragm; the amplitude of the latter is, in turn, larger than that of pulses from the edge regions.

The qualitative agreement of these results with theory[10] is obvious. Just as predicted by the theory, generation begins in the center of the crystal, where the population inversion density is highest. The cylindrical reflector used in the experiment has created precisely this type of inhomogeneity in the population inversion. Generation in crystalline regions removed from the center is observed later, and the delay time increases with the distance from the crystal center. The generation propagates in the transverse direction during a time interval comparable with the length of the pulse. The time of spatial development of generation, amounting to 3–10 nsec, is in agreement with the time given in [10]. "Double" and "wavelike" pulses seen in the oscilloscope traces are due to mode beats.

It should be noted that the lengths of pulses emitted by the individual regions of the crystal end face are, as a rule, close to the length of the integral pulse. According to the theory,[10] the length of pulses from the end face regions should be almost twice as small as the integral pulse

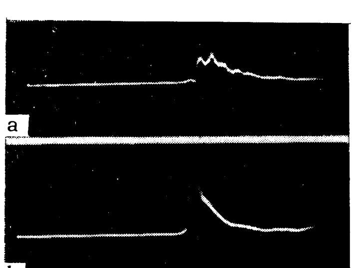

FIG. 5. Oscilloscopic traces of pulses from a laser with bleachable solution of vanadium phthalocyanin acting as shutter. a–pulse from center of crystal end face; b–pulse from entire crystal end face.

length. This discrepancy can be ascribed to the inhomogeneity of the refractive index of the crystal. The refractive-index inhomogeneity of the crystal may hinder or help the "spillover" of the generation field from the center to the edges of the crystal, depending upon the sign of the lens in the crystal, and, consequently, it may substantially affect the length of the pulses.

The degree of inhomogeneity of the crystal over the end face can be determined from the interference pattern. In good quality crystals, the inhomogeneity amounts to 5–10 rings per cm for a crystal 12 cm long. However, the inhomogeneous heating of the crystal during pumping causes an additional inhomogeneity of the refractive index. In the case of comparatively low pump powers, this inhomogeneity was measured by Veduta, Leontovich, and Smorchkov.[12] Aplet, Jay, and Sooy[13] showed that the inhomogeneity caused by strong pumping depends upon the finish of the lateral surface (coarse or fine grinding). The form of the inhomogeneity of the refractive index during the actuation of the Q-switch has not been determined in our experiments. However, the lengthening of the pulse edges and of the integral pulse duration indicate that the crystal inhomogeneity at the instant of generation should have been of the positive lens type.

To study the wedge-type inhomogeneities of the refractive index in the resonator, the crystal end face used as the second mirror of the resonator was thrown out of adjustment by 1′. The field in such a resonator should "slip off" towards the "open" edge, i.e., toward the edge associated with a longer optical path; consequently, the generation of a giant pulse should begin at the open end of the resonator and then move towards the center of the crystal and the opposite edge. Figure 7 shows diagrams of pulses emitted simultaneously by the center of the end face and by the regions with x = ± 0.8a. The generation of a giant pulse began at the "open" edge (x = 0.8a), and in 5 nsec had spread to the opposite edge of the resonator.

5. CONCLUSIONS

An experimental study of the structure of a giant pulse in a laser with instantaneous Q-switching indicates that the spatial development of generation in the transverse direction occurs in time comparable to the length of an integral pulse. The spatial development process is largely determined by inhomogeneities which characterize both, the population inversion density and the refractive index of the crystal. Further study of the complex processes of space-time development of generation following the actuation of the Q-switch calls for experiments to measure inhomogeneities of complex dielectric permittivity at the instant of actuation of the Q-switch, and for a generalization of the theory[10] to cover the case of an inhomogeneous index of refraction.

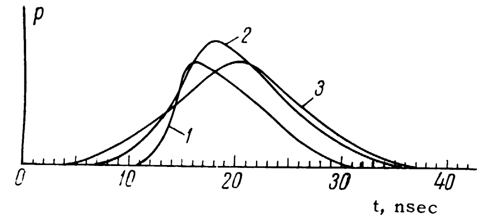

FIG. 7. Oscilloscopic traces of pulses from a laser with an inclined mirror, obtained at various distances of the end-face region from the crystal center. 1–x/a = 0.8; 2–x/a = 0; 3–x/a = 0.8.

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