# INVESTIGATION OF THE TIME-DEPENDENT CHARACTERISTICS OF A Q-SWITCHED RUBY LASER DRIVEN BY AN EXTERNAL SIGNAL

A. N. BONDARENKO, G. V. KRIVOSHCHEKOV, V. A. SMIRNOV and K. G. FOLIN

Institute of Semiconductor Physics, Siberian Division, USSR Academy of Sciences

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The shape and duration of a giant pulse from a ruby laser driven by a signal from another laser are investigated. Both lasers are Q-switched. It is shown that simpler and shorter pulses are generated whenever the energy of the external signal exceeds in magnitude the energy stored in a mode.

## INTRODUCTION

A previous study[1] reported on the investigation of the emission spectrum and the period of linear development of generation in a Q-switched ruby laser. Radiation with a different spectral composition from another Q-switched laser was injected into its resonator during the Q-switched pulse. It was found that the emission spectrum of the laser fully coincided with that of the injected emission and the period $\tau_d$ of generation development was shortened. The dependence of $\tau_d$ on the injected energy $\Delta W$ was in a qualitative agreement with theory.

The present paper reports on the results of investigating the shape and duration $\tau_i$ of a ruby laser emission pulse, the laser being driven by an external signal.

As we know, the initial theoretical calculation of a giant pulse length (see[2] for example) does not agree with the experimental value. This is due to the finite time of generation development over the cross section of the active rod, caused in turn by an inhomogeneous population inversion density and refractive index of the crystal[3,4].

Letokhov and Suchkov[3] showed that the rate of the transverse generation development v is proportional to the ratio $I_0(x)(dI/dx)^{-1}$, where x is the coordinate perpendicular to the rod axis and $I_0(x)$ is field intensity distribution at the end of the linear generation development. On this basis we can expect an increase of v when energy with uniform transverse field distribution is admitted to the resonator. Furthermore pulses of "complex" shape[6,7] whose origin is not fully known are frequently observed in practice.

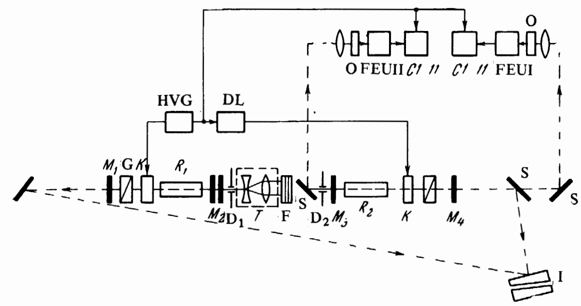


FIG. 1. Diagram of the experimental setup. $M_1$, $M_4$ – mirrors with 98% reflectivity; $M_2$ – resonance mirror; $M_3$ – mirror with 30% reflectivity; $R_1$, $R_2$ – ruby crystals; G – polarizer; K – Pockels call; $D_1$, $D_2$ – diaphragms with 0.8 mm diameter; T – telescope; F - neutral filters; S – semitransparent mirror; I – Febry-Perot etalon; O – opal glass; HVG – high-voltage pulse generator; DL – delay line.

## EXPERIMENTAL METHODOLOGY

To clarify the effect on pulse length exerted by field intensity distribution over the cross section of the active rod during the linear development of generation, and to discover the origin of pulses of "complex" shape, we assembled an apparatus whose schematic is shown in Fig. 1. The apparatus comprised two ruby lasers with an instantaneous Q-switch and the recording instruments. Ruby crystals of 12 mm dia and 120 mm long, with an unpolished lateral surface, were housed in close fitting reflectors and pumped by IPF-2000 lamps.

In the first part of the experiment the shape and duration of pulses from the entire end face and its portions were compared to determine if the "complex" pulse shape is the result of independent generation within various portions of the end face. For this purpose the emission from one end face of ruby $R_2$ was directed by semitransparent mirror S to photomultiplier FÉU I and the emission from various portions of the second end face was isolated by an 0.8 mm diaphragm placed 60 mm from the face and was directed to photomultiplier FÉU II. To provide a uniform illumination of the photocathodes the emission was focused on opal glass O in front of the photomultipher. The scope sweeps were started at the same time as the opening of the laser shutter. The time resolution of the recording instruments was 4 nsec or better.

According to the measurements the compared pulses had the same shape that generally changed from flash to flash. Figures 2 a-c shows the oscilloscope traces of pulses whose appearance is approximately equiprobable. The period of linear generation development also varied with the changing pulse shape. In the case of single-pulse generation, $\tau_d$ was the longest, amounting to 115 nsec in our experiment (Fig. 2a). In "double-pulse" generation (Fig. 2c), $\tau_d$ shortened down to 95 nsec, while the laser parameters remained unchanged.

We then investigated the shape and duration of a pulse when the emission from another laser was injected into the resonator after opening its shutter. The lasers were synchronized according to the method described in[1].

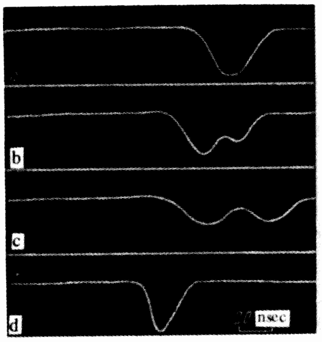

FIG. 2. Oscilloscope traces of $R_2$ ruby emission pulses. a – c – for $\Delta W = 0$; d – for $\Delta W = 10^{-4}$ J.

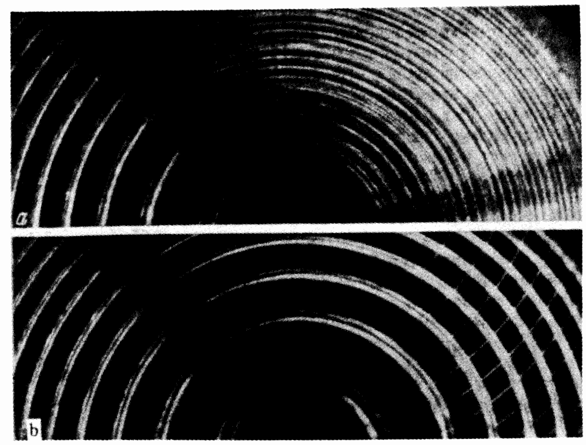

FIG. 3. Interference pattern of emission. Left – $R_1$ ruby; right – $R_2$ ruby; a – for $\Delta W = 0$; b – for $\Delta W = 10^{-4}$ J.

To obtain a uniform distribution of the injected energy over the cross section of ruby $R_2$, a 0.8 mm beam was formed by diaphragm $D_1$ 5 cm from the end face of the ruby; the beam was then expanded by optical system T to 12 mm. Diaphgram $D_2$ was removed. The output pulse of the second laser was recorded and at the same time the spectrograms of both lasers from the same Fabry-Perot etalon were photographed. The dispersion range of the etalon was 0.715 $cm^{-1}$ and its limit of resolution was $5 \times 10^{-3}$ $cm^{-1}$ (150 MHz). The resonators of both lasers were 56 cm long. Figure 3a shows the emission spectrogram of both lasers when the injected energy $\Delta W = 0$, and Fig. 3b shows the case of $\Delta W = 10^{-4}$ J. It is clear that the spectrum of the second laser becomes identical to that of the first and that the second pulse maximum vanishes (Fig. 2d). When $\Delta W < 10^{-9}$ J no spectrum "capture" is observed and the second laser generates the pulses shown in Figs. 2a-c. The energy $\Delta W$ was injected into the resonator of the second laser 15 nsec after the shutter was opened when the mode's own energy $W_0$ was of the order of $10^{-9}$ J. According to the oscilloscopic trace in Fig. 2d, the slope of the leading edge of the pulse increased although its total length decreased insignificantly (by 15—20% on the average).

## DISCUSSION OF RESULTS

In our experiment the generation of "double" pulses was not due to slow operation of the Q-switch, since the resonator shutter opened in 5 nsec. The almost complete equality in the shape of pulses from the entire end face and from a portion thereof indicates that the complex pulse shape is not due to the superposition of pulses generated independently by various portions of the end face. Neither can we attribute it to the beats of neighboring modes[4,8], since we recorded emission from the entire ruby end face and the spectral width was $\sim 0.7$ $cm^{-1}$. The beats of modes from various portions of the face would average out under these conditions.

The equality of the $\Delta W$ threshold of spectrum "capture" and the threshold determining the vanishing point of the second pulse maximum allows us to assume that the complex shape of the giant pulse appears to be caused by the influence of initial conditions (fluctuation of spontaneous emission, length of resonator, etc.) on the gain of individual mode groups during the linear development of generation. The group of modes with the largest gain leads the generation process. The second group of modes, with a randomly achieved lower gain, develops over a longer period of time and is emitted in the second pulse. The fact that the first mode group does not consume the entire inversion seems to be due to the negligible differences in gain and to the effect of spatial inhomogeneity of inversion caused by the distribution of the standing wave field of the generated modes. Based on this assumption we can readily see why the linear development time of a "complex" shape pulse is always shorter than that of a simple pulse (Fig. 2a-c). The energy $\Delta W$ injected into the resonator and exceeding the level of natural oscillations in the initial stage of the linear development completely eliminates the randomizing effect of initial conditions and always results in the generation of a simple single pulse. The slight shortening of the pulse appears to be due to a small increase in the rate of transverse development of generation. Although the emission injected into the resonator has a uniform distribution of intensity over the cross section, the inhomogeneities of the ruby index of refraction and of the population inversion density are such as to sharply change the distribution at the end of the linear generation development and $dI \neq 0$.

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