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CONTROL OF LASER RADIATION PARAMETERS

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Control of the radiation parameters of a copper vapour laser

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Abstract. **The possibility of controlling the pulse shape and duration and the beam divergence of a copper vapour laser operating in the mode of double pump pulses, when the first pulse excites lasing in the active medium and the second amplifies it. It is shown that a change in the delay of the second pump pulse relative to the laser pulse initiated by the first pump pulse allows an efficient control of the laser-radiation characteristics. In this case, the coefficient of laser-radiation conversion into a beam with a diffraction-limited divergence may reach $\sim 80\,\%$.**

Keywords: *copper vapour laser, radiation control, radiation divergence.*

Pulsed copper vapour lasers (CVLs) are widely used to pump dye lasers due to their good energy characteristics – a high efficiency and significant pulse and mean output power. A drawback of CVLs is a large divergence of radiation primarily related to the short laser-pulse duration ($\sim 10-20$ ns), which substantially reduces the dye-laser pumping efficiency. To form laser radiation with a diffraction-limited divergence, unstable resonators are used [1]. Due to high gains, a short inversion lifetime, and large axial dimensions of the active medium, the formation of beams with diffraction divergence in such resonators is accompanied by high energy losses.

By now, dozens of papers devoted to CVLs with unstable resonators have been published [2–5]. However, the maximum ($\sim 83\,\%$) coefficient of radiation conversion into a beam with diffraction divergence was achieved in a CVL due to a combination of low- and high-current discharges using a switch – a tacitron operating in the pulse-control mode [6]. A considerable increase in the coefficient of laser-radiation conversion into a beam with diffraction divergence was achieved upon the formation of such a CVL pump pulse that the initial part of the laser pulse was a plateau with a minimum height and a duration equal to the beam-formation time. Studies in Ref. [6] have shown that this technique for forming the CVL radiation with diffraction divergence also makes it possible to significantly improve the dye-laser characteristics. The limited switching capabilities of tacitrons and technical difficulties in implementing the pulse-control mode are the disadvantages of this method that appreciably restrict the possibilities of using it in practice. This work considers the possibility of forming the above regime using a combination of two independent excitation pulses.

This technique was experimentally verified in a CVL with an UL-102 gas-discharge tube, in which the gas-discharge channel is an Al_2O_3 ceramic tube with a 2-cm inner diameter and 40-cm length and neon serves as a buffer gas. The experimental setup (Fig. 1) operates as follows. Storage capacitors *C1* and *C2* are charged from high-voltage rectifiers *1* and *2* through charging chokes *L1* and *L2*, diodes *D1* and *D2*, and an inductor *L*, which are connected in parallel to the gas-discharge tube. Low- and high-current excitation pulses are formed by switches *K1* and *K2* due to a discharge of the storage capacitors through the tube. The low-current discharge phase is formed with a TGI1-270/12 thyratron used for *K1*. The high-current discharge phase is formed with the switch *K2* (TGI2-500/20 thyratron). The thyratron are triggered by a driving generator (*4*) through adjustable delay lines (*3*) and (*5*), respectively, making it possible to smoothly change the relative delay of the excitation pulses applied to the gas-discharge tube.

At the initial stage of the experiment, the delay between these pulses was such that the excitation pulse formed by

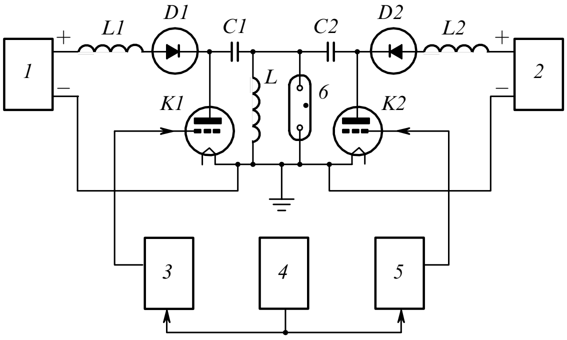

Figure 1. Schematic of the experimental setup: (*1*, *2*) high-voltage rectifiers; (*3*, *5*) controllable delay lines; (*4*) master oscillator; (*6*) gas-discharge tube; (*C1*, *C2*) storage capacitors; (*K1*) TGI1-270/12 thyratron; (*K2*) TGI2-500/20 thyratron; (*D1*, *D2*) charging diodes; (*L*) shunting inductor; and (*L1*, *L2*) charging chokes.

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switch *K2* appeared immediately after the low-current pulse. The parameters of the excitation pulses were determined by the condition of a self-heating operating mode in the UL-102 tube. After the required laser operating conditions were reached, the pump parameters were optimised. The output voltage of the high-voltage rectifier (*1*) was selected to be minimum, at which lasing was induced by a low-current excitation pulse, and the voltage at the second high-voltage rectifier was to ensure the self-heating CVL operating mode. Subsequent studies were performed at the selected pump parameters and a 12.5-kHz excitation-pulse repetition rate.

The low- and high-current excitation pulses were formed by discharges of the storage capacitors *C1* (2200 pF) and *C2* (1340 pF) at output voltages of rectifiers (*1*) and (*2*) of 2.3 and 5.1 kV and consumed currents of 190 and $\sim$ 210 mA, respectively. A laser pulse excited by a low-current pulse appeared $\sim$ 70 ns after its onset. For a mean output power of $\sim$ 13 mW, the laser-pulse FWHM duration was 45 ns and the 0.1-level duration was $\sim$ 110 ns. In this case, no lasing was observed in the high-current pulse. The position of the low-current excitation pulse after the high-current pulse resulted in a generation of a typical CVL pulse in a high-current excitation pulse appearing $\sim$ 40 ns after the onset of the exciting pulse. The laser-pulse FWHM duration and the mean power were $\sim$ 20 ns and $\sim$ 3.2 W, respectively.

Subsequent investigations were performed for the case of a low-current pulse followed by a high-current excitation pulse. As the delay between the pulses decreased, an enhancement of the part of the laser pulse that coincided with the leading edge of the high-current excitation pulse was observed (Fig. 2). The arrow shows the direction of the change in the delay between the excitation pulses. The current and voltage pulses shown in Fig. 2 were measured using a coaxial current shunt and a noninductive ohmic divider; laser pulses were detected by an FK-32 coaxial photocell and recorded by a S1-75 oscilloscope. A laser pulse (*4*) in Fig. 2 corresponding to a high-current discharge is presented qualitatively (in arbitrary units), since the amplitudes of pulses (*3*) and (*4*) differ by more than two orders of magnitude. Figs 3 and 4 show changes in the mean CVL output power and duration (FWHM) of the amplified laser pulse, respectively, as functions of the position of the high-current excitation pulse moving relative to the laser pulse excited by the low-current pulse from the laser-pulse trailing edge to its onset (shown by arrows). The origin of coordinates ($t = 0$ on the horizontal axis) corresponds to the onset of the laser pulse excited by the low-current pulse.

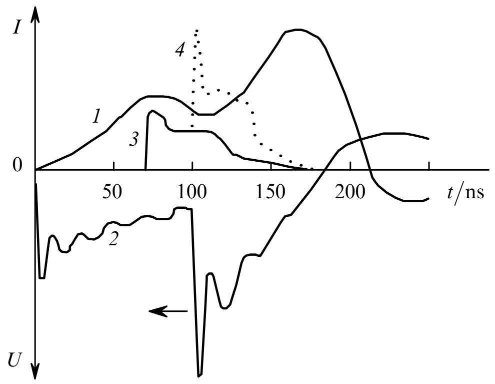

Figure 2. Oscillograms of (*1*) a current pulse, (*2*) a voltage pulse across the gas-discharge tube, (*3*) a laser pulse induced by a low-current excitation pulse, and (*4*) a laser pulse (*3*) amplified by a high-current excitation pulse.

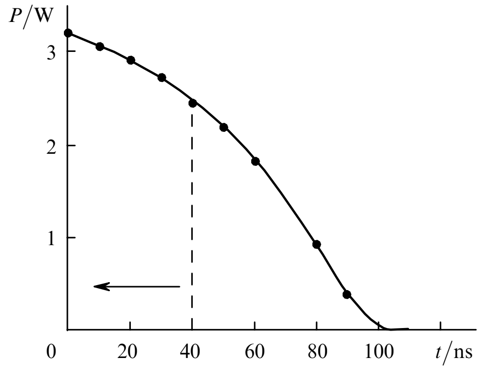

Figure 3. Mean laser output power as a function of the temporal position of a high-current excitation pulse relative to the laser pulse induced by a low-current excitation pulse.

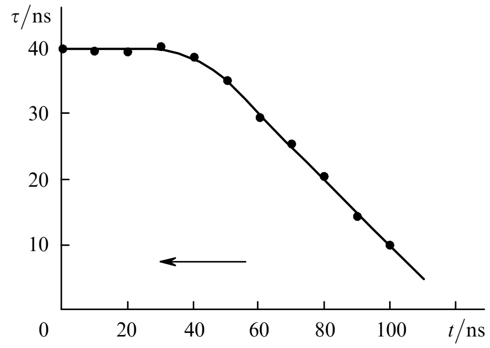

Figure 4. FWHM duration of the amplified laser pulse as a function of the delay of the high-current excitation pulse relative to the laser pulse induced by the low-current excitation pulse.

The coefficient of laser-light conversion into radiation with diffraction-limited divergence in this CVL operating mode must reach $\sim$ 80 % (the dashed line in Fig. 3), since, according to Ref. [6], the formation time of a diffraction beam is $\sim$ 42 ns for an unstable resonator with a magnification $M = 30$. A characteristic feature is that the observed enhancement of the lasing induced by the high-current pump pulse represents the radial – temporal profile of the low-current-induced laser pulse. For example, intensified lasing at a wavelength $\lambda = 578.2$ nm in the form of a ring near the walls of the tube's gas-discharge channel was observed at the laser-pulse trailing edge. When the high-current excitation pulse moved from the laser-pulse trailing edge to its onset, the radial lasing profile at 578.2 nm was gradually smoothed for $\sim 20 - 25$ ns; subsequently, lasing was also intensified in the form of a ring in the radial profile of radiation at $\lambda = 510.6$ nm, which was then also smoothed.

The studies performed confirmed the possibility of achieving a pulse-control mode [6] using a combination of two independent exciting pulses. In this case, the functional capabilities of controlling the radiation characteristics of lasers on self-contained transitions are wider than in the case of a control using a single switch (tacitron).

Note that it is always difficult to obtain a good laser-beam divergence at a sufficiently high laser power and efficiency under usual excitation conditions because of a comparatively short laser-pulse duration ($\sim 10-15$ ns) and a small number of transits of light in the resonator [2-5]. This is caused by the fact that the diffraction-beam formation time τ_0 at the resonator exit is comparable to the laser-pulse duration [2, 3]:

$$\tau_0 = l_0 \frac{2L}{c},$$

where $l_0 = 1 + \ln M_0 / \ln M$; $M_0 = D_1^2/2\lambda f_1$; $M = f_1/f_2$; c is the velocity of light; L is the resonator length; f_1 and f_2 are the focal lengths of the resonator mirrors; D_1 is the diameter of the largest mirror; and λ is the radiation wavelength.

The studies performed in Ref. [6] and this work clearly show the way for solving this problem. In a conventional excitation mode [2-5], the radiation emerging from the resonator is represented by a core with a diffraction-limited divergence and background radiation with a higher divergence. As a rule, the background radiation power exceeds the lasing threshold of dye lasers, which requires a 'purification' of laser radiation using diaphragms. In our case, the background radiation power is inferior to the lasing threshold and, according to Ref. [6], plays a positive role in forming the dye-laser oscillation.

Since this regime of forming a population inversion is of practical importance, it requires a more detailed study especially under conditions of a higher CVL mean output power and efficiency.

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