

LASERS AND LASER BEAMS

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Copper bromide vapour laser with an output pulse duration of up to 320 ns

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Abstract. **We report the development of a copper bromide vapour laser with an output pulse duration of up to 320 ns. To lengthen the pulse, the discharge current was limited using a compound switch comprising a pulsed hydrogen thyratron and a tacitron. This technique permits limiting the excitation of the working levels at the initial stage of the discharge development to lengthen the inversion lifetime. The longest duration of a laser pulse was reached in tubes 25 and 50 mm in diameter for a pulse repetition rate of 2–4 kHz.**

Keywords: *copper bromide vapour laser, long pulse, inversion, excitation.*

1. Introduction

The interest in lengthening the duration of output pulses in lasers utilising self-terminating metal transitions is caused by several reasons. It still remains to fully elucidate the potentialities of metal vapour lasers from the standpoint of obtaining a 'long' pulse which is in demand by several practical problems. The term long pulse is used in reference to a laser pulse whose duration is significantly (by a factor of five or more) longer than the values typical for metal vapour lasers (20–40 ns) [1–5]. The increase in laser pulse duration is of certain interest in the development of brightness enhancement systems – laser monitors [6–9] – in which the inversion lifetime determines the maximum attainable to the object of observation. Furthermore, laser pulses of long duration are required in the development of laser systems with a high beam quality, i.e. with the minimal (diffraction-limited) divergence [10].

The output pulse duration of lasers operating on self-terminating transitions in metal vapour depends both on the characteristics of the active medium (geometric dimensions, buffer gas pressure, vapour density of the working substance) and on the pump conditions. Among these are the shape of the excitation pulse and the build-up rate of the current flowing through the gas-discharge tube (GDT).

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The output laser pulse may be lengthened by changing the operating mode both in the scheme of direct discharge of the storage capacitor (typical for the pumping of metal vapour lasers) and in unconventional excitation schemes. For instance, the output pulse of a copper vapour laser (CVL) was observed to lengthen from 20 to 60 ns on lowering the pump voltage, the buffer gas pressure and the pulse repetition frequency (PRF) [11]. The longest pulse duration was achieved with a tube of larger diameter (26 mm instead of 10 mm) for a PRF of 1 kHz. In Ref. [12] the pulse duration of a copper bromide vapour laser was lengthened from 60 to 80 ns on lowering the output voltage of the high-voltage rectifier from 6 to 4 kV.

The authors of Ref. [13] observed the lengthening of the output CVL pulses to 120 ns on lowering the PRF from 2 to 0.01 kHz. The longest CVL pulse duration of 140 ns was obtained using the scheme of the direct discharge of the storage capacitor for a PRF of 0.5 kHz [14]. The longest pulse duration of a copper bromide vapour laser amounted to 100 ns for a PRF of 3–5 kHz [15].

The data obtained are consistent with the estimates of the longest output pulse duration in lasers utilising self-terminating transitions made in Ref. [16]. According to Ref. [16], the output pulse duration does not exceed 206 ns under excitation by rectangular pulses.

The duration of output pulses may by significantly lengthened by way of controllable limitation of discharge current, i.e. by forming an excitation pulse of 'complex' shape [17, 18]. In Refs [17, 18] this pulse was formed using a tacitron connected in series in the discharge circuit. Varying the duration of excitation pulses permitted controlling the output pulse duration in a range of 3–200 ns [17] and obtaining the longest CVL pulse duration to date equal to 230 ns [18].

Practically all experiments in obtaining long output pulses were carried out with CVLs. At the same time, copper bromide vapour lasers, whose medium is characterised by a higher resistance, are of interest from the standpoint of lengthening further the output pulse duration. Therefore, the aim of our work was to investigate the possibility of lengthening the output pulses of a copper bromide vapour laser.

2. Experimental techniques

In our experiment we employed the active element of the CuBr laser with external heating of the active zone, whose design was discussed earlier in Refs [19–22]. Use was made of five tubes with the following dimensions: length 90 cm, inner diameters of 25 and 50 mm; length 30 cm, inner diameters of 6, 8, and 12 mm. The tubes were placed into the external heater to provide similar temperature modes for different PRFs. Containers with copper bromide were heated independently of the heating of the active zone; their temperature was automatically stabilised at 710 K with an accuracy of ±5 K. Neon at a pressure of 30 Torr served as a buffer gas.

The pumping was performed with a TGI1-1000/25 thyratron generator made according to the scheme of direct discharge of the storage capacitor (Fig. 1, tacitron T2 is short-circuited). The PRF was varied from 1.5 to 11 kHz. Considering that the increase in output duration pulse is observed for a relatively low output voltage of the high-voltage rectifier [11, 12], in all experiments the supply voltage was equal to 3.5–4.0 kV for a current of 150–200 mA.

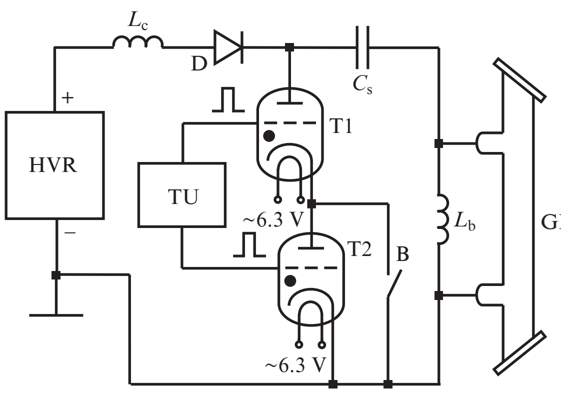

Figure 1. Pumping circuit:
(L_c) and (D) charging choke and diode; (C_s) storage capacitor; (L_b) shunt inductance; (B) bridge; (T1) TGI1-1000/25 thyratron; (T2) TGU1-5/12 tacitron; (HVR) high-voltage rectifier; (TU) triggering unit.

When varying the PRF, the capacitance C_s of the storage capacitor was varied from 1650 to 4800 pF to stabilise the energy input. Interestingly, varying the capacitance in this range did not exert an appreciable effect on the output pulse duration. A similar result was observed by the authors of Ref. [23] for a CVL.

On connecting the TGU1-5/12 tacitron, the current was limited by varying the tacitron conductance due to the variation of the filament voltage of the hydrogen generator and the bias voltage of the grid. The voltage, current and laser pulses were recorded using a Tektronix P6015A voltage probe, a Pearson Current Monitor 8450 and a FK-22 coaxial photocell, respectively. The average output power was measured using an Ophir 20C-SH power meter. The sensor signals were delivered to a LeCroy WJ-324 four-channel digital oscilloscope. The oscilloscope was synchronised using the current through the GDT.

3. Experimental results

The dependence of laser pulse duration on the tube diameter and the PRF was investigated for a closed bridge B (Fig. 1), i.e. under excitation in the scheme of direct discharge of the storage capacitor without discharge current limitation. The data shown in Fig. 2 suggest that the output laser pulse is longest in the tubes of larger diameter, which is consistent with the data obtained by different authors in CVLs. In this case, of interest from the standpoint of increasing the pulse duration is a frequency range of 2–4 kHz. This is so because that the specific resistance of a plasma column is inversely proportional to the prepulse electron density n_{e0}, and therefore lowering the frequency, which results in a lowering of n_{e0}, entails an increase in plasma resistance and, hence, a delay in the discharge development with the formation of favourable conditions for lengthening the population inversion lifetime. Figure 3 shows the oscilloscope traces of the voltage, current and laser pulses for different PRFs for a GDT 25 mm in diameter. One can clearly see that the delay of current and laser pulses relative to the voltage pulse increases with lowering the PRF.

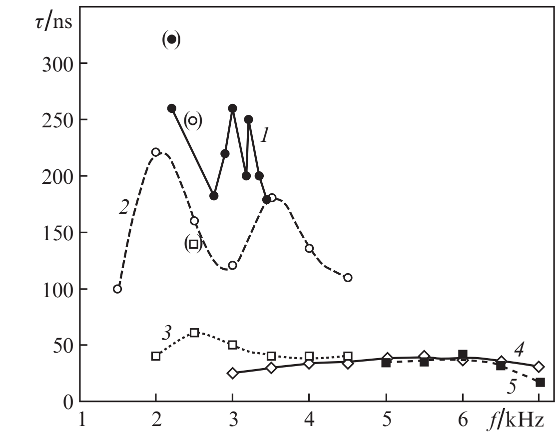

Figure 2. Dependences of laser pulse duration on the PRF for tubes of diameter (*1*) 50, (*2*) 25, (*3*) 12, (*4*) 8 and (*5*) 6 mm. The points without parentheses correspond to the mode with an uncontrollable discharge of the storage capacitor, the points in parentheses stand for the duration of laser pulses in the current limitation mode for the same GDTs.

In metal halide vapour lasers, a pump pulse fulfils not only the excitation of metal atoms but also the dissociation of halide molecules and the heating of the active medium. That is why these lasers are characterised by the existence of the lower threshold in PRF. For CuBr lasers studied in the present work, the threshold frequency is equal to about 2 kHz. The longest laser pulses are observed at this PRF – 220 ns for a GDT 25 mm in diameter and 260 ns for a GDT 50 mm in diameter, which is much longer than the values obtained for metal vapour and metal halide vapour lasers [10–15] in the mode of an uncontrollable discharge of the storage capacitor.

An increase in laser pulse duration is also observed under variation of the working vapour density. This is most pronounced on turning on/off the heating of the containers with copper bromide. Figure 4 shows the oscilloscope traces for two laser operation modes: stationary and short-time (transient) modes. Use was made of the mode involving current limitation with a tacitron (without bridge B). The tacitron operated in a self-breakdown mode, and no control pulse was applied to the grid. On going over to the transient mode (Fig. 4a), the duration of the output pulse increases significantly (up to 300 ns), which is accompanied with a lengthening of the leading edge of the voltage pulse. This may be attributed to a slower discharge development in the GDT and the consequential later self-breakdown of the tacitron connected in series with the GDT.

Figure 5 shows the oscilloscope traces for the GDT of diameter 12, 25 and 50 mm. The oscilloscope traces in Figs 5a–5c were recorded in the tacitron-controlled mode (without bridge B). One can see that the use of the current limitation mode makes it possible to additionally increase the dura-

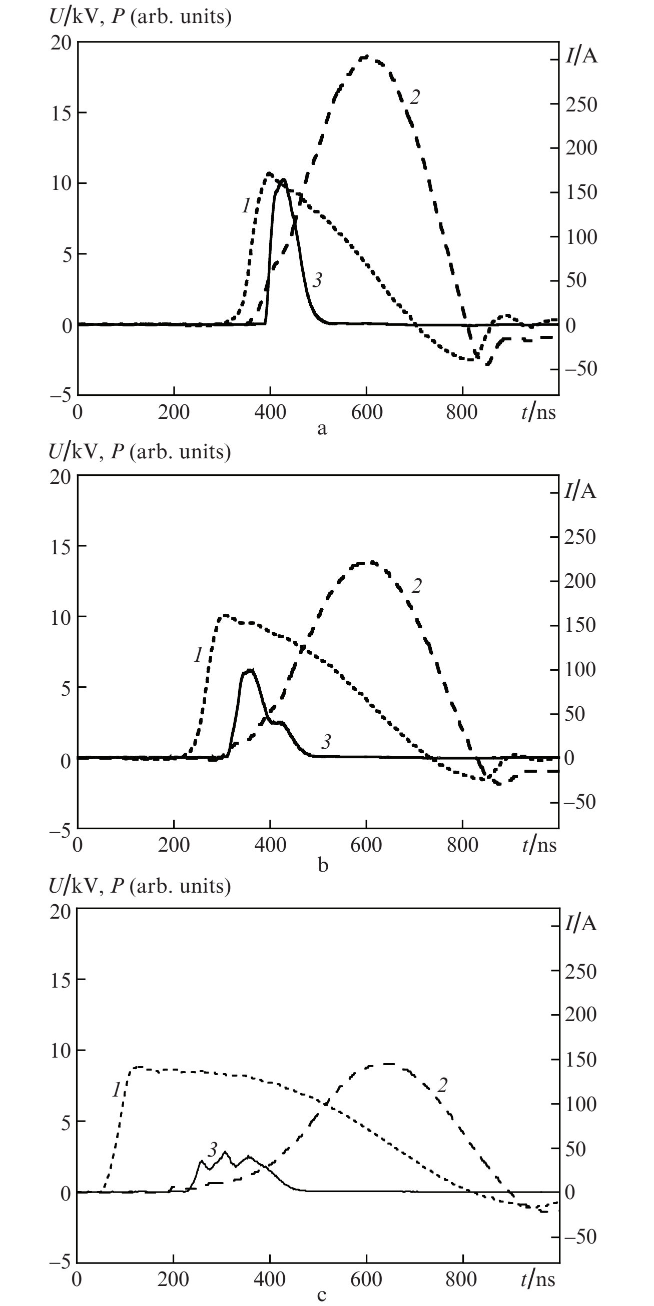

Figure 3. Oscilloscope traces of the pulses of the voltage across (*1*) the GDT, (*2*) the GDT current and (*3*) lasing for a PRF of (a) 4.5, (b) 3.5 and (c) 2.0 kHz for tubes 25 mm in diameter. The average output power corresponding to Fig. 3a is equal to 220 mW.

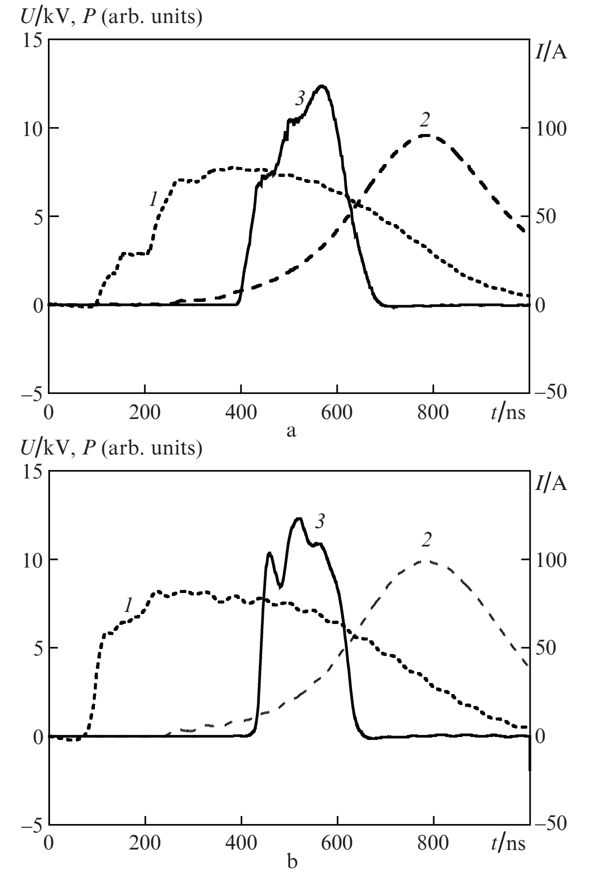

Figure 4. Oscilloscope traces of (*1*) the voltage, (*2*) current and (*3*) laser pulses in (a) the transient and (b) stationary laser operating modes for a PRF of 2.2 kHz and a GDT 25 mm in diameter.

tion of laser pulses (Fig. 2). Specifically, for the GDT 50 mm in diameter the laser pulse duration lengthened from 260 ns in the ordinary excitation mode (Fig. 5d) to 320 ns with current limitation (Fig. 5c). A strong suppression of the tacitron gives rise to the effect of 'split' lasing (Fig. 5b), when lasing is almost quenched at the instant of tacitron suppression and resumes as the current builds up. The control mode is characterised by a significant reduction of the voltage across the GDT.

4. Conclusions

The data presented in our work demonstrate the realistic possibility of generating laser pulses longer than 300 ns by using the self-terminating transitions in metal vapour lasers, in particular in copper vapour and copper bromide vapour lasers.

In medium- and large-diameter tubes, the duration of laser pulses increases without recourse to special techniques when operating at PRFs (2–4 kHz), which are relatively low for metal halide vapour lasers.

The technique of discharge current limitation with the use of a compound switch comprising pulsed hydrogen thyratron and tacitron makes it possible to limit the pumping rate of the upper working levels at the initial stage of discharge development and to lengthen the population inversion lifetime.

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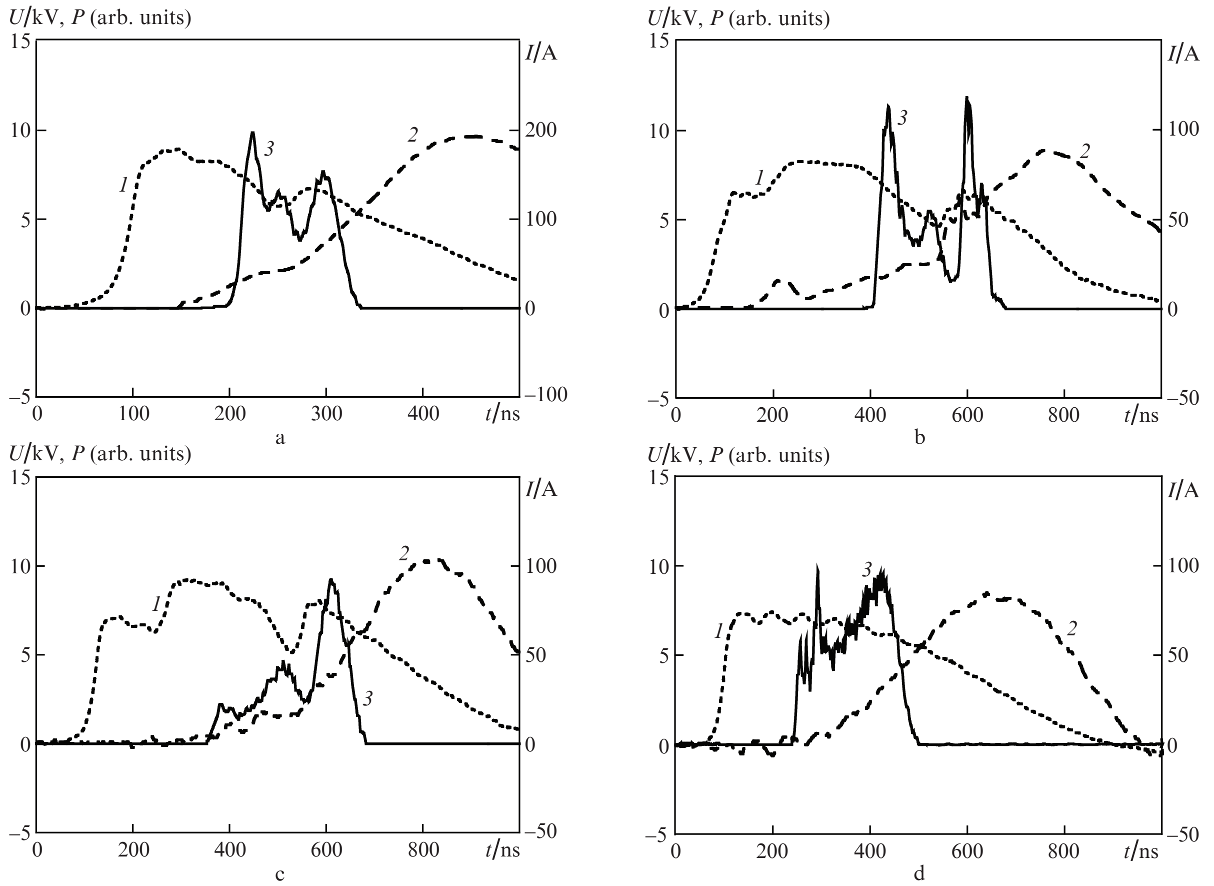

Figure 5. Oscilloscope traces of the pulses of the voltage across (*1*) the GDT, (*2*) the GDT current and (*3*) lasing for tubes (a) 12, (b) 25 and (c, d) 50 mm in diameter for modes (a – c) with and (d) without current limitation.

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