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Control of an average output power of a CuBr laser

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Abstract. **We have studied the pump parameters of a CuBr laser (pulse repetition rate of 14 kHz) with an independent heating of the active medium and an additional excitation source, providing an operational control of the radiation parameters in a given time interval. We have fabricated an experimental setup that makes it possible to change the average output power by applying a control pulse which is ahead of the main pulse by 0.12 – 20 μs. It is shown that to ensure the effective control of the laser power, the voltage amplitude of the additional excitation pulse should be within 12 % – 28 % of the main pulse amplitude. In this case, the proposed control regime allows a 2.5-fold decrease in the time delay between the control and main excitation pulses due to a higher energy of the additional pulse compared to self-heating regime of the laser operation.**

Keywords: *gas-discharge CuBr laser, average output power, additional and main excitation pulses.*

1. Introduction

Microprocessing of materials by metal vapour lasers (MVLs) requires control of the radiation parameters for each individual laser pulse. Therefore, the problem of operational and accurate control of these parameters is still relevant. The authors of [1 – 3] proposed and implemented the methods of operational control of MVL characteristics by employing additional excitation pulses. The control mechanism involves the effect of additional pulses on the concentration of metal atoms at the lower laser level. In this case, the effect can be manifested both in the population and in the population relaxation of the lower working level after the passage of an additional excitation pulse [1, 4]. With this control, the energy input into the discharge remains constant, no matter whether the generation takes place or not. Note that the authors of papers [1 – 3] studied the pure metal vapour lasers operating in the self-heating regime. In this paper, studies were performed using a copper bromide vapour laser. This laser is characterised by good energy characteristics and a simple technology for manufacturing the active element in comparison with a pure copper vapour laser. Use of active impurities (H_2, HBr) in the working mixture ensures an output power and lifetime of the active element, corresponding to such practical applications as atmosphere probing and accurate processing of materials for electronics and medicine. Moreover, the low working temperature of the active volume allows one to employ external heating of the working area of the gas discharge tube (GDT) [5]. Temperature control of the active volume by an independent power source creates conditions for laser operation with low powers deposited into the discharge at relatively large working volumes of the active element.

The paper is devoted to elucidation of the operation characteristics of a copper bromide vapour laser with an external heater, depending on the parameters of an additional excitation pulse and the regime of its switching on.

2. Experimental

In the experiments we used an active element with an external heater, similar to that described in [6]. The GDT was made of optical quartz with an inner diameter of 38 mm and a wall thickness of 2 mm. The length of the active zone was equal to 900 mm. The electrical block diagram of the CuBr-laser excitation is shown in Fig. 1. The laser had a plane-parallel resonator (*9*). The heating element (*12*) maintained the specified temperature of the GDT wall (*11*) by using a heat stabiliser

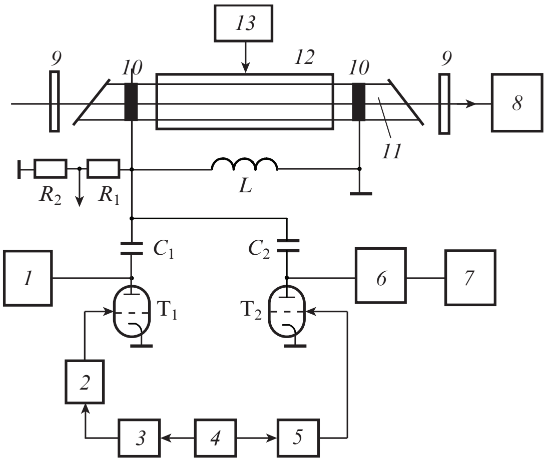

Figure 1. Electrical block diagram of the experimental setup: (*1*) and (*6*) main and additional high-voltage pulsed power supplies; (*2*) and (*5*) generators triggering main and additional thyratrons T_1 and T_2 (TGI1-1000/25); (*3*) scheme of the delay between the main and additional excitation pulses; (*4*) trigger pulse generator; (*7*) voltage regulator of additional excitation pulses; (*8*) IMO-2N power meter; (*9*) plane-parallel mirror resonator; (*10*) electrodes; (*11*) GDT; (*12*) heating element; (*13*) heat stabiliser; $L = 300$ μH is the charging inductance; $C_1 = 2.2$ nF and $C_2 = 3.3$ nF are the working capacitors.

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(*13*). The excitation circuit consisted of the main (*1*) and additional (*6*) high-voltage pulsed power supplies, a trigger pulse generator (*4*), thyratrons T_1 and T_2, the delay circuit of the main excitation pulses (*3*), the charging inductance L and working capacitors C_1 and C_2. The pulse-periodic discharge was implemented at a pulse repetition rate of 14 kHz between the electrodes (*10*). The buffer gas pressure (neon) was 51 Torr.

The laser operated as follows. The working capacitor C_1 was charged from the pulsed high-voltage power supply (*1*) and the capacitor C_2 – from the controlled pulsed additional power supply (*6*). The capacitors were charged through the charging inductance L. The trigger pulse generator (*4*) included a thyratron T_2, which produced an additional excitation pulse with adjustable amplitude on the electrodes of the GDT (*11*). The parallel generator (*4*) through the delay circuit (*3*) triggered the thyratron T_1 which produced the main high-voltage excitation pulse with an amplitude of 6 kV in the laser GDT. The delay circuit made it possible to adjust the delay time t_d between the main and additional excitation pulses in the range 0.05–20 μs. The voltage regulator (*7*) of the additional excitation source (*6*) provided additional variation of the amplitude of excitation pulses on the electrodes of the laser GDT from 0.6 to 2 kV, when the main pulse was ahead of the excitation pulses by 0.05–20 μs. The change in the control pulse characteristics and the time of its switching on within the specified limits had no effect on the main pulse parameters. We measured the average output power with an IMO-2N calorimeter. The amplitude-time characteristics of the additional and main excitation pulses were measured with a Tektronix TDS 3032 oscilloscope from a Tektronix R6015A voltage divider. The power of the main power supply was 1 kW, and that of the additional supply – 0.3 kW.

3. Experimental results and discussion

We investigated the control of an average output power of a CuBr laser at a constant power of excitation pulses and a pulse repetition rate of 14 kHz. The IMO-2N calorimeter measured the total average output power of 1 W at wavelengths λ = 510.6 and 578.2 nm. Figure 2 shows the oscillograms of the additional excitation pulse with an adjustable amplitude U_a and of the main pulse with an amplitude of ~6 kV at a 3.2-μs time delay between them.

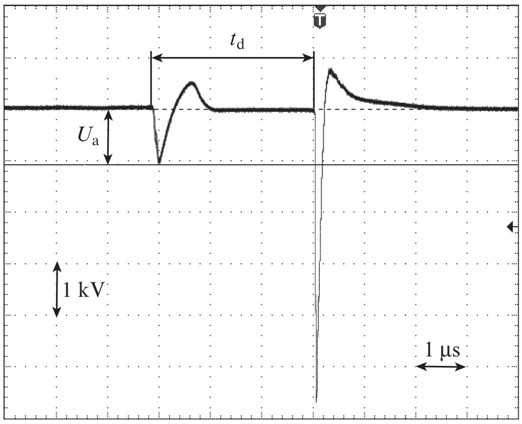

Figure 2. Oscillograms of the additional excitation pulse with the amplitude U_a and main excitation pulse at a constant amplitude with a changing time delay t_d between the main and additional pulses.

Figure 3 shows the typical dependences of the average output power on the adjustable amplitude of the additional excitation pulse U_a on the GDT electrodes at different time delays t_d. The first experiments showed that the average output power was affected both by the amplitude U_a and by the time delay t_d; however, at $U_a \leqslant 0.7$ kV such effects were absent. In addition, the average output power decreased rapidly at $t_d < 1$ μs in the case of smaller amplitudes U_a.

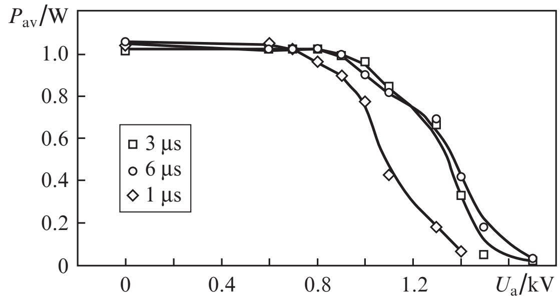

Figure 3. Dependences of the average output power P_{av} on the voltage amplitude U_a of the additional excitation pulse at different time delays t_d.

Figure 4 presents the dependences of the average output power P_{av} on the time delay t_d between the additional and main excitation pulses and the voltage amplitude U_a of the additional excitation pulse. These dependences have five specific time points: the point $t_d = 0.12$ μs when the initial average output power was determined by a given amplitude U_a; the point $t_d = 0.4$ μs, corresponding to the minimum time of a decrease in P_{av} to the minimum value for the given amplitudes U_a; the point $t_d = 3-6$ μs, corresponding to the recovery time of P_{av} to the maximum possible value; the point $t_d = 10$ μs (the lifetime of the metastable laser level), corresponding to the second decrease in P_{av} by a small value; and the point $t_d = 20$ μs, corresponding to a reasonable recovery time of P_{av} up to a possible achievable value.

For the time delay 0.12 μs, the average output power rapidly decreased with increasing amplitude of the additional excitation pulse and reached a minimum value of 0.2 W at $U_a = 1.5$ kV. Lasing was absent at $U_a = 1.7$ kV, and appeared

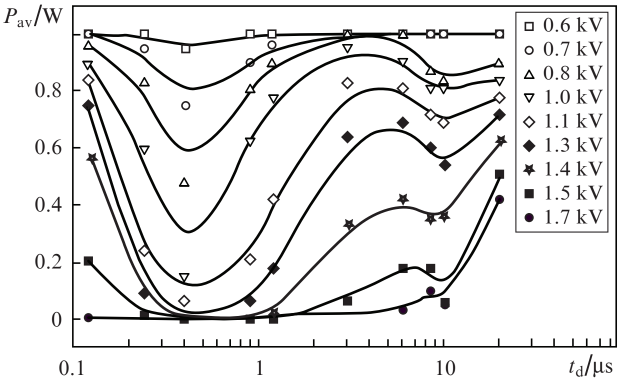

Figure 4. Dependences of the average output power P_{av} on the time delay t_d between the additional and main excitation pulses at different voltage amplitudes U_a.

again at $t_d > 3$ µs. At $t_d > 0.12$ µs, the average output power sharply decreased and reached a minimum value at $t_d = 0.4$ µs, independently of the amplitude U_a. Thus, regardless of the voltage amplitude of the additional excitation pulse, at a time delay changing from 0.05 to 0.4 µs the average output power rapidly decreased to a minimum value, and then with a further increase in the delay time slowly increased. A rapid decrease in the average output power for $t_d < 0.4$ µs illustrates well the process of population of the metastable level of the active medium of the CuBr laser, and a slow increase in the average power at $t_d \geqslant 0.4$ µs is probably due to the relaxation of the population of the lower working level after the passage of an additional pulse excitation [4]. For the additional pulse amplitudes of 0.6 and 0.7 kW, the average output power decreased from 0.95 and 0.75 W at the time delay $t_d = 0.4$ µs, and then with increasing t_d to 3 µs, it was recovered to its initial value (1 W). In other cases, with increasing amplitude U_a the maximum decrease in the average output power was also achieved at $t_d = 0.4$ µs, and at long delays (3–6 µs) it increased to its maximum value. In this case, when the delay time was increased up to 20 µs, the average output power was still lower than its initial value.

To effectively control an average output power, the optimal are the laser operation regimes with the amplitude of the additional excitation pulse from 0.7 to 1.4 kV at time delays of up to 3 µs. In this case, the proposed control regime allowed a 2.5-fold decrease in the delay time between the control and main excitation pulses due to a higher energy of the additional pulse, compared to self-heating regime the laser operation [1]. This meant that the average output power in our case was reduced to zero within 0.4 µs, and in the self-heating regime – within 1 µs. Thus, depending on the practical application of the laser one can select the required time regime of changes in the average output power. The amplitude of the additional excitation pulses was 12%–28% of the amplitude of the main pulse.

4. Conclusions

Studying the CuBr laser with an independently heated GDT and an additional excitation pulse, we have found the optimal regimes of operational control of an average output power by changing the amplitude and time delay between the additional and main excitation pulses. We have shown that the optimal control of the average output power requires the voltage amplitude of the additional pulse to be 12%–28% of the amplitude of the main pulse. We have determined the characteristic time delays $t_d = 0.4$ and 10 µs, which may correspond to the minimum average output power generated by the CuBr laser. It is shown that a rapid decrease in the average output power was observed at $t_d \leqslant 0.4$ µs, and its increase – at $0.4 < t_d \leqslant 3$ µs. The proposed regime of laser operation allowed a 2.5-fold decrease in the delay time between the control and main excitation pulses due to a higher energy of the excitation pulse as compared to the self-heating regime of the laser operation.

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