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CuBr + Ne + HBr-laser with submicrosecond delay between generation pulses

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The results of development and implementation of CuBr + Ne + HBr-laser that generates a sequence of two pulses with a delay of less than 100 ns are presented. For this purpose an excitation system was developed that provides for the generation of a sequence of excitation pulses with the adjustable time and energy parameters. The possibility of obtaining the radiation pulses of the same amplitude was demonstrated experimentally. The dependence was established between the amplitude of each radiation pulse and the ratio of the excitation pulse energies.

Keywords: CuBr-laser, excitation source, high voltage modulator, time delay, atypical mode.

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Currently the development of the lasers based on self-limited transitions in metal pairs is concentrated on the improvement of efficiency of their excitation and frequency-energy characteristics, and also on the expansion of practical use in various fields of science, technology and medicine [1]. The main areas providing for the solution of the specified objectives may be divided into modification of the modes of operation of the active medium (optimization of plasma processes kinetics) [2,3] and modification of excitation pulse parameters (optimization of pumping pulse parameters) [4]. In particular, paper [5] shows the possibility to improve the frequency-energy characteristics with the variation of the speed of voltage pulse growth at a gas-discharge tube (GDT). Besides, the change in the excitation pulse parameters makes it possible to control the radiation characteristics by using an additional pulse — so called preionization pulse [6]. Such approach may be especially effective for the media on the metal halide vapors, which was also demonstrated in some papers. In particular, it was shown that at the expense of introducing an additional excitation pulse it was possible to control the energy, timé and spatial parameters of generation [7], and also vary the duration of the radiation pulse [8].

This paper presents the results of development and testing of the method to generate the radiation pulses of the CuBr-laser with a delay of less than 100 ns. Such generation mode is interesting from the fundamental point of view and from the point of view of laser imaging systems development. Implementation of this mode is possible due to modification of the active medium operation parameters and due to use of a special excitation system [9,10].

For the experimental study, an active element was made on vapors of copper bromide with the following parameters: length of the active zone 90 cm, diameter 5 cm, pressure of buffer gas (Ne) was 30 Torr. Measurement of the electrical characteristics of discharge was carried out using a current sensor Pearson Current Monitor 8450, a voltage sensor Tektronix P6015A and an oscilloscope LeCroy WJ-324. To generate the excitation pulses, thyratrons TGI1-1000/25 were used. To record the radiation pulses, coaxial solar cells (CSC 22-SPU-M) were used.

The diagram of the experimental setup that explains the principle of operation is shown in Fig. 1. It consists of GDT, the excitation system and system of operation parameters registration. For simplification, the measuring elements are not given in the figure. The following designations are introduced in the figure: PS1, PS2 — power supply sources; CU1, CU2 — control units; HV1, HV2 — high voltage generators; $C1$, $C2$ — accumulating reservoirs; VL1, VL2 — high voltage switchboards; $L1$ — charging inductance; $R1$ — ballast resistance; PC — personal computer; CB — control board; HVM — high voltage modulator; GDT — gas-discharge tube; CuBr — copper bromide powder; HBr — hydrogen-containing additive; H_{GDT} — active volume furnace; H_{CuBr} — heating element of copper bromide; H_{HBr} — heating element of the hydrogen-containing additive, M — mirror; STM — semi-transparent mirror; PM — power meter. A key feature of the high voltage modulator is the possibility to adjust the time shift between the start pulse of gas-discharge switchboards (VL1, VL2) in a nanosecond range. Using PC and CB, the main units of the excitation system are controlled.

The mode of operation of the active element was selected so that the maximum average power of generation was provided at the operation of only PS1. In this case the wall temperature was 870 °C, the temperature of containers with copper bromide — 515 °C, and temperature of HBr generator — 160 °C. Use of the hydrogencontaining additive is the necessary condition to improve the GDT impedance. PS1 makes it possible to implement the repetitively-pulsed

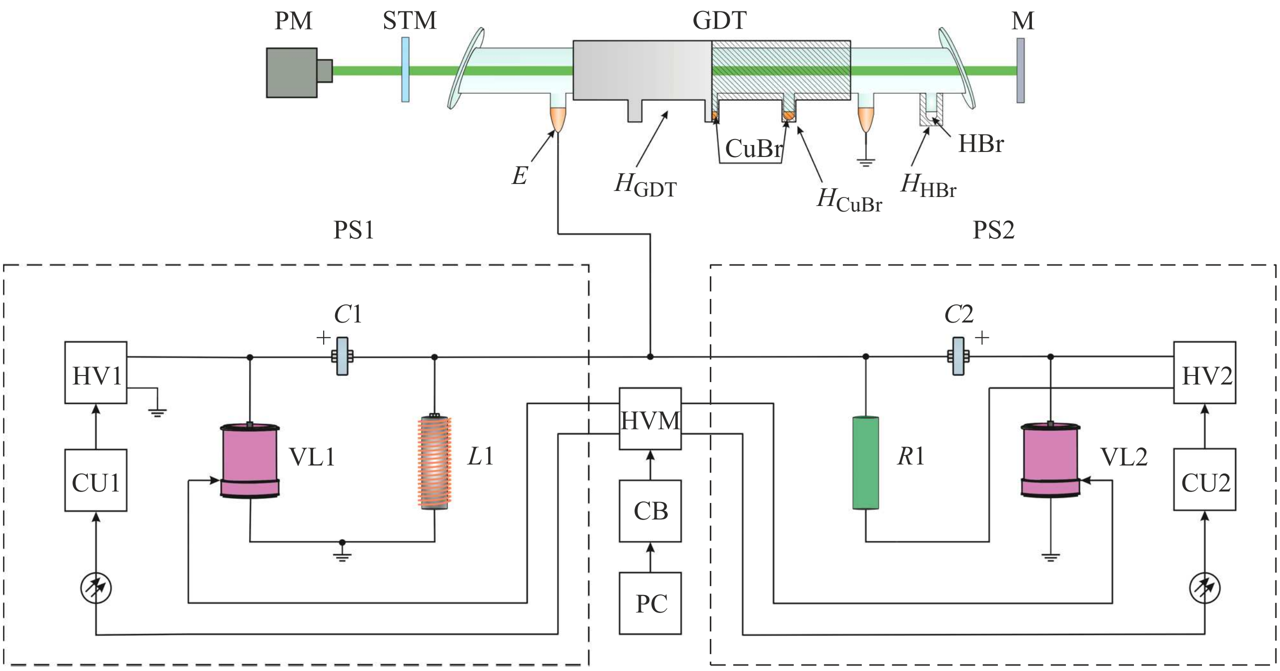

Figure 1. Diagram of the experimental set-up.

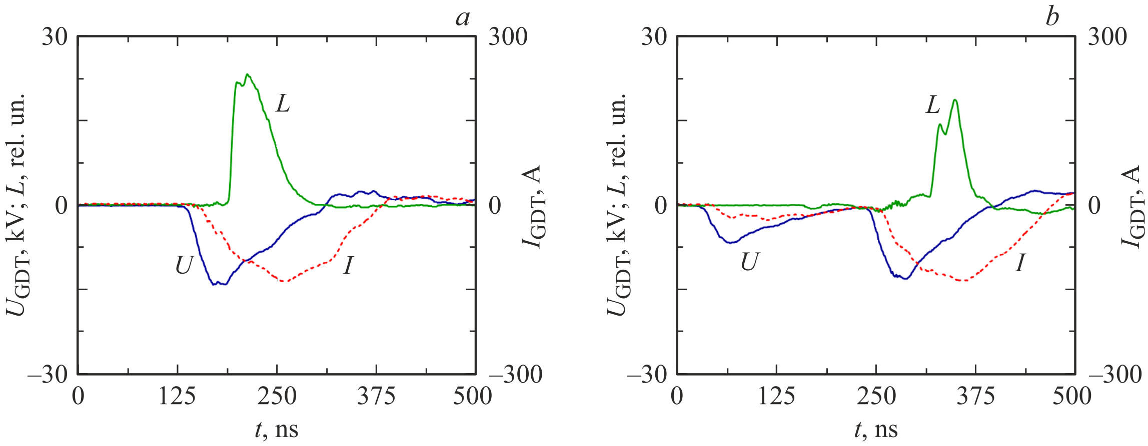

Figure 2. Pumping and generation pulses. See explanation in the text.

mode of operation of the studied active medium on copper bromide vapors. Pumping power (P_{ext}) from PS1 was approximately 1.8 kW, and the pulse repetition rate was $f = 11.85$ kHz. The power of generation in the repetitively-pulsed mode, in the specified mode of operation of PS1, which did not change for the entire experiment, was 10 W. Fig. 2, *a* presents the voltage (U) and current (I) pulses through the GDT, and also the generation pulse (L) in the moment of presence of the pulse from PS2. PS2 generates a pre-ionization pulse with the same f as PS1 (11.85 kHz), as a result of which the generation pulse energy reduces (Fig. 2, *b*), and at a certain ratio of pre-ionization pulse amplitude from PS2 and excitation from PS1 the generation may be fully suppressed. For example, at the amplitude of the excitation pulse 15 kV it will be sufficient to generate a pre-ionization pulse with the amplitude of 9 kV with a pause between pulses of 230 ns, in order to fully suppress the generation, i. e. the amplitude of the pre-ionization pulse is approximately 30 % less than the amplitude of the excitation pulses (it should be underlined that this value is not constant and depends on the duration of the pause between the voltage pulses). This dependence is caused by the population of the metastable level of active substance (copper) atoms.

In process of the experimental studies an atypical mode of operation of the considered active medium was found: when the duration of the pause between the pre-ionization pulse and the excitation pulse is less than 300 ns, and also at a certain level of power of PS2 another additional radiation pulse is generated before the main generation pulse. We

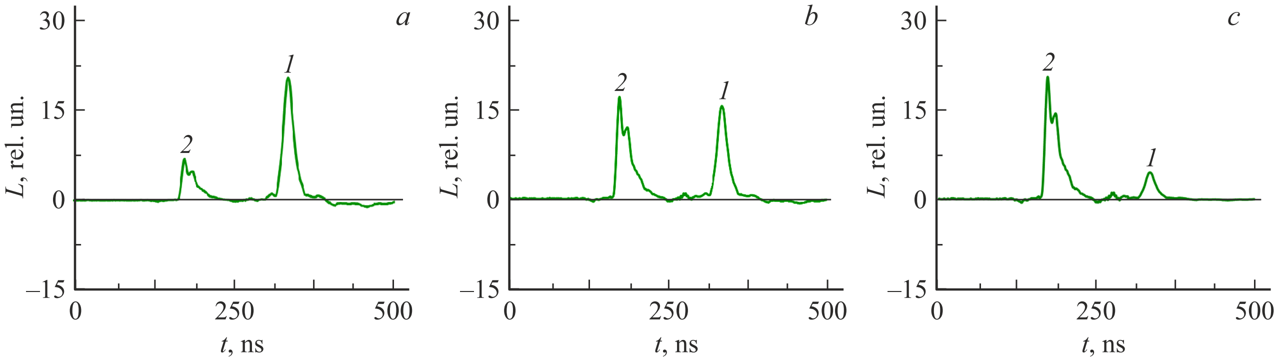

Figure 3. Generation pulses (L) in the mode of doubled pulses at different level of voltage and, accordingly, the power of the additional source of power supply (PS2). a — P_1, b — P_2, c — P_3.

will further call this pause a time delay t_d, and the found atypical mode will be called by a mode of double pulses.

Fig. 3 presents the generation pulses at fixed time delay t_d and different energy of the pulse generated by the PS2 source. The generation pulse *1* is formed by operation of the main source of power supply (PS1), and the generation pulse *2* — due to the additional source of power supply (PS2). You can see that the ratio of the generation pulse amplitudes depends on the parameters of the pre-ionization pulse of the additional excitation source PS2 (at the constant level of power of PS1). If in this case the power of PS2 is indicated as $P1$, $P2$ and $P3$ for the three given cases, respectively, it would be fair to write that $P1 < P2 < P3$. The experimental studies have shown that as time delay t_d decreases, it is necessary to increase the power PS2 to generate an additional generation pulse with the amplitude equal to the amplitude of the main generation pulse. The power of PS2 varied from 200 to 500 W.

Further the dependence was established between the ratio of the generation radiation power P' in the mode of doubled pulses and generation power P_G in the repetitively-pulsed mode depending on the time delay t_d. We will designate this ratio as η and call it the conversion coefficient (Fig. 4):

$$\eta = \frac{P'}{P_G}.$$

The paper for the first time demonstrated the ability to form the pulses of generation with the same amplitude and time delay of less than 100 ns. For these purposes the excitation system was developed, and the excitation pulse parameters were defined, which provide for the specified generation mode.

It is known that the specific time of relaxation of the lower (metastable) level of copper atom is units-tens of microseconds. This is exactly the fact that to a large extent limits the limit repetition rates of the generation pulses in this medium. In our experiments we demonstrated that at a certain excitation mode it is possible to achieve the generation with a delay of up to 72 ns, which corresponds to frequency of ~ 14 MHz. Let us highlight that this mode is not typical (repetitively-pulsed). We believe that within the first pulse the inversion is partially cleared (probably, not in the entire volume of the active medium). The second pulse provides for additional excitation, which creates inversion and formation of the second generation pulse. The similar effect was described in the experimental paper [11], the authors of which observed the formation of the copper laser generation pulse sequence with a delay of around 220 ns. In our experiments we also recorded the fact that the generation of the first and second pulses is observed in different parts of the GDT volume. It is also shown experimentally that it is possible to implement the mode, where the amplitudes of the pulses (the first and the second) will be the same. The dependence was studied between the ratio of the radiation power P' in the mode of doubled pulses and generation power P_G in the repetitively-pulsed mode depending on the time delay t_d. Further direction of the papers will be related to the study of the process kinetics in the active medium.

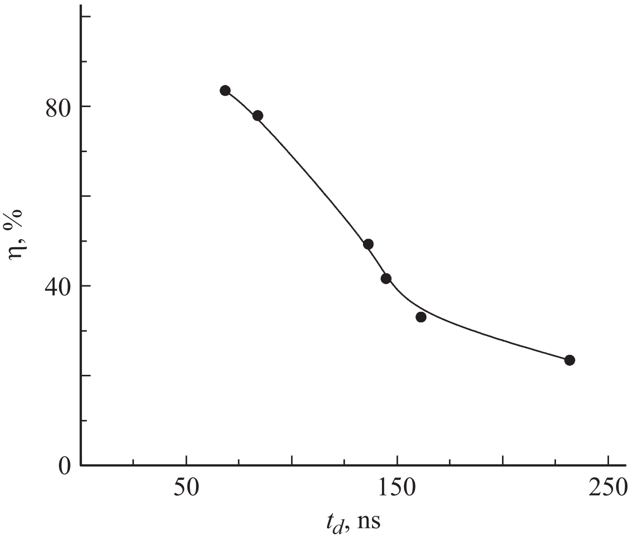

Figure 4. Dependence of conversion coefficient η on time delay t_d.

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Conflict of interest

The authors declare that they have no conflict of interest.

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