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A copper bromide vapour laser with a high pulse repetition rate

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***Abstract*. The results of an experimental study of a copper bromide vapour laser with a discharge-channel diameter above 2.5 cm and a high pump-pulse repetition rate are presented. A TGU1-1000/25 high-power tacitron used as a switch made it possible to obtain for the first time a fairly high output radiation power for pump-pulse repetition rates exceeding 200 kHz. At a maximum pump-pulse repetition rate of 250 kHz achieved in a laser tube 2.6 cm in diameter and 76 cm long, the output power was 1.5 W. The output powers of 3 and 10.5 W were reached for pump-pulse repetition rates of 200 and 100 kHz, respectively. These characteristics were obtained without circulating a buffer gas and (or) low-concentration active impurities through the active volume.**

Keywords: *metal halide vapour lasers, output characteristics, repetitively pulsed laser.*

1. Introduction

Repetitively pulsed copper vapour and copper halide vapour lasers (CVLs and CHVLs, respectively), which are capable of producing output powers of tens and hundreds of watts at pulse repetition rates of up to tens of kilohertz, are widely used in industry, medicine, and research [1 – 5]. However, at present, stable lasers of this type operating at pulse repetition rates above 100 kHz with a high mean power attract increasing attention as a possible tool in studies of fast processes, applications in high-speed data-recording optoelectronic systems, atmospheric remote sensing, etc.

Unfortunately, to date, high pulse repetition rates have been achieved only in small-diameter gas-discharge tubes (GDTs), which can provide only low output powers. For example, the maximum pulse repetition rates are 235 kHz in CVLs [6] and 300 kHz in CHVLs [7], when GDTs with diameters of 0.8 and 1.5 cm, respectively, are used. The mean output power in this case is no higher than a few tens of milliwatts. In addition, the information on the service life of CVLs and CHVLs operating at high pulse repetition rates is virtually absent. Note that the main mechanism that limits the pulse repetition rate in metal vapour lasers and metal-compound vapour lasers has not been clarified. Discussions on this subject are still in progress (e.g., [8 – 13]). However, model estimates performed by the method of double pulses have shown that pulse repetition rates $f = 50 - 100$ kHz can be obtained in CVLs [9] and CHVLs [14].

It was shown in [7] that the specific pump power of a CHVL was 3 – 5 times lower than that for a CVL of similar dimensions. Since the relaxation times of the main plasma parameters in a CHVL are shorter than in a CVL [15], the optimum (and maximum) pulse repetition rates in a CHVL should be higher. Admixtures of hydrogen H_2 in small amounts can additionally increase the maximum attainable pulse repetition rate and output power for GDTs not only of small but also of medium diameters (above 2 cm). Analysis of the works devoted to the study of CuBr lasers doped with H_2 [16], hybrid lasers [17], and CVLs with improved kinetics [18, 19], in which the working medium has a composition similar to that of a $CuBr - H_2$ laser, confirms this assumption. The highest output characteristics (the efficiency, the mean and specific output powers) were obtained in lasers of these two types.

The authors of paper [7] obtained an output power of 4.8 W at $f = 100$ kHz in a CuBr laser with a GDT of a medium diameter of 2 cm and 80-cm long without specially added H_2. The maximum pulse repetition rate was 160 kHz. This rate was limited by a TGU1-5/12 tacitron used as a switch. In one of the recent works [19] devoted to the study of the pulse repetition rates of CVLs with an improved kinetics (using the three-stage magnetic compression of the pump pulse), the output power obtained in a GDT 2.5 cm in diameter and 61-cm long was 9 W at $f = 100$ kHz. At the same time, our studies of the pulse repetition rates of a CuBr laser [14] with a GDT 2.5 cm in diameter and 80-cm long, which were performed in a regime of double pump pulses with a repetition rate of up to 30 kHz, show that the pulse repetition rate can exceed 500 kHz.

The aim of this work was, using a high-frequency TGU1-1000/25 switch with a higher power, to perform a regular pumping of a CuBr laser at pulse repetition rates above 100 kHz, to study the behaviour of energy parameters in the presence of small additions of hydrogen, and to determine the maximum achievable pulse repetition rates in this laser with a GDT diameter exceeding 2 cm.

2. Experimental technique and results

To study the maximum pulse repetition rates that can be achieved in $CuBr - H_2$ lasers of medium dimensions (with GDT diameters above 2 cm), we manufactured a laser tube

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of a special design 2.6 cm in diameter with a 76-cm distance between the electrodes, which is a self-heating GDT described in [20]. This GDT was additionally equipped with a heat-insulating screen and a device for controlling the GDT temperature and maintaining it at level providing a stable output power in a steady-state laser operation regime.

The active medium was excited according to the scheme used in [7], i.e., the scheme of direct discharge of the storage capacitor (KVI-3) through the GDT with the help of a high-power TGU1-1000/25 tacitron. The discharge circuit and the pump pulse characteristics were not specially optimised. The main switch was triggered from a modulator unit based on a TGU1-5/12 tacitron. The latter was initiated by a transistor submodulator and a G5-27A pulse generator. The current, voltage, and lasing pulses were measured with a Rogowski loop, a low-inductance TVO resistor divider, and an FK-22 coaxial photocell, respectively. Spectrally pure neon at a pressure of 30 – 50 Torr was used as a buffer gas. Hydrogen at a pressure of 0.2 – 0.5 Torr was added to the active medium.

The experimental procedure was as follows. First, the energy characteristics of the $CuBr - H_2$ laser were measured at a standard pulse repetition rate $f = 10$ kHz. Then, the rate increased up to 80 kHz with a step of 10 kHz, and above 80 kHz, the step was 20 kHz. The GDT was turned on independently at each new pulse repetition rate, the tube was driven to a steady-state operation regime, and the current, voltage, and radiation pulses were recorded. As f increased, the working capacitance C_w was gradually reduced in order to maintain a constant energy input to the GDT.

The experimental results showed that the maximum pump-pulse repetition rate of the laser provided by the switch was 250 kHz (Fig. 1). The mean output power P_g at this rate was 1.5 W, and at $f = 200$ kHz, the output power was 3 W. The range of optimal pulse repetition rates (at which the maximum output power was achieved) was 40 – 100 kHz, and, as the pulse repetition rate was increased, the output power slowly decreased. Preliminary GDT service-life tests were performed at $f = 100$ kHz. The output power was maintained at a level of 10 W for several tens of hours, and the maximum value of P_g at this rate was 10.5 W.

In earlier studies of CuBr lasers without controled H_2 admixtures [21], the maximum output power was achieved at $f = 16 - 20$ kHz, and, it decreased at higher pulse repetition rates. As is demonstrated by the results of this and other works devoted to $CuBr - H_2$ lasers [22], CVLs with improved kinetics [18, 19], and studies of a hybrid BrID laser [17], H_2 admixtures lead to a shift of the optimum pulse repetition rate of GDTs of not only small diameters to the region of higher rates. In recent works, this effect was qualitatively explained [12] by the formation and presence of electronegative molecules (HBr, HCl) in the active media of these lasers. These molecules have large cross sections for dissociative attachment of electrons, enhancing the plasma bulk recombination rate.

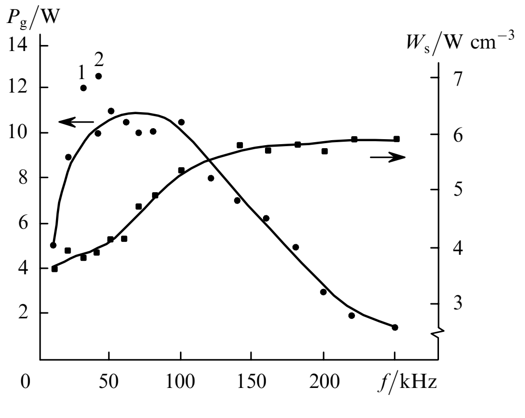

Figure 1. Output power P_g and specific pump power W_s deposited to the discharge as functions of the pump-pulse repetition rate f at $p_{Ne} = 30$ Torr and $p_{H_2} = 0.3$ Torr.

In our experiment, the maximum lasing efficiency (calculated with respect to the electric power consumed from the rectifier) was 0.7 % at $f = 50$ kHz and $P_g = 11$ W. This comparatively low efficiency is explained by the fact that, as was already mentioned, the exciting circuit was not additionally optimised. Also note that the output powers P_g obtained are not maximum for the given pulse repetition rates and correspond to stationary thermal conditions of the laser operation. Moreover, selecting an optimal proportion of added gases (neon – hydrogen) was a difficult problem. As a result, the curves presented in Fig. 1 correspond to added hydrogen in a concentration somewhat different from the optimal value. A slight increase in the amount of hydrogen in the mixture at $f = 30$ and 40 kHz has led to a rise in the output power up to 12 and 12.5 W, respectively, and an increase in the efficiency up to 0.8 %. These values are marked as points 1 and 2 in Fig. 1.

Apart from the dependence of the mean output power P_g on the pump-pulse repetition rate f, Fig. 1 also shows the specific pump power W_s deposited to the discharge unit volume as a function of f. When calculating (or, more correctly, evaluating) W_s, the entire volume of the active medium between the electrodes was taken for the working volume (the contraction region was neglected). As f changed (especially, at $f > 100$ kHz), the power W_s was maintained at an approximately constant level for the GDT temperature conditions to be stationary. Comparing the values of W_s in Fig. 1 to those obtained earlier in CVLs with GDTs of similar dimensions shows that, due to lower operating temperatures in the CHVL under study, its pump powers W_s are an order of magnitude lower than W_s in CVLs.

Fig. 2 shows oscillograms of the current, voltage, and lasing pulses for various pulse repetition rates f. One can see that, up to a pump-pulse repetition rate of 150 kHz, the lasing pulse P_0 coincides with the peak of the voltage pulse U_{max}. With a further increase in f, a delay of P_0 with respect to U_{max} is observed. However, in contrast to CVLs in which, with an appropriate increase in f, the lasing is initiated at the trailing edge of the pump pulse (far from its peak) [6], the $CuBr - H_2$ lasing occurs close to U_{max}. Typical current and voltage (across the working capacitor) values at $f = 100 - 200$ kHz are 150 – 80 A and 9 – 7 kV, respectively.

Comparing the output characteristics of the $CuBr - H_2$ laser without a buffer gas circulation to those of a CVL with an improved kinetics [19] of the same volume shows that their output powers at $f = 100$ kHz are 10.5 and 9 W, respectively. However, at pulse repetition rates of 20 – 50 kHz, the output power of the latter laser is four times higher than that of the $CuBr - H_2$ laser. This difference is explained by the fact that the laser described in [19] is a flow-gas laser, whose output power P_g is always higher, since its

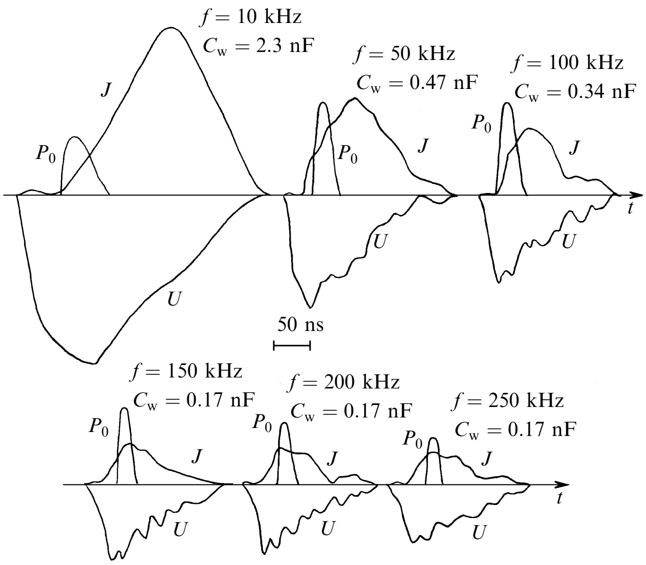

Figure 2. Oscillograms of the current J, voltage U, and lasing P_0 pulses for various pulse repetition rates f and working capacitors C_w.

working mixture is continuously renewed. Another possible reason for an increased P_g is that HBr and HCl admixtures are present in flow-gas lasers in a 'pure' form, leading to a more rapid plasma relaxation during the interval between pulses. Note also that different pump schemes used in [19] and in this work were optimised to different pulse repetition rates.

It was found in the experiments that the laser beam diameter decreased by a factor of two at pump-pulse repetition rates of 200–250 kHz, and the energy losses in the tacitron significantly increased at 250 kHz. The power consumed from the rectifier increased by 900 W compared to that consumed at 10 kHz. Therefore, the limitations imposed on the pulse repetition rate are of technical rather than physical nature. The output powers obtained at high pulse repetition rates are not optimal and can be increased.

3. Conclusions

The tests of a CuBr – H_2 laser which uses a direct discharge of a storage capacitor through a gas-discharge tube and a TGU1-1000/25 tacitron as a switch made it possible to obtain for the first time a significant output power at pump-pulse repetition rates $f > 200$ kHz. At a maximum pump-pulse repetition rate of 250 kHz achieved in a laser tube 2.6 cm in diameter and 76-cm long, the output power was 1.5 W. The output powers at $f = 200$ and 100 kHz were 3 and 10.5 W, respectively. The above characteristics were obtained without circulating a buffer gas and/or low-concentration active impurities through the active volume. The highest possible pulse repetition rate was limited by the capabilities of the switch employed. The experimental results show that there is an actual possibility of further increasing the pulse repetition rate and output power of metal halide vapour lasers with large-volume active elements.

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References

1. Soldatov A.N., Solomonov V.I. *Gazorazryadnye lazery na samoogranichennykh perekhodakh v parakh metallov* (Self-Contained Metal Vapour Gas-Discharge Lasers) (Novosibirsk: Nauka, 1985).
2. Little C.E., Sabotinov N.V. (Eds) *Pulsed Metal Vapor Lasers* (New York: Kluwer Acad. Publ., 1996) Vol. 5.
3. Little C.E. *Metal Vapor Lasers: Physics, Engineering & Applications* (Chichester, UK: John Wiley & Sons, 1998).
4. Evtushenko G.S., Klimkin V.M. *Opt. Atmos. Okeana*, **12**, 875 (1999).
5. Webb C.E. *Proc. SPIE Int. Soc. Opt. Eng.*, **4184**, 183 (2001).
6. Soldatov A.N., Fedorov V.F. *Izv. Vyssh. Uchebn. Zaved., Ser. Fiz.* (9), 80 (1983).
7. Evtushenko G.S., Petrash G.G., Sukhanov V.B., Fedorov V.F. *Kvantovaya Elektron.*, **28**, 220 (1999) [*Quantum Electron.*, **29**, 775 (1999)].
8. Bokhan P.A., Silant'ev V.I., Solomonov V.I. *Kvantovaya Elektron.*, **7**, 1264 (1980) [*Sov. J. Quantum Electron.*, **10**, 724 (1980)].
9. Bokhan P.A., Zakrevskii D.E. *Zh. Tekh. Fiz.*, **67**, 54 (1997).
10. Yakovlenko S.I. *Kvantovaya Elektron.*, **30**, 501 (2000) [*Quantum Electron.*, **30**, 501 (2000)].
11. Isaev A.A., Mikhkel'soo V.T., Petrash G.G., Peet V.E., Ponomarev I.V., Treshchalov A.B. *Kvantovaya Elektron.*, **15**, 2510 (1988) [*Sov. J. Quantum Electron.*, **18**, 1577 (1988)].
12. Petrash G.G. *Preprint FIAN* (28) (Moscow, 1999).
13. Petrash G.G. *Kvantovaya Elektron.*, **31**, 407 (2001) [*Quantum Electron.*, **31**, 407 (2001)].
14. Shiyanov D.V., Evtushenko G.S., Fedorov V.F. *Opt. Atmos. Okeana*, **13**, 254 (2000).
15. Hogan G.P., Webb C.E., in *Pulsed Metal Vapor Lasers* (New York: Kluwer Acad. Publ., 1996) Vol. 5, p. 67.
16. Astadjov D.N., Dimitrov K.D., Jones D.R., Kirkov V.K., Little C.E., Sabotinov N.V., Vuchkov N.K. *IEEE J. Quantum Electron.*, **33**, 705 (1997).
17. Jones D.R., Maitland A., Little C.E. *IEEE J. Quantum Electron.*, **30**, 2385 (1994).
18. Withford M.J., Brown D.W., Piper J.A. *Opt. Lett.*, **23**, 1538 (1998).
19. Marshall G.D., Coutts D.W. *IEEE J. Selected Topics Quantum Electron.*, **6**, 623 (2000).
20. Sukhanov V.B., Evtushenko G.S., Shiyanov D.V., Chernyshev A.I. *Opt. Atmos. Okeana*, **13**, 1053 (2000).
21. Kazaryan M.A., Petrash G.G., Trofimov A.N. *Trudy FIAN*, **181**, 54 (1987).
22. Elaev V.F., Lyakh G.D., Pelenkov V.P. *Opt. Atmos. Okeana*, **2**, 1228 (1989).