Frequency characteristics of a CuBr laser

D.V. Shiyanov, G.S. Evtushenko, and V.F. Fedorov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received February 14, 2000

The frequency characteristics of a CuBr laser have been experimentally studied both in the regime of regular pulses emitted at a repetition frequency from several kilohertz to hundreds kilohertz and in the model regime of paired pulses emitted at a repetition frequency up to 30 kHz with a regulated time lag between pulses. The data obtained showed that the pulse repetition frequency as high as 500 kHz and even more can be achieved in a CuBr laser.

Introduction

Some practical applications of metal-vapor lasers, including atmospheric optics, require a high pulse repetition frequency.[1,2] Typical values of this frequency for metal-vapor lasers (MVL's) are from several kilohertz to several tens kilohertz. Some papers report obtaining the pulse repetition frequency higher than 50 kHz (see Refs. 3 and 4), and the frequency higher than 100 kHz was reported in only a few papers.[5–8] Discussion of the factors restricting the pulse repetition frequency was started by Petrash, Bokhan, et al.[9,10] and is now continuing.[3,4,11,12] Omitting the discussion of which of the factors is the decisive: high pre-pulse concentration of electrons or insufficient relaxation rate of metastable atoms, let us note that the characteristic relaxation time known in the literature for the electron and atomic components ranges from 10^{-5} to 10^{-6} s. Consequently, the limiting values of the pulse repetition frequency can achieve 100–1000 kHz. By the way, these authors in their first papers independently assumed, based on analysis of results obtained with the use of paired pulses, that the pulse repetition frequencies as high as ~100 kHz can be obtained in metal-vapor lasers.[13,14]

In our earlier paper[8] we noted that the CuBr laser possess better, as compared with pure Cu laser, frequency characteristics, what allows the pulse repetition frequency up to 300 kHz and probably even higher to be achieved. In this paper we study the limiting pump pulse repetition frequencies using the model pumping mode. The active medium of a CuBr laser was pumped by paired pulses with a regulated time lag between the two. The pulses were emitted with the pulse repetition frequency of 10–30 kHz. Thus, analogously to Refs. 11 and 15, we had the regime of paired pulses in combination with peculiarities typical of the repetitively pulsed regime. This pumping regime more closely simulates the regime of regular pulses than the simple method of paired pulses does.

1. Experiment

In the experiment we used the quartz gas-discharge tubes for the CuBr laser with the discharge channel from 0.6 to 3.0 cm in diameter and 20 to 80 cm long working zone. The design of the gas-discharge tubes was similar to that described in Ref. 8. The distance between branches with containers for copper bromide was 10 to 15 cm. The temperature of the branches and walls of the gas-discharge tube was measured with a thermocouple. The preparation of the gas-discharge tube for operation was described in Ref. 8. Spectrally pure neon at the pressure of 30–100 mm Hg was used as a buffer gas. The pump circuit employed TGI1–1000/25 thyratrons, TGU1–5/12 tasitrons, and the GMI–34 modulator tube (in this case a partial discharge of a working capacitor into the gas-discharge tube occurred) as switches. Current and voltage pulses were recorded by usual methods with the use of a Rogowskii loop and ohmic divider, while laser pulses were recorded with a coaxial photodiode (FEK–19). The experimental setup is schematically shown in Fig. 1.

The technique of the experiment aimed at obtaining the maximum pulse repetition frequency in a CuBr laser was the following. The discharge was excited by paired pulses due to direct discharge of the working capacitors C_1 and C_2 (see Fig. 1) through the gas-discharge tube and switches T_1 and T_2, respectively. A master oscillator allowed us to change the time lag between the pulses in a pair from 0.1 to 10 μs. First, the laser was brought up to a stable regime of lasing maintained by the first pulse. Then the second pulse was shifted with respect to the first one unless second lasing pulse appeared. In this way the maximum values of pulse repetition frequency for gas-discharge tubes of different diameter were determined. By varying the capacities of C_1 and C_2 capacitors, we measured the duration, amplitude, and shape of pump pulses. Typically, the duration of pump pulses was about 150 ns (at half maximum).

0235-6880/00/03 230-04 $02.00

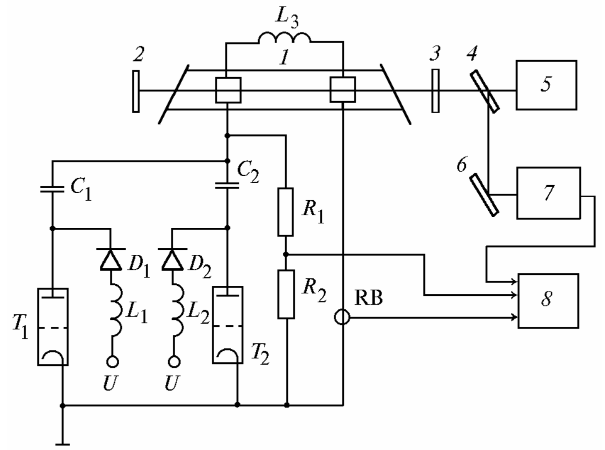

Fig. 1. Experimental setup: gas-discharge tube (*1*); mirrors of plane-parallel cavity (*2* and *3*); plane-parallel plates (*4* and *6*); IMO–2M calorimeter (*5*); FEK–19 coaxial photodiode (*7*); S1–122A oscilloscope (*8*); TGI 1–1000/25 thyratrons (T_1 and T_2); charging inductances and diodes $L_1 = L_2$, $D_1 = D_2$; by-pass inductance L_3; working capacitors C_1 and C_2; voltage divider R_1 and R_2; Rogowskii loop (RB).

This circuit was used for the case of regular pump pulses in the frequency range from 10 to 50 kHz. High pump frequencies (up to 300 kHz) were obtained in the circuit with the TGU1–5/12 tasitron as a switch (Fig. 2). This pumping circuit (with the open switch *K*) was also used for obtaining the regimes of "reduced energy depositionB at high pulse repetition frequencies.[16] The GMI–34 modulator tube used as a switch allowed us to obtain 2 to 3 times shorter pump pulses than those in the circuit with thyratrons and 1.5–2 shorter than those with tasitron. Unfortunately, we failed to obtain the regime of regular pulses emitted with the frequency higher than 50 kHz in the circuit with a modulator tube switch.

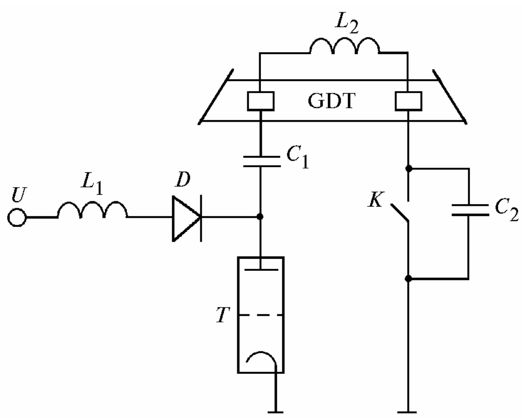

Fig. 2. Simplified pump circuitry of CuBr laser with use of tasitron generator in regime of reduced energy deposition (open switch *K*): by-pass inductance L_2; additional capacitor C_2 with the capacity less than C_1; vacuum relay *K*.

2. Experimental results and discussion

The obtained limiting values of the pulse repetition frequency in a the CuBr laser with the gas-discharge tube having a discharge channel from 0.6 to 3 cm in diameter indicate that in the thinnest tube of 0.6 cm in diameter and 20 cm in length the maximum pulse repetition frequency was 160 kHz. In this case the specific power deposited in a unit volume was 70 W/cm^3. That high power leads to an excessive ionization and overheating of the active medium and, as a result, to a decrease in the maximum pulse repetition frequency.[8,12] In the gas-discharge tube of 1 cm in diameter and 35 cm in length, the specific deposited power was lower – 16 W/cm^3, and the maximum pulse repetition frequency was 200 kHz. The highest value of the model pulse repetition frequency (with the thyratron generator) was obtained in the tube 1.6 cm in diameter and 40 cm in length. In this case the voltage across a rectifier was 3 kV, and the mean current was 160 mA at $C_1 = 2$ nF and $C_2 = 0.47$ nF. The specific deposited power in this case was 6 W/cm^3, and the minimum time lag between laser pulses τ was equal to 3 μs, what corresponds to the pulse repetition frequency of 333 kHz. The oscillograms of the voltage, current, and lasing pulses are shown in Fig. 3.

One can see from this figure that the energy deposited into the discharge by the first pulse is three times higher than that deposited by the second pump pulse. Lasing in the second pulse occurred at the inverse relation of the specific deposited power, however the maximum values of the pulse repetition frequency can be obtained just in the above case. This can likely be explained by the fact that a part of energy of the first pulse is more efficiently consumed for dissociation of the CuBr molecules.

The values of model maximum pulse repetition frequencies correlate well with those obtained in the actual repetitively pulsed mode. Thus, the maximum value of the pulse repetition frequency of the regular pump pulses (300 kHz) was obtained in the tube of 1.4 cm in diameter and 25 cm in length, in the tube of 0.8 cm in diameter and 40 cm in length it was 270 kHz, and in the tube of 0.4 cm in diameter and 30 cm in length it was 160 kHz (Ref. 8).

It should be noted that while working with the thyratron generator we failed to fully optimize the parameters of excitation, dissociation, thermal conditions, etc. In particular, to obtain high pulse repetition frequency, the pump pulses should be further shortened to duration close to the lifetime of the population inversion.

Using the GMI–34 modulator tube as a switch in the pumping circuit, we succeeded to shorten the pump pulses (at half maximum) down to 40 ns. In this case the minimum time lag between two pump pulses (lasing occurs in both pulses) is 1.5 μs in the gas-discharge tube of 2.5 cm in diameter and 80 cm in length at the 30 kHz repetition frequency of regular pulses. This time lag corresponds to the maximum pulse repetition frequency higher than 660 kHz. The oscillograms of this operating regime of a CuBr laser are shown in Fig. 4.

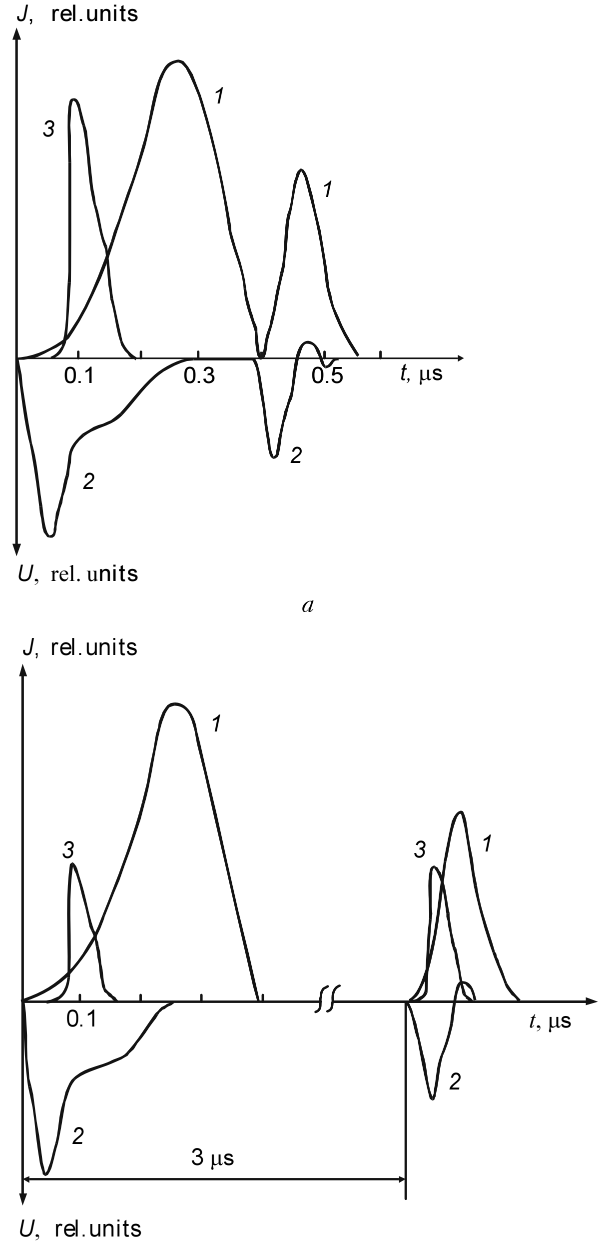

Fig. 3. Oscillograms of current (*1*), voltage (*2*), and lasing (*3*) pulses of a CuBr laser pumped by paired pulses. Gas-discharge tube was 1.6 cm in diameter and 40 cm in length, p_{Ne} = 30 mm Hg; repetition frequency of regular pulses was 10 kHz; time lag between the pulses in a pair τ = 0 (*a*) and 3 μs (*b*).

Unfortunately, technical problems associated with the deposition of low energy with the use of the modulator-tube switch did not allow us to pump tubes of small diameter (1–1.5 cm), in which the higher maximum pulse repetition frequency can be expected. At the same time, the experiments conducted show that the regime of high frequencies is realizable in tubes of medium (and, possibly, large) diameter. This depends on the energy and the rate of its deposit into the active medium.

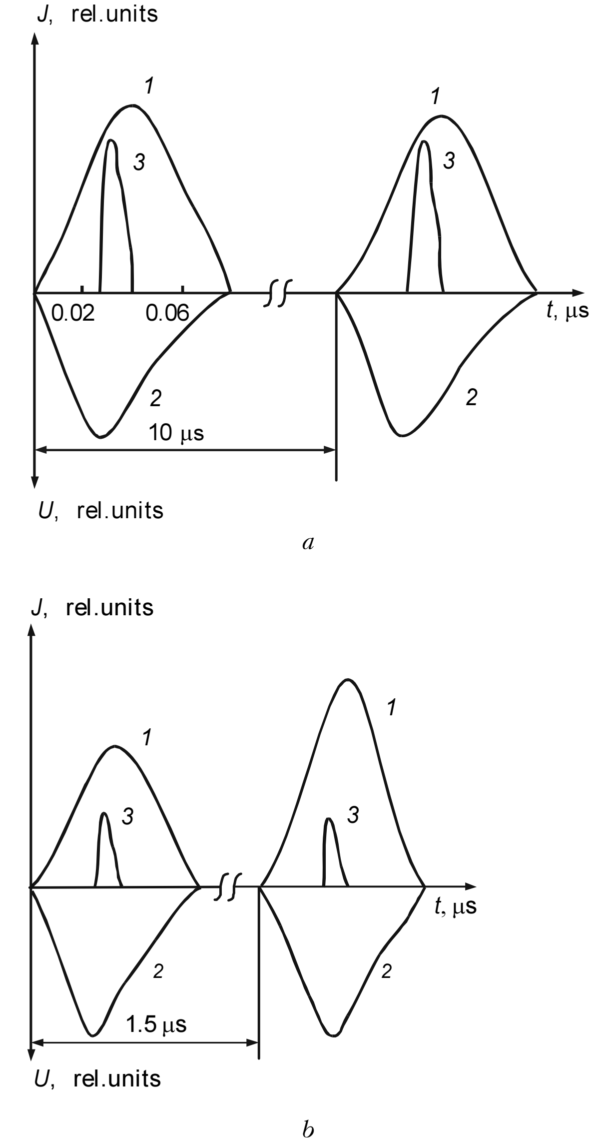

Fig. 4. Current (*1*), voltage (*2*), and lasing (*3*) pulses of a CuBr laser pumped via a modulator tube switch. Gas-discharge tube was 2.5 cm in diameter and 80 cm in length; p_{Ne} = 30 mm Hg; repetition frequency of regular pulses 30 kHz; time lag between the pulses in pair τ = 10 (*a*) and 1.5 μs (*b*).

Conclusion

Thus, the experimental studies of frequency characteristics of CuBr lasers in the regime of paired regular pump pulses at the repetition frequency up to 30 kHz demonstrated the possibility of achieving the pulse repetition frequency in a CuBr laser 500 kHz as high and even higher. The regime of high repetition frequencies (higher than 100 kHz) can be realized not only in narrow tubes (~ 1-cm-diameter), but in gas-discharge tubes of large diameters (~ 2 cm) and volume (~ 1 liter) under the condition that a low pump pulse energy is fast deposited into the discharge.

Acknowledgments

The authors are thankful to Professor G.G. Petrash for his attention to this work and V.B. Sukhanov and V.M. Klimkin for useful discussions.

The work was partially supported by the Russian Foundation for Basic Research (Grant No. 99–02–17016a).

References

1. G.S. Evtushenko, Izv. Vyssh. Uchebn. Zaved., Fizika **42**, No. 8, 89–96 (1999).
2. G.S. Evtushenko and V.M. Klimkin, Atmos. Oceanic Opt. **12**, No. 9, 840–848 (1999).
3. V.M. Batenin, V.V. Buchanov, M.A. Kazaryan, I.I. Klimovskii, and I.E. Molodykh, *Lasers at Self-Limited Transitions of Metal Atoms* (RFFI, Moscow, 1998), 544 pp.
4. C.E. Little, *Metal Vapour Lasers. Physics, Engineering & Applications* (John Willey & Sons Ltd., Chichester, UK. 1998), 620 pp.
5. T.S. Falen, IEEE J. Quant. Electron. **13**, No. 3, 546–547 (1977).
6. A.N. Soldatov and V.F. Fedorov, Izv. Vyssh. Uchebn. Zaved., Fizika **26**, No. 9, 80–84 (1983).
7. G.S. Evtushenko, Yu.P. Polunin, and V.F. Fedorov, Zh. Prikl. Spektrosk. **46**, No. 6, 1009–1011 (1987).
8. G.S. Evtushenko, G.G. Petrash, V.B. Sukhanov, and V.F. Fedorov, Kvant. Elektron. **28**, No. 3, 220–222 (1999).
9. G.G. Petrash, Usp. Fiz. Nauk **105**, No. 4, 645–676 (1971).
10. P.A. Bokhan, V.A. Gerasimov, V.I. Solomonov, and V.B. Shcheglov, Kvant. Elektron. **5**, No. 10, 2162–2173 (1978).
11. P.A. Bokhan and D.E. Zakrevskii, Zh. Tekh. Fiz. **67**, No. 5, 54–62 (1997).
12. G.G. Petrash, "*Processes determining achievable pulse repetition rate in pulsed metal-vapor lasers*,B Preprint No. 28 Physical Institute AS, Moscow (1999), 36 pp.
13. A.A. Isaev, M.A. Kazaryan, and G.G. Petrash, Kratkie Soobshcheniya po Fizike, No. 2, 27–29 (1973).
14. P.A. Bokhan and V.I. Solomonov, Kvant. Elektron., No. 6, 53–57 (1973).
15. A.A. Isaev, V.T. Mikhelson, G.G. Petrash, V.E. Peet, I.V. Ponomarev, and A.B. Treshchalov, Kvant. Elektron. **15**, No. 12, 954–961 (1988).
16. G.S. Evtushenko, G.G. Petrash, V.B. Sukhanov, V.F. Fedorov, and D.V. Shiyanov, Kvant. Elektron. (2000) (in press).