Quantum Electronics **42** (10) 877–879 (2012)

PACS numbers: 42.55.Lt; 42.60.Lh
DOI: 10.1070/QE2012v042n10ABEH014897

Copper bromide vapour laser with a pulse repetition rate up to 700 kHz

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Abstract. **The results of the experimental study of a copper bromide vapour laser at high repetition rates of regular pump pulses are presented. A record-high pulse repetition rate of 700 kHz is attained for lasing at self-terminating transitions in copper atoms. To analyse the obtained results, use is made of the data of numerical modelling of the plasma kinetics in the phase of pumping and discharge afterglow.**

Keywords: *copper bromide vapour laser, self-terminating transitions, pulsed pumping, pulse repetition rate, excitation, lasing.*

1. Introduction

The main operation regime in atomic vapour lasers on self-terminating transitions is the repetitively pulsed regime with the repetition rate of pump pulses up to tens of kilohertz. In this range of repetition rates the best results were obtained with respect to the mean power and lasing efficiency [1–3]. However, in a number of papers it was noted that the pulse repetition rates f in metal vapour lasers (MVLs) and metal compound vapour lasers can exceed 100 kHz. For copper and copper compound vapour lasers the practically significant levels of power and efficiency amounted to more than 10 W and 1%, respectively, at $f = 100$ kHz [4–7]. A striking example of practical use of active media of metal vapour lasers with a high pulse repetition rate is presented by high-speed laser projection microscopes [7]. Attaining high repetition rates is of interest also for understanding the physical processes that underlie the limitations of frequency and energy characteristics of lasers of such class. At present, the maximal pulse repetition rate for transitions in copper atom is 230 kHz in copper vapour laser [8] and 400 kHz in copper bromide vapour laser [9]. However, the analysis of model experiments [10, 11] and numerical simulations allows the suggestion that the obtained values are not ultimate, and, in the first place, for lasers with modified kinetics, in which the relaxation of the electron component parameters (temperature and concentration of electrons) between the pulses occurs during the time less than 1 μs [12–15]. Therefore, the repetition rate may approach 1 MHz, and possibly even greater values. This class of lasers includes the copper bromide vapour laser with admixture of hydrogen (which is always present in small amounts in the active medium) or hydrogen bromide.

The present paper is devoted to experimental study of characteristics of a copper bromide vapour laser at a high repetition rate of pump pulses (up to 0.8 MHz), as well as to their analysis making use of model calculation data.

2. Experimental technique and procedure

In the work we used a gas discharge tube (GDT) with the channel diameter 0.7 cm and the length of the active zone 14 cm, placed in a metal housing with independent heating, which was switched on only when the self-heating regime was not attained. The small diameter of the GDT was chosen on purpose to promote efficient functioning of diffusion mechanism, alongside with the processes of bulk plasma relaxation, during the pauses between the pulses. As a buffer gas we used neon at a pressure of 25 Torr (in the cold GDT). The operating pressure of copper bromide vapour in the discharge was maintained by controlled heating of branch pieces of the tube with copper bromide. The discharge always contained hydrogen (in small amount), which is confirmed by the presence of Balmer series emission lines.

The GDT was pumped using a regular high-voltage pulse generator based on a GMI-27B modulator tube in the grounded-grid circuit. The circuit operates in the regime of a partial discharge of the 37-nF storage capacitor. The main advantage of this circuit engineering solution in designing the output stage of the modulator is the short switching time (~8 ns in operation with active load) acquired due to reducing the effect of complex feedbacks via the parasitic capacities of the tube. The drawback consists in the absence of current amplification, which imposes particular requirements to the generator of initiating pulses.

By pumping the GDT at high repetition rates, the modulator produced current pulses with the front no longer than 15 ns, the pulse repetition rate being smoothly controlled within two ranges: from 10 to 100 kHz and from 100 to 800 kHz. The exciting pulse duration (FWHM) is specified within the limits of 40–150 ns. By varying the filament and bias voltages, one can control the amplitude of the current pulses in order to provide the optimal operation regime. The power consumed by the GDT and the elements of the circuit from the source increased with increasing repetition rate of pump pulses from 350 W (for $f < 500$ kHz) to 450 W (for $f > 600$ kHz). In the experiment the power was kept within this

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Received 15 May 2012; revision received 10 July 2012
Kvantovaya Elektronika **42** (10) 877–879 (2012)
Translated by V.L. Derbov

range by controlling the voltage applied to the storage capacitor.

The voltage, current and lasing pulses were registered using a TektronixP6015A voltage tester, a Pearson Current Monitor 8450 current probe and a FK-22 coaxial photoelectric cell, respectively. The mean output power was determined using an Ophir 20C-SH power meter. The signals, registered by the sensors, were applied to a LeCroy WJ-324 four-channel digital oscilloscope.

3. Experimental results and discussion

The obtained results show that lasing at 510.6 nm ($2P_{3/2} - 2D_{5/2}$ transition) and 578.2 nm ($2P_{1/2} - 2D_{3/2}$ transition) is observed in a wide range of pump pulse repetition rates, from a few units to 700 kHz. A part of the obtained results is presented in Fig. 1 in the form of oscillograms.

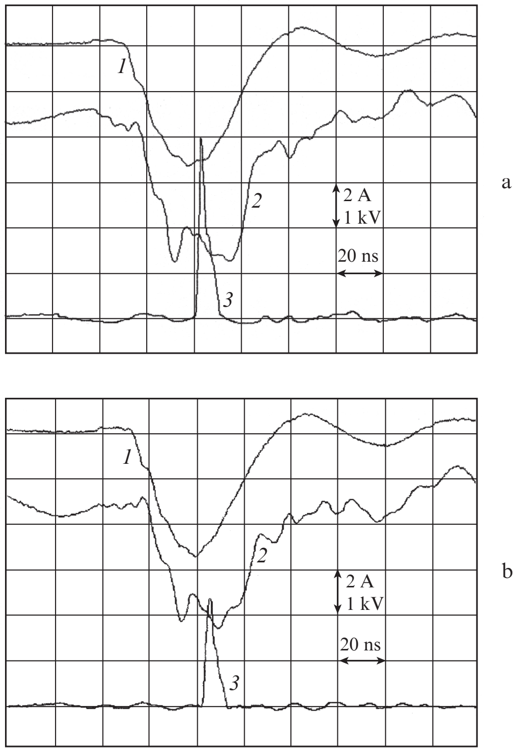

Figure 1. Oscillograms of GDT voltage (*1*), current (*2*), and laser pulse (*3*) at repetition rates (a) 513 and (b) 606 kHz.

It is important to note, that lasing is achieved in each of the regularly following pulses. The lasing pulse is produced in the maximum of the pump pulse rather than in its front, as for typical repetition rates (5–25 kHz). With the repetition rate increasing from 300 to 700 kHz the lasing pulse is somewhat shifted to the back part of the pump pulse. The mean total lasing power at both lines is not large for high values of f: it amounts to 130 mW at the repetition rate 520 kHz and falls down to 30 mW with an increase in the repetition rate up to 630 kHz. The lasing pulse duration (FWHM) at $f = 300$ kHz amounts to ~6 ns and slightly decreases with increasing repetition rate. At $f \lesssim 600$ kHz the major contribution to the total output power comes from the green line at 510.6 nm. With the growth of the repetition rate its contribution strongly decreases, so that in the frequency range of 650–700 kHz only the yellow line (578.2 nm) is actually present. At $f = 750$ kHz the lasing vanishes at this line as well.

To analyse the obtained data, we modelled numerically the plasma kinetics in the phase of pumping and during the pulse separation. The calculations were based on the model, described in [12, 14, 15]. From the results of modelling, a part of which is presented in Fig. 2, it follows that the population of the lower $2D_{5/2}$ level at high pump pulse repetition rates essentially exceeds that of the $2D_{3/2}$ level and attains 10^{14} cm^{-3}. As a consequence, the population inversion (with statistical weights taken into account) for the $2P_{3/2} - 2D_{5/2}$ transition disappears earlier than for the $2P_{1/2} - 2D_{3/2}$ transition. During the pulse separation (up to 1 μs) even some pumping of the $2D_{5/2}$ level from the ground state of the copper atom occurs, since the temperature of electrons after a fast fall (from 2.5 to 1 eV directly after the pump pulse) slowly decreases during the pulse separation to 0.4–0.5 eV (Fig. 3). As to the concentration of electrons, which during the pulse separation is nearly $\sim 10^{13}$ cm^{-3}, it insignificantly (by 1.5 times) grows in the pumping phase. As follows from [12], such values of the electron concentration should not be critical for achieving the inversion for the considered transitions. However, the pre-pulse concentrations of metastable states at the level of 10^{14} cm^{-3} are quite capable of quenching the inversion and lasing at the self-terminating transitions in copper atom.

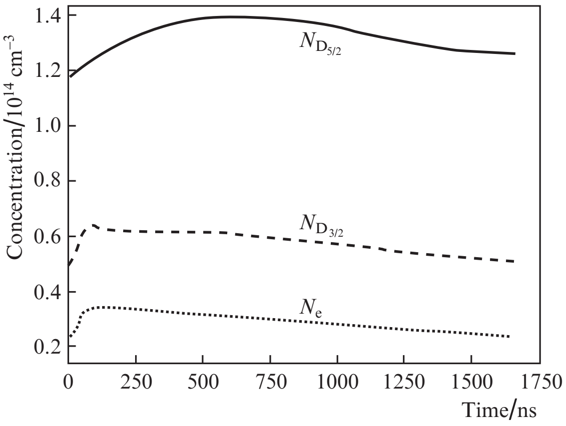

Figure 2. Time dependences of the concentrations $N_{D_{5/2}}$ and $N_{D_{3/2}}$ of metastable copper atoms and the concentration N_e of electrons.

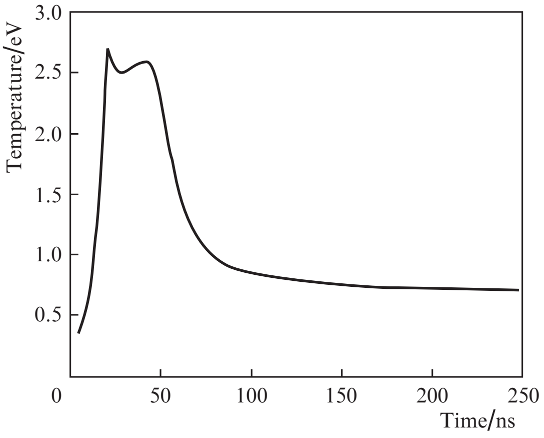

Figure 3. Time dependence of the electron temperature in the phase of pumping and the first afterglow period.

4. Conclusions

In the present paper we intended to demonstrate the principle possibility of achieving pulse repetition rates greater than 0.5 MHz in a laser on self-terminating transitions in copper atoms. This problem was solved in the case of a copper bromide vapour laser with a small active volume. In future, using the dosed hydrogen bromide doping and increasing the active volume, we intend to improve the frequency and energy characteristics of the laser. To understand the mechanism limiting the output laser parameters, we plan in the nearest future to perform thorough numerical modelling of plasma kinetics at the pump pulse repetition rate up to 1 MHz.

Acknowledgements. The authors express their gratitude to D.V. Shiyanov, V.B. Sukhavov and E.V. Yaroslavtsev for help in preparing the experiment and for the discussion of the results obtained.

The work was supported by the Ministry of Education and Science of the Russian Federation (Government Order No. 7.586.2011).

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