Low-power copper bromide laser

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The paper reports the development of a 1.5 W copper bromide vapor laser at the Institute of Atmospheric Optics SB RAS. This model will be used as a basic prototype for small-scale production of this type lasers. The paper discusses design features of active elements and power supply and shows the laser block diagram, external appearance, and basic technical and operating parameters.

Introduction

Nowadays, among numerous modifications of copper vapor lasers, of greatest practical interest are pure copper vapor lasers (CVL) and copper bromide lasers (CBL), which can be operated in the sealed-off mode. However, if commercial CVLs are manufactured by many companies both in Russia and abroad, then, according to the available information, the small-series production of CBLs is developed only in Bulgaria (Pulse Light Company). This situation cannot be considered as normal, because CBLs, though, certainly, being inferior to CVLs in some respects, have a number of important advantages. In particular, CBLs operate at higher optimal pulse repetition frequencies and, correspondingly, have a higher efficiency, all other conditions being the same. In addition, the prime cost of CBL active elements appears to be two to three times lower than that of CVLs, what is very important from the viewpoint of market competition.

This paper reports the development of low-power CBL at the Institute of Atmospheric Optics SB RAS (Tomsk, Russia). This laser can be used as a basic model for small-series production. The external appearance of the laser is shown in Fig. 1.

Fig. 1. Appearance of the laser.

Basic specifications

Lasing wavelength, nm	510.6, 578.2
Operation mode	repetitively pulsed
Pulse repetition frequency, kHz	~30
Mean output power at both lines, W	
operating power	1.5–2
power at HBr generator off	0.5–0.7
Power consumption, kW	1.1
Beam divergence, mrad	5
Beam diameter, mm	15
Expected operational life, h	> 1000
Cooling agent	air
Overall dimensions, cm	40×25×100
Mass, kg	~ 30

The laser block diagram is shown in Fig. 2.

1. Design of active element

The developed active elements (AE) have two distinctive features: they are fully self-heating[1] and equipped with a built-in hydrogen bromide (HBr) generator. Consider them in more detail.

The term "self-heating" means that the working concentration of metal vapor is generated using the energy of discharge initiated in the buffer gas (neon is used more frequently as a buffer gas for copper vapor lasers). Another way of metal heating up to the melting point assumes the use of external (independent of discharge) heaters of the active zone of the gas-discharge tube. In particular, this method was employed in the first CVLs. As to CBLs, this design is used most widely until now. Likely, both these methods of generating metal vapor have their own merits and demerits. This issue is beyond the scope of the paper, and we will only note the motives, which made us to reject external heaters in the CBL design.

The *first* motive is rationality and advisability. Indeed, having the natural heater with the power of several kilowatts, it seems illogical to complicate the laser design with additional heaters having the tenfold lower power.

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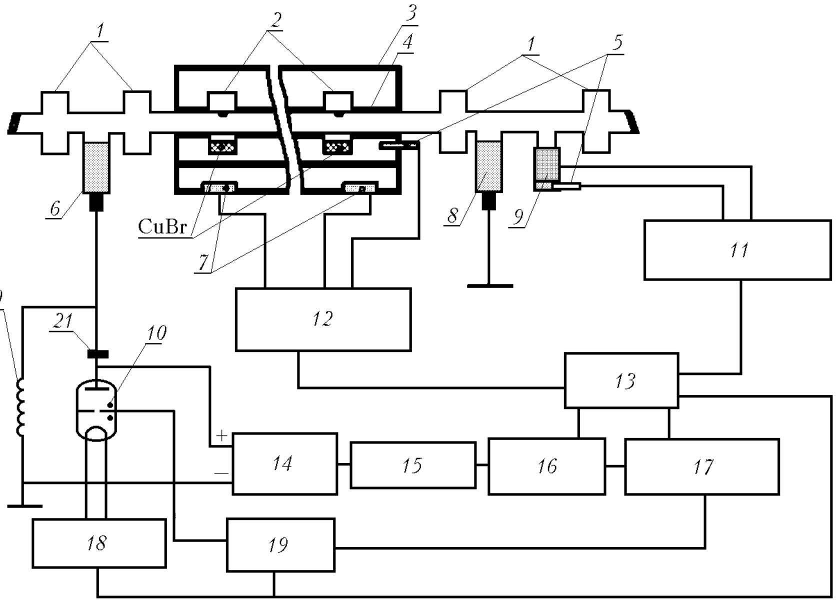

Fig. 2. Block diagram of the laser: trap *1*, containers with CuBr *2*, heat chamber *3*, thermal insulator *4*, thermocouple *5*, cathode *6*, fan *7*, anode *8*, HBr generator *9*, thyratron *10*, HBr pressure controller *11*, chamber temperature controller *12*, adjustable rectifier *13*, high-voltage rectifier *14*, transformer *15*, half-bridge circuit *16*, control and protection system *17*, thyratron filament and hydrogen stabilizer *18*, thyratron startup circuit *19*, charging inductance *20*, working capacitor *21*.

The *second* motive is that because it is very technically difficult to make the containers with CuBr (*2* in Fig. 2) fully insulated from the heat released in discharge, the process of vaporization appears to be connected with two heaters. This means that any (deliberate or accidental) variation of energy deposited into discharge will necessary affect the temperature of the containers. As a result, the laser output power can change quite markedly, which will require the corresponding change in the temperature of the external heater. Conversely, a decrease or increase of the container temperature immediately changes the conductivity of the active channel and, as a consequence, disturbs the established thermal conditions.

The worst result of this mutual dependence can be the overheating of the CuBr containers, because a large amount of CuBr in the laser active volume has a negative effect on the AE operational life. And because unplanned fluctuations of the deposited energy are quite frequent, the maintenance of a laser during its operation requires continuous attention of highly qualified, specially trained personnel. This problem is removed, if all supply voltages are stabilized. For low-power lasers, this is a realizable condition, but at high deposited energies the problem becomes very difficult technically.

And, finally, external heaters should be located just near the discharge channel. In this case, the probability of high-voltage breakdown to the conductive parts of the heater is high, due to which the AE can fail. The higher is the CBL power, that is, the higher voltages are applied to the AE, the more significant is this mechanism. The laser can be made secure from such failures by arranging all containers with metal inside one rather bulk case heated from the outside. Roughly such design is used by the developers of the already mentioned Pulse Light Company. It is clear that in this case the problem is removed at the expense of the more complicated and expensive design.

Summarizing the discussion about the ways for generation of the working concentration of metal vapor in the CBL active volume, we should note the following. All the above problems are not speculative or farfetched. We constantly faced these problems in practice, when used CBLs with external heaters. Therefore, the transition to the self-heating AE designs is, in our opinion, a quite natural and practically necessary stage in development of commercial CBLs.

A few words should be said also about another design feature of our AEs, namely, about the built-in hydrogen bromide (HBr) generator (*9* in Fig. 2).

It is well-known[2] that small additions of electronegative admixtures (H_2, HBr, HCl, etc.) into the active medium lead to a considerable improvement of power parameters (pulse repetition frequency, mean output power, efficiency) of metal vapor lasers. Thus, the problem was reduced to the purely engineering task: maintaining the optimal concentration of admixture in the sealed-off AE during the whole laser's operating life. The point is that in our first experiments, when studying the lasing characteristics of CBL with hydrogen admixtures, we discovered the following effect. One-time optimal addition of hydrogen (from an external reservoir) enhances the laser's power parameters for very limited time – several tens of hours. As this time elapses, the laser efficiency and output power begin to decrease, coming back to their initial (without hydrogen) values. Thus, we have come to the conclusion that the design of the sealed-off AE should include a regulable hydrogen generator.

However, the practical implementation of this idea failed. The tested CPHB-1 and CPHB-2 hydrogen generators,[3] which are reversing by definition, failed to ensure the hydrogen evacuation from the laser active volume (which is, clearly, the necessary condition for the standard operation of laser). At the same time, in the test experiments the reversing mode of operation of the hydrogen leak valves fully corresponded to the certified values. We explained these results by the fact that hydrogen in the free state cannot exist in the CBL active volume, and, consequently, this admixture appeared to be of little use for our purposes.

The problem was solved once we proposed, designed, and manufactured an HBr generator, operating by roughly the same principle as CPHB. When the generator is heated, it emits HBr, and the equilibrium HBr concentration, whose magnitude is directly connected with the temperature, is established in the AE volume. When the generator is cooled, the reverse process, namely, HBr evacuation, begins. The studies of CBLs with HBr generators allowed us to draw two principally important conclusions.

First, as to the improvement of the CBL power parameters, the H and HBr additions are absolutely identical.[4]

Second, the both modes (direct and reverse) of the HBr generator can be used at any AE temperatures: from the room temperature to the working one.

Thus, the problem of maintaining the optimal concentration of the electronegative addition in the AE was completely solved.

To be noted is one more very useful function, performed by the HBr generator in this AE. In the evacuation mode, not only excessive HBr, but also some bad by-products are removed from the laser active volume. This is supported indirectly by the fact that worked-out AEs after several clearing cycles began to work at the same level of the output power as immediately after the production. This allows us to hope that the service life of AEs equipped with HBr generators will be much longer.

For realization of the self-heating conditions, the AE working zone was placed in the heat chamber *3* (see Fig. 2), made as a metal untight case having a rectangular shape. The chamber was heated by the heat released from the discharge and cooled due to blowing by the fans *7* installed on the case bottom. The temperature was controlled by the thermocouple and automatically maintained at a fixed level with the temperature controller *12*. The dependence of the laser output power (with the HBr generator off) on the temperature in the heat chamber is shown in Fig. 3.

The heat chamber can be operated in the mode of forced blowing (fans operate continuously), which is still controlled by an operator. Roughly for 3 min of such forced blowing, the temperature of the containers with CuBr decreases so that the lasing is fully terminated. We believe that the use of this operation immediately before the laser is turned off is very important. In this case, due to the efficient cooling of the containers, the concentration of the CuBr molecules in the active zone appears to be lower than that of the molecules emitted into the near-electrode areas during the laser operation. As a result, the establishment of the equilibrium concentration is accompanied by the transport of working molecules back into the active zone. In this way the electrodes are cleared, that is, the effect of one of the main mechanisms responsible for AE "ageing" is mitigated.

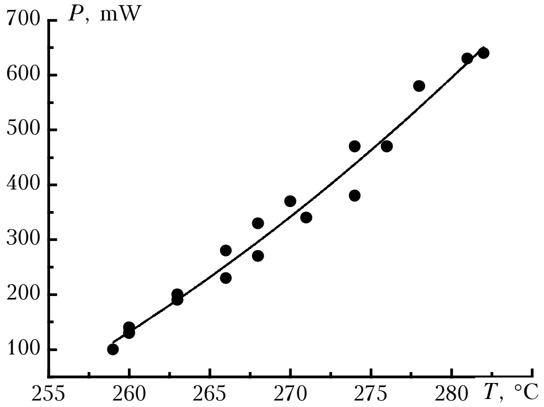

Fig. 3. Mean output power of the laser (with HBr generator off) as a function of temperature in the heat chamber.

The HBr generator *9* is made as a container built-in into the AE and placed in the heater. The heater temperature is controlled by the thermocouple and automatically maintained at the fixed level with the temperature controller *11*. The generator working temperature is selected experimentally based on the maximum of the mean laser output power.

2. Power supply of the laser

Now we describe the CBL power supply, whose block diagram is also shown in Fig. 2. When designing the power supply, we had two basic tasks to solve: to make the power supply as compact as possible and maximally facilitate the operating conditions of a thyratron, which is most important and the weakest part of almost any power supply for metal vapor lasers. To solve the first task, the power supply was connected as a half-bridge and placed in the common case with the AE. For more reliable operation of the thyratron, the mode of pulsed charge of the working capacitor was chosen.

In general outline, the operating principle of the power supply is the following. The mains voltage, rectified in the rectifier *13* (maximal value of 250 V), is applied to the half-bridge circuit *16*. The primary winding of the high-voltage pulsed transformer *15* (transformer ratio of 40) serves a load of half-bridge bipolar pulses. High-voltage pulses induced in the transformer secondary winding, having passed through the high-voltage rectifier *14*, acquire the identical polarity and charge the working capacitor *21* through the inductance *20* up to 10 kV. At the needed time, a start pulse is applied to the thyratron grid from the thyratron startup unit *19*. The thyratron switches on, and the working capacitor discharges through the thyratron and AE. The laser power supply unit has no mains voltage stabilizer, and therefore the variations of the mains voltage automatically influence the mean output laser power. This dependence is shown in Fig. 4.

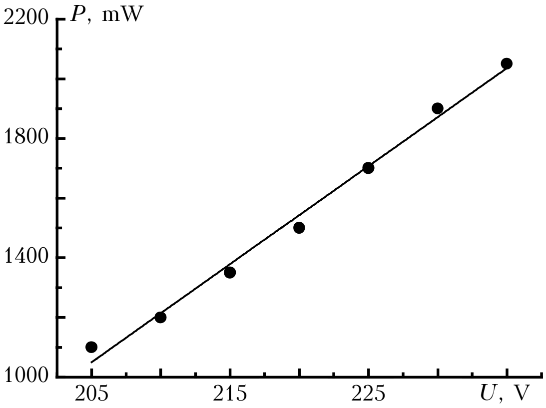

Fig. 4. Mean output laser power (at the optimal HBr concentration) as a function of the mains voltage.

The half-bridge circuit *16* is assembled of powerful field-effect transistors, controlled by a microcontroller being a part of the control unit *17*. The half-bridge circuit used by us differs from the classical one in the following. First, the working capacitors during the working cycle are charged from zero to a maximal value. Second, to decrease the power dissipated at the transistors, they are turned on and off at the time, when the direct current through the transistor terminates. This is achieved through the properly selected values of the half-bridge working capacitances and the inductance of the throttle, which is connected in series with the primary winding of the high-voltage transformer.

The working cycle of the half-bridge looks as follows (Fig. 5). First, one of transistors is switched on, and the current pulse ~ 20 μs passes through the primary winding of the transformer *15*. As this takes place, the working capacitor *21* is charged up to the maximal voltage. Then the transistor is switched off, and 5 μs later the start pulse is applied to the thyratron grid from the unit *19* and the capacitor *21* discharges through the AE. After that, a pause of 11 μs follows, another transistor is switched on, and the process repeats accurate to the polarity of the current pulse through the transistor and the primary winding *15*. Thus, the duration of one working cycle is 36 μs, and the laser pulse repetition frequency appears to be ~ 27.7 kHz. During the pause mentioned above, the thyratron anode is at zeroth potential, which provides for the effective process of deionization in the gas medium of the thyratron. Just this circumstance determines the main practical value of the chosen mode of pulsed charging of the working capacitor.

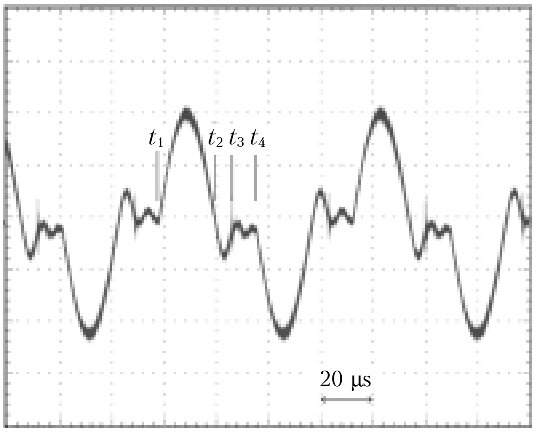

Fig. 5. Oscillogram of current pulses in the primary winding of the high-voltage transformer. Time t_1 – first half-bridge transistor switches on; t_2 – first half-bridge transistor switches off; t_3 – thyratron switches on; t_4 – second half-bridge transistor switches on.

The working voltage of the source is changed with the regulable thyristor rectifier *13*. The dc voltage can be regulated from 0 to 250 V manually or automatically. In the latter case, the thyristor rectifier is controlled by the microcontroller being a part of the control unit *17*. The program of increase of the working voltage is made so that the laser ramp-up is performed stage by stage. The electrophysical parameters of the gas-discharge channel, dependent on the AE temperature, vary smoothly, and the power supply as a whole operates stably.

The high-voltage transformer *15* is wound on two ferrite rings 125 mm in diameter and placed in a reservoir with oil. The transformer primary winding has 30 turns, and the secondary winding is divided into six sections, each of 200 turns, connected in series. The high-voltage rectifier *14* is connected as a bridge in 60 high-frequency diodes. As a switcher *10*, our circuit employs the TGI 500/16 thyratron. The filaments of the cathode and the thyratron hydrogen generator (unit *18*) are independent and stabilized. Due to this, the thyratron operates in the optimal mode as the mains voltage varies from 190 to 250 V.

In the process of laser operation, the current in the primary winding of the transformer *15* and the current consumed by the source from the adjustable rectifier *13* are controlled continuously. The comparator compares these currents with the pre-chosen values. If one or both controlled currents exceed these preset values, then the protection system, which is a part of the unit *17*, terminates the feeding of enabling pulses to control gates and resets the voltage across the thyristor rectifier *13*. After the 1-s pause, the voltage at the output *13* smoothly increases up to the maximal value for 3 s, and the feeding of enabling pulses to control gates resumes.

The protection is activated by the early breakdown of the thyratron, abnormal situations in the cold AE, and stray pick-up in the control system. To mitigate the effect of the last cause and to provide for the stable work of the power supply as a whole, the following measures were undertaken. The microcontroller with the voltage regulator and both thermoregulators are placed in metal cases. The control signals from the microcontroller are picked off through optrons. The thyratron control unit *18* has an independent power supply. The adjustable rectifier *13* employs an opto-thyristor module. Thus, the main units of the power supply appear to be galvanic-decoupled.

The laser is controlled with four double-pole switches on the back panel of the laser body. They are: the power on/off switch, the high voltage on/off switch, the HBr generator on/off switch, and that for switching the heat chamber from the automatic temperature control mode to the forced blowing mode. The laser body contains five additional trimming resistors, which allow changing the following parameters: working voltage, temperature of activation of regulators of the thermal chamber and the HBr generator, filament voltages of the cathode and the thyratron of the HBr generator.

It is anticipated that already in the following models the laser ramp-up and termination will be fully automatic. The sequence of all needed operations will be programmed in an additional microcontroller.

Conclusions

As a main result of this work, we would like to note the following. In this paper, we reported likely the first, in Russia, attempt to develop the commercial prototype of the CuBr laser. As a rule, in the process of manufacturing a new device, new ideas on how to enhance the already approved design appear. In this aspect, our case is no exception. Moreover, the process of modification has already started, but its finish is still far distant. Nevertheless, we believe that already now, due to the quite acceptable technical, operating, and economical parameters, the proposed model can compete with traditional lasers used in scientific research, medicine, and show business. By now, the indisputable leaders at the market of low-power lasers are so-called diode lasers, to compete with which is a difficult task. In this connection, noticing the practical value of the model developed by us, we consider it, to high extent, as a some basic model. This means that the most part of technical solutions, found by us in the course of this work, will be also used in developments of power supplies for already available AEs of CuBr lasers with the planned mean output power up to 50 W.

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