# Temperature regime of a CuBr laser operation

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The distribution of temperature along the active zone of a self-heated CuBr laser is studied. It is shown that the near-electrode regions contribute significantly to formation of the temperature field. The influence of temperature inhomogeneities on the characteristics of laser radiation is determined.

The efficient operation of a CuBr laser is connected with the homogeneity of medium parameters' distribution along the discharge channel. One of the important parameters of an active medium is the temperature of the walls of the discharge channel. In Ref. 1 it was noted that the method of creating and maintaining temperature in the working zone (dissipation of the discharge energy) in copper vapor lasers produces temperature differences at a certain pressure of the buffer gas and thus affects the characteristics of laser radiation. In Ref. 2 a model was proposed for the dynamics of the electric field. This model explains, to some extent, the existence of these inhomogeneities. In Ref. 3 a particular attention was paid to the role of near-electrode zones, whose significance is caused by the absence of vapor of the working substance, which has a decisive effect on the plasma conductivity. Thus, we can assume that temperature inhomogeneities connected with the dissipation of the discharge energy do exist in CuBr lasers also. The assumed temperature inhomogeneity must produce some peculiarities in both the formation of the population inversion and lasing over the extension of the working channel.

The inhomogeneities arising along the working channel of a CuBr laser were the goal of our study along with the determination of their influence on the radiation characteristics.

## Experimental setup

The experimental setup (Fig. 1) consisted of a high-voltage power supply, a switch formed by two TGI1–1000/25 thyratrons operated in parallel, and a master oscillator operating at a pulse repetition frequency from 15 to 25 kHz. The electric circuit used provides for direct discharge of a capacitor through the switch and the gas discharge tube (GDT).[4] The capacitor had a capacitance of 2200 pF. The peaker of 500 pF capacitance was connected in parallel with the GDT. The working zone of the gas discharge tube was 1.5 m in length and 40 mm in diameter. The working substance (copper bromide) was loaded to branch containers distributed uniformly along the working channel at a 210-mm spacing. Specialized furnaces heated the containers to produce the working pressure of CuBr vapor in the working channel. The working temperature of the containers was optimized in terms of lasing power by tuning the power supply of the furnaces. A plane-parallel cavity used consisted of a totally reflecting mirror with a dielectric coating and a glass plate as an output mirror. Six chromel-alumel thermocouples were arranged along the GDT working channel. They measured the temperature of the wall of working channel and thus determined the temperature profile and the temperature variation as the GDT was heated and cooled. Prior to the experiment, the thermocouples were checked in a furnace. Their accuracy proved to be 6°C, i.e., within the error of the measurement device. The current pulse was picked off with a shunt, and the voltage pulse was picked off with a low-inductance divider. The output laser power was measured with an IMO–2 calorimeter. To measure the output power at the green and yellow lines separately, the beam was split by a prism, and then the two resulting beams were directed to two IMO–2 calorimeters. Neon was used as a buffer gas.

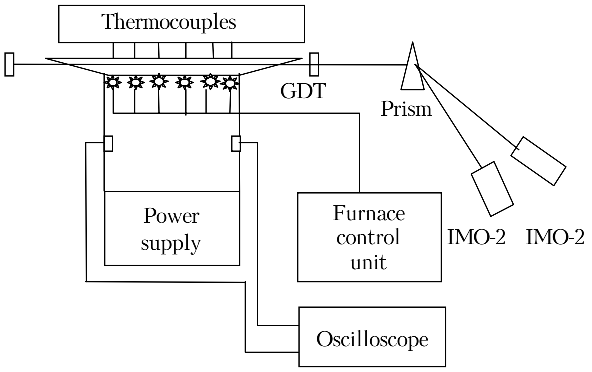

**Fig. 1.** Experimental setup.

## Results and discussion

In metal-vapor self-heated lasers, heat release along the discharge channel is inhomogeneous under certain conditions.[1] This inhomogeneity is significant at a certain pressure of the buffer gas, and it affects the

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power and other characteristics of lasing. It is interesting to consider the influence of thermal inhomogeneities arising because of self-heating for a CuBr laser as well. In contrast to pure copper vapor lasers, CuBr vapor lasers provide, in the case that the working substance is in specialized branch containers along the working channel, some extra capabilities in studying processes in the near-electrode and central zones. The working substance from the containers is entered into the discharge channel with specialized furnaces. So turning the furnaces on or off, we can turn on or off certain zones of the working channel. This can hardly be done in copper-vapor lasers. Lasing occurs at a certain pressure of the CuBr vapor. Changing the power, we can adjust the furnaces for the optimal temperature, at which the output power reaches its maximum at the given parameters.

It should be noted that under conditions of constant pump parameters, as the GDT heats up, the relative content of the green and yellow emissions in the laser beam gradually changes. As the total power increases, the green-to-yellow power ratio decreases. Certain values of the ratio correspond to the optimal conditions, pre-optimal conditions, and the so-called conditions of overheating, when the total power starts to decrease. Thus, one can qualitatively judge on the processes in different zones of the GDT from the power ratio between the green and yellow lines.

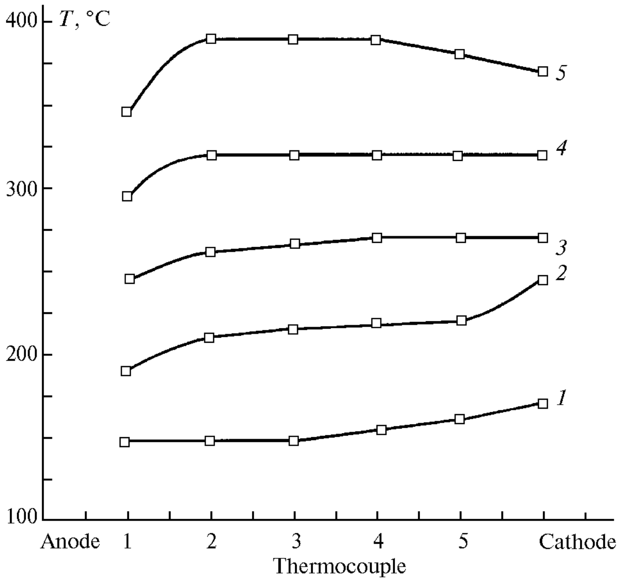

**Fig. 2.** Dynamics of the temperature profile as the discharge channel heats up: 7-minute heating (curve *1*), 8-minute heating (*2*), 10-minute heating (*3*), 12-minute heating (*4*), and 60-minute heating (*5*). Established conditions. Buffer gas (neon) pressure of 30 mm Hg. Consumed power of 3 kW.

The thermocouples arranged along the discharge channel make it possible to determine the dynamics of the GDT temperature profile as the GDT heats up (Fig. 2). It is known that heat losses are proportional to the temperature gradient, therefore the initial moment, at which all zones have the same temperature, shows how the heat is released in the discharge along the working channel. The losses of heat reach maximum in the near-electrode zones due to the heat outflow through the ends and minimum in the central zone due to a heat-insulating material. At the initial moment of GDT heating (Fig. 2, curve *1*) the temperature in the near-cathode zone increases much faster than in other zones. The heat release not only compensates for the end losses, but keeps the temperature in the zone higher than that in the central zone. Under the established conditions (Fig. 2, curve *5*), when heating and thermal losses are balanced, this effect is not observed, and heating of the central part prevails. At the same time, this does not mean that energy release changed and became homogeneous. It is interesting to consider the dynamics of the temperature profile as the discharge channel cools down (Fig. 3).

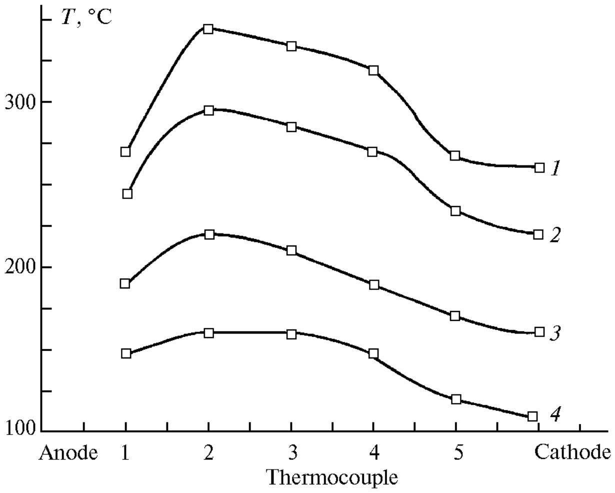

**Fig. 3.** Dynamics of the temperature profile as the discharge channel cools down: 3-minute cooling (curve *1*), 5-minute cooling (*2*), 8-minute cooling (*3*), and 13-minute cooling (*4*). Established conditions. Buffer gas (neon) pressure of 30 mm Hg. Consumed power of 3 kW.

Its behavior characterizes the state of thermal conductivity of a heat-insulating material. We used kaolin wool as the insulating material. Kaolin wool increases its thermal conductivity at annealing, and the temperature dependence is nonlinear. In our case, the heat-insulating material having such properties helps to maintain the working temperature within the range of lasing. Figure 4 shows the temperature profile along the working channel at the initial phase of heating and under the established conditions. The heat release in the near-cathode zone increases with the decreasing pressure. The highest temperature difference arises at the neon pressure of 5 mm Hg. Under the established conditions, this is reflected in the elevated temperature in the near-cathode zone.

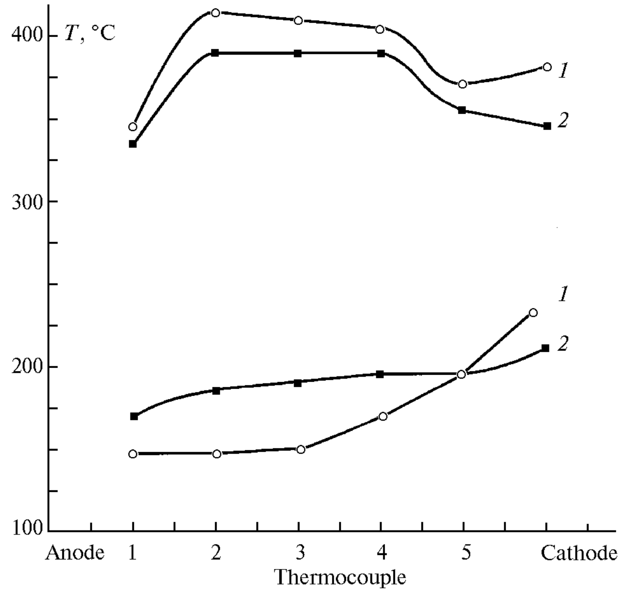

**Fig. 4.** Temperature profile along the working channel at the initial stage of heating and under the established conditions: neon pressure of 5 mm Hg (*1*) and 50 mm Hg (*2*). Consumed power of 3 kW.

Table 1 presents the results demonstrating the effect of the inhomogeneous release of the discharge power on the formation of laser radiation. This effect can be tracked from the change of the green-to-yellow power ratio by turning off the furnaces near the cathode and anode alternatively.

**Table 1. Influence of the near-electrode zones on the green-to-yellow line power ratio**

| Total power, W | Green-to-yellow ratio | Note |
|---|---|---|
| 19 | 0.89 | All furnaces are turned on |
| 16 | 0.72 | One furnace near the anode is off |
| 16 | 3 | One furnace near the cathode is off |

Turning off the anode furnace increases the fraction of the emission at yellow line in the beam. In this case, the emission power at the green line decreases by 2.3 W, whereas the power at the yellow line decreases by 0.7 W. That is, the green line is efficiently generated in this zone, what can be explained by the lower working temperature caused by the end losses. Turning off the cathode furnace leads to a sharp increase in the power at the green line. Note that in this case the power at the green line increases from 9 to 12 W, whereas the power at the yellow line decreases from 10 to 4 W. Such a behavior of the components of laser radiation is possible at overheating of the working medium in terms of the green line. The decrease of pressure of the CuBr vapor (turned-off cathode furnace) leads to pressure optimization, and the power at the green line increases.

Thus, it can be concluded that the near-cathode zone produces a far greater contribution to the total power at the line $\lambda = 0.578$ nm. The emission at green line is most efficiently formed in the near-anode zone.

The inhomogeneous temperature distribution along the working channel must also manifest itself in the temperature that is maintained by the furnaces in the branch containers. To reveal this effect, we should consider the operation of the furnaces together with the GDT and then to determine what temperature is maintained by the furnaces in the absence of the discharge in the GDT. The results are shown in Table 2.

**Table 2. Influence of heat released in the discharge on the furnace operation conditions**

| Furnace # | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Joint operation of GDT and furnaces (*T*, °C) | 385 | 400 | 400 | 400 | 385 | 410 |
| Operation of furnaces without GDT (*T*, °C) | 320 | 340 | 330 | 330 | 350 | 385 |
| Temperature difference, °C | 65 | 60 | 70 | 70 | 35 | 25 |

Energy released by a repetitively pulsed discharge contributes to heating of the branch containers. The higher is the temperature of their heating by discharge, the lower is the temperature to be maintained by the furnaces. The part of temperature provided by the discharge is determined as the temperature maintained by the furnace operating together with the GDT minus the temperature provided by the furnace only. The measurements have shown that if in the near-cathode zone this difference is 65°C, then in the near-anode zone it is much lower and equals 25°C.

**Table 3. Lasing characteristics of the near-anode, central, and near-cathode zones of the GDT**

| Output power, W | Part of green line, in % | Note |
|---|---|---|
| 4 | 75 | Near-cathode zone is operating |
| 1.75 | 77 | Central zone is operating |
| 1.5 | 100 | Near-anode zone is operating |

To study the role of thermal inhomogeneities in the lasing process, the GDT was conditionally divided into three zones, each containing two furnaces. Each of these zones was turned on in turn, input power being the same. Table 3 gives the output power obtained in each of the cases, as well as the percentage of the emission at the green line. The output power reaches its maximum at the near-cathode zone turned on. The part of the green line increases while approaching the anode, and in the near-anode zone the laser generates at only the green line in our case.

The operation of the near-cathode and near-anode zones at the central furnaces turned off is more complicated. We can see that the near-cathode zone independently gives 4 W, whereas the near-anode zone gives 1.5 W. Their joint operation gives the total power much higher than the simple sum. The green-to-yellow line power ratio was measured in the process of heating. The results are given in Table 4.

**Table 4. Output power at joint operation of near-cathode and near-anode zones**

| | | | | |
|---|---|---|---|---|
| Total output power, W | 5.5 | 7 | 7.5 | 7.75 |
| Green-to-yellow line ratio | 2.1 | 1.8 | 1.5 | 1.4 |

Analysis of the results shows that gradual diffusion of the copper bromide to the central zone takes place, and lasing in this zone gives an extra power. It is interesting that the output power increases mostly due to the contribution coming from the yellow line.

To improve the output characteristics of the CuBr laser, we have conducted tentative research into the system “master oscillator–amplifier,” since an amplifier also can introduce some corrections to the output laser parameters, such as the green-to-yellow line power ratio. Two identical GDT’s, whose dimensions were the same as in the GDT described above, were used as an amplifier and generator. The amplifier was first put into operation as a generator, and the parameters of laser radiation were recorded. In our case, the system “master oscillator–amplifier” not only summed up the powers of the master oscillator and the amplifier, but also gave an extra power gain of 25–30%. Besides, we had the possibility of meeting the requirements to radiation with the master oscillator only, but also to tune the laser line ratio with the amplifier.

## Conclusion

In the experiments discussed, it was found that CuBr lasers at the buffer gas pressure from 5 to 50 mm Hg are characterized by a rather strong inhomogeneity of the discharge energy dissipation along the working channel. This inhomogeneity significantly affects the characteristics of laser radiation. It influences the operation conditions of the furnaces that heat the CuBr containers, which necessitates their adjustment to optimal conditions. It is shown that controlling the furnaces we can change the green-to-yellow line ratio in the output laser beam. The influence of temperature inhomogeneities on the formation of radiation is determined. The regularities revealed are proposed to be used in the system “master oscillator –amplifier.”

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