The influence of input power scaling on characteristics of CuBr+Ne and CuBr+Ne+H_2 lasers

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We describe the possibility of increasing average output power (with some loss in efficiency) of the medium sized sealed-off CuBr+Ne and CuBr+Ne+H_2 laser systems while scaling the pump power. It has been established that with increasing specific pump power the optimal pressure of hydrogen admixture maximizing the lasing power grows.

Introduction

Energy characteristics of copper-vapor lasers (CVL), i.e., the efficiency and generation power, depend in many cases on the level of energy pumped into the gas-discharge tube (GDT).[1,2] In practice, it is often desirable that the laser operates in a steady-state mode with either high efficiency or maximum mean power of output radiation. To solve this problem, the pump power should be varied. For a concrete GDT, using the self-heating regime, this makes a certain problem.

In this case a successful experiment was performed by Mildren and colleagues for a copper-vapor laser with an improved kinetics.[3] For the maintenance of the steady-state thermal regime in increasing the pump power from 6 kW to 9 kW the authors reduced the thermal insulator thickness. In this case the mean radiation power from a tube of medium size (diameter of 1.75 cm, length of 100 cm, and accordingly the active volume of 0.24 l) reached 90 W at the efficiency about 1%.

In the study we present in this paper we tackled the following problems:

– to study experimentally the possibility of scaling pump power in CuBr+Ne and CuBr+Ne+H_2 lasers of medium size (without buffer gas pumping);

– to study the influence of different pumping levels on the efficiency and mean power of generation;

– to determine the optimal values of H_2 pressure at different levels of pump energy;

– to make a comparative analysis of the results with characteristics of copper-vapor lasers with close parameters of pumping.

Experimental technique

We investigated energy characteristics of a CuBr laser with and without H_2 admixture, depending on pump power, with a gas-discharge tube of 2.6-cm diameter and 76-cm length. The gas-discharge tube operated in self-heating mode.[4,5] The tube design enabled connecting a pressure gauge of a deformation type (the scale value is 0.01 Torr) to control the H_2 admixture pressure. The H_2 gas was entered into the gas-discharge tube through the main line from a gas bottle. We used Ne as a buffer gas.

The laser excitation was performed with the pump pulse not optimized, i.e., no special circuitries were used for increasing voltage and pulse compression. A standard circuit of direct discharge of a storage capacitor of KVI-3 type into the GDT was used through a TGI1-1000/25 thyratron with water-cooled anode. To switch pump power higher than 3 kW, we used two thyratrons operated alternatively.

The recording of electric current pulses, voltage, and laser emission was made using a Rogowski coil, a low-inductance divider on TVO resistors and a coaxial photocell FK-22. The signals were recorded with a Tektronix TDS 3032 oscilloscope. The radiation power was controlled by an IMO-2 power meter, and the GDT wall temperature was controlled using a Chromel-Alumel thermocouple.

The scaling of power from 1 to 5 kW, pumped into GDT from a power supply, was made first for CuBr+Ne and then for CuBr+Ne+H_2 laser at about the same frequencies of pulse repetition and the same source voltage by varying the storage capacitance. The GDT wall temperature at the pump power of 1, 3, and 5 kW was kept constant by varying thickness of the GDT thermal insulator layer. Measurements were carried out at low (25 Torr) and high (100 Torr) pressure of Ne.

The optimal pressure of H_2 admixture (when the radiation power is maximum) at different levels of pump power was determined as follows. For each fixed value of the pump power several measurements were conducted. Hydrogen at a pressure of 0.1 Torr was filled in into a cold evacuated GDT, then Ne was added at a pressure of 25 Torr and the radiation power was measured. Then, at the same pressure of the buffer gas all the procedure was repeated again with the pressure of H_2 admixture being increased every time in a step 0.05 Torr. In this way, we

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determined the optimal value of admixture resulting in the peak of output power.

Experimental results

The increase of power to pump laser was accompanied by a decrease of the heat insulator thickness at GDT. The power growth followed the increase in the electric current from 180 to 800 mA that was achieved by increasing the storage capacitance. As an illustration, Table 1 shows the GDT excitation parameters under Ne pressure of 25 Torr and at H_2 admixture at 0.35 Torr partial pressure.

Table 1. Parameters of CuBr+Ne+H_2 laser pumping at different pump powers

P_s, kW	C_{op},pF	f, kHz	U, kV	J, A	P_{sp}, W/cm^3
1	660	18.5	6	0.18	2.5
3	1566	17	6	0.5	7.5
5	1700	17.5	6.2	0.8	12.5

Earlier in Ref. 6 we have determined that at supply voltage of 6 to 7 kV and at 1 to 1.5 kW power consumed from the source the optimal H_2 admixture in GDT was 0.35 Torr at Ne pressure of 100 Torr. These admixture values were selected at scaling of the CuBr+Ne+H_2 laser pumping.

During the operation of CuBr+Ne laser in the absence of hydrogen at pumping power higher than 3 kW problems arose with the power deposition into the GDT. Thyratrons failed to operate without failures. Therefore, we had to carefully select the voltages of cathode heater and H_2 generator of thyratrons. This was manifested especially strongly at operating pressure of the buffer gas of 25 Torr. With increasing Ne pressure up to 100 Torr, the discharge resistance increased and the coupling between GDT and pumping generator was improved, and thus the operation of pump circuit eased.

Besides, the operation of laser at pump power of 5 kW was followed by strong heating of the GDT electrodes, especially of the cathode. This called for their forced cooling. It was for this reason that we didn't manage to investigate in detail the power characteristics of the laser in such a mode, since after reaching GDT any maximum value in the output power GDT ought to be turned off.

Figure 1*a* shows the results on the behavior of CuBr-laser radiation power at operating Ne pressure of 25 Torr without and with H_2 admixture depending on the pump power. One can see that increasing the specific power by a factor of five, from 2.5 to 12.5 W/cm^3, the radiation power increased twice, and the introduction of H_2 admixture in the active medium increased the output power by more than two times.

The same figure shows the behavior of the lasing efficiency for these same cases. Adding H_2 increased more than twice the efficiency, but with the increase of pump power, it decreased almost twice.

The same pattern was observed for the case when Ne pressure was 100 Torr (Fig. 1*b*). Only, in this case, the generation power and the efficiency are much lower than in the previous case. It was shown in Ref. 6 that this took place because of the insufficiently high voltage at the discharge gap.

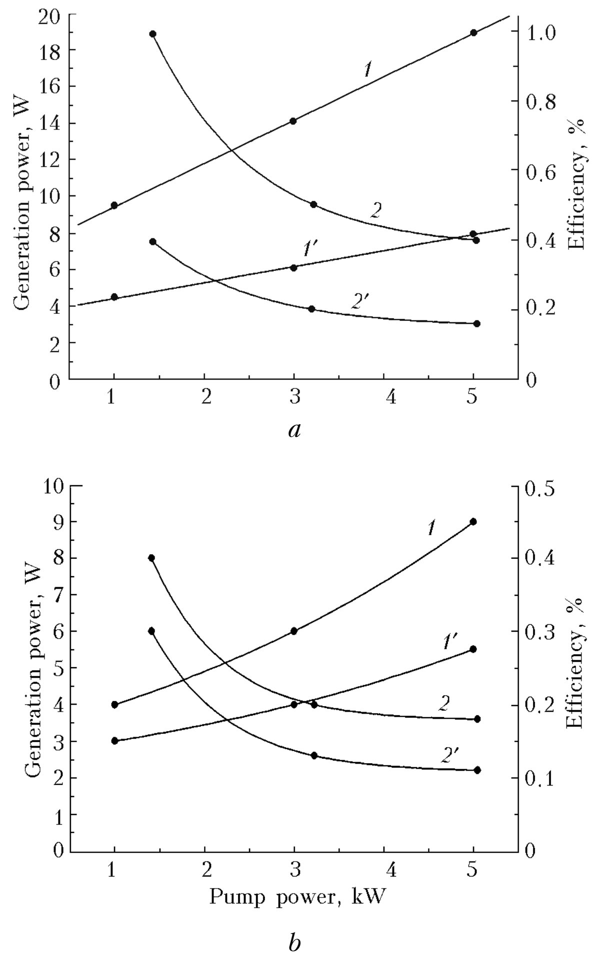

Fig. 1. Dependence of the radiation power (*1*) and the efficiency (*2*) of CuBr+Ne+H_2 laser as well as of the radiation power (*1′*) and the efficiency (*2′*) of CuBr+Ne laser on the pump power. Pressure of the buffer gas, Ne, is 25 (*a*) and 100 Torr (*b*).

Besides, in the paper the optimal pressures of H_2 admixture to CuBr+Ne+H_2 laser were determined at 1, 3, and 5 kW pump power. Results are shown in Fig. 2. It is clearly seen from Fig. 2 that at higher energy contributions higher partial pressures of the admixtures are needed, that is, the range of optimal pressures is shifted from 0.3 Torr at 1 kW to 0.4 Torr at 5 kW. The reason is that the energy contribution increase, in our case, is due to the growth of the consumed electric current. Consequently, the electron concentration grows as well as its prepulse value. This implies that for efficient plasma relaxation in the afterglow a greater amount of hydrogen is necessary.

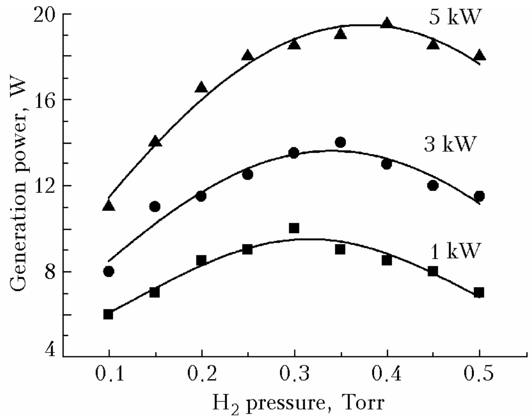

Fig. 2. Dependence of the radiation power of CuBr+Ne laser on the pressure of H_2 admixture at different levels of pump power. The buffer gas, Ne, pressure is 25 Torr.

In comparing the output characteristics obtained for CuBr + Ne and CuBr + Ne + H_2 lasers (of 400-cm^3 volume) with a copper-vapor laser of about the same volume – Crystal LT 40Cu (of 350-cm^3 volume) it is clear that CuBr laser with H_2 admixture even at P_{spec} = 12.5 W/cm^3 yields to the copper-vapor laser (CVL). At the specific input power of 11 W/cm^3 the radiation power of a standard CVL LT 40Cu is 40 W (Ref. 2) and the radiation power of CuBr laser is twice as low. However, in realizing the same power (4 kW) for pumping an active element of CuBr laser of larger volume (up to 4 l) we can obtain the output power of more than 40 W and at higher efficiency.[7–9] It should be noted that powers for CVL, given in Ref. 2, were obtained using Bloomlein circuit with the voltage doubling and compression of the pump pulse.

Conclusions

The experimental results allow us to make the following conclusions:

– the variation of efficiency of heat insulation of an active element of CuBr laser, including a sealed-off one, makes it possible to vary within wide limits the pump power and to increase twice the output radiation power (though with the loss of efficiency);

– increasing the pump power the value of optimal hydrogen admixture grows;

– the advantages of the CuBr laser with active admixtures as compared with a standard CuBr laser will be most evident for active elements of large volumes.

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