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Effect of gas mixture composition and pump conditions on the parameters of the CuBr – Ne – H_2 (HBr) laser

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***Abstract*. The optimal pressures of the active H_2, HBr impurities and the working substance (copper bromide) for an effective operation of the CuBr laser are determined experimentally. It is shown that to achieve the highest output laser parameters by increasing the voltage across the gas-discharge tube and the pump pulse repetition rate, it is also necessary to increase the amount of the impurity introduced. At the same time, the optimal pressure of copper bromide decreases with increasing the pulse repetition rate.**

Keywords: *copper bromide vapour laser, active impurity, pump conditions.*

1. Introduction

Years of intense activity by various research groups in the world engaged in research and development of copper vapour lasers (CVLs) have culminated in commercial production of efficient sources of coherent radiation for various applications in science, engineering and medicine [1 – 3].

In recent years, scientists have been mainly interested in CVLs whose active medium is modified by introducing active impurities such as H_2, HBr and HCl [2, 4, 5]. The presence of such electronegative impurities in the active medium accelerates relaxation and recombination of plasma in the time interval between pulses and leads to an increase in the voltage across the gas-discharge tube (GDT) during the pump phase [4, 5]. In turn, this leads to an increase in the pulse repetition rate, efficiency and the output power of lasers [2, 5].

Among the CVLs with modified kinetics, a copper bromide vapour laser occupies a special place. Despite its relative simplicity compared to the well-known CVL, the CuBr laser with H_2 or HBr admixture has high frequency and energy parameters [6, 7].

At present, the active elements of the CuBr laser can work either in the self-heating regime or by using the independent heating of copper bromide containers [8, 9]. They are equipped with special generators of H_2 and HBr [7, 10] which are used for introducing the required amount of admixture to the main buffer gas – neon. However, a number of questions concerning the choice of the optimal quantity of admixtures and their dependence on the pump conditions still remains to be solved.

In particular, the following problems are still waiting for their solution:

(i) How does an increase in the pressure of the buffer gas neon (from 10 to 100 Torr) affect the pressure of the H_2 admixture required for attaining the highest radiation power?

(ii) What is the pressure of the H_2 admixture required for attaining the highest radiation power upon an increase in the voltage across the GDT and in the pump power?

(iii) What will be the optimal pressure of the H_2 admixture upon a transition to high pulse repetition rates (up to 100 kHz)?

(iv) How will the optimal pressure of the vapours of the active substance (copper bromide) change upon an increase in the pressure of the buffer gas Ne and the pulse repetition rate?

(v) What are the pressures of other impurities, especially HBr, required for achieving the maximum radiation power of the CuBr laser under various conditions of excitation? (It was established by us earlier that, like H_2, this admixture also increases the efficiency and laser power, and the use of HBr instead of H_2 is preferable from technological point of view [7].)

The present study is devoted to an analysis of these problems.

2. Experimental

Gas-discharge tubes with diameters 2.6 and 3.8 cm for active zone lengths of 76 and 96 cm respectively were used to study the energy parameters of a CuBr laser with H_2 and HBr impurities depending on the excitation conditions. In addition, the pressure of the optimal concentration of the H_2 admixture in the GDT with a large active volume (diameter 5 cm, length 145 cm) was determined quantitatively. In all the cases, the self-heating design of the GDT was used [9] and a differential manometer (with a scale division of 0.01 Torr) could be connected to it from the anode side to control the pressure of the active substance and the active impurities being introduced.

The GDT had inbuilt reversible generators of HBr, intended not only for supplying it to the working zone of the laser, but also for pumping back to the generator. The

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concentration of HBr was varied over a wide range by the heater temperature. The optimal concentration of the admixture was determined from the maximum radiation power. For a constant temperature of the heater, the HBr concentration was fixed at a certain level. H_2 was supplied to the GDT of the laser from the cylinder through the main pipeline.

The GDT was excited by using a direct discharge of a KVI-3 capacity across the GDT using a thyratron switch. A water-cooled TGI1-1000/25 thyratron was used for pumping GDTs of diameters 2.6 and 3.8 cm with switchable powers up to 3 kW. The 4 – 5 kW power switching for a GDT of diameter 5 cm was carried out by alternately triggering two thyratrons. A TGU1-1000/25 tacitron was used for exciting a GDT of diameter 2.6 cm at frequencies 30 – 100 kHz. No special optimisation (pulse compression, voltage elevation) of the pump pulse was performed. The radiation power was measured with an IMO-2 power meter, and the temperature of the GDT wall was measured with a chromel – alumel thermocouple.

The optimal pressure of the H_2 admixture (corresponding to the maximum output power of the CuBr laser) at different pressures of the Ne buffer gas and different pulse repetition rates was determined as follows. Several measurements were made for each fixed pressure of the Ne buffer gas at a given pulse repetition rate in the pressure range of 15 – 100 Torr. First we measured the output power of a laser operating on pure neon (at a pressure of, for example, 15 Torr) without H_2 impurity. Then H_2 was supplied to the cold evacuated GDT (pressure 0.1 Torr) followed by neon (at a pressure of 15 Torr), and the radiation power was measured. The entire pressure was repeated for the same pressure of the Ne buffer gas, but the pressure of the H_2 admixture was increased each time with a step of 0.05 Torr. Thus, the optimal pressure of the H_2 admixture corresponding to the maximum output power was determined. In all cases, the power supply voltage and the input electric power were maintained at a fixed level.

The effect of the H_2 admixture on the parameters of the CuBr laser operating on high-pressure neon during scaling of the power supply voltage was studied using the following technique. The power supply voltage was varied from 4 to 10 kW with a step of 1 kW. The output power of the laser with and without H_2 admixture in the range 0.1 – 0.4 Torr was measured at each point by using the above technique.

The optimal concentration of HBr admixture under various conditions of laser pumping differed from analogous measurements with H_2 admixture when hydrogen was supplied to the cold GDT. In this case, lasing was achieved without the HBr admixture. After the establishment of a stable power level, the readings of the manometer connected to the GDT were nullified and the HBr generator was switched on. Thus the optimal pressure of HBr corresponding to the maximum output power was determined. The vapour pressure of the working substance CuBr for a laser operating at high pulse repetition rates and at various pressures of the buffer gas was estimated quantitatively in the same way as the pressure of HBr. The discharge was triggered and the GDT was brought to the working temperature without CuBr vapour supply. Then the readings of the manometer connected to the GDT were nullified and the CuBr containers were heated. The readings of the manometer were recorded at the maximum radiation power.

Note, however, that by the pressure of the working substance CuBr, we mean the fraction of pressure by which the total gas pressure in the GDT increases. This happens due to the supply of not only vapours of CuBr in pure form, but also the products of its dissociation which later participate in chemical reactions with bromine, hydrogen, etc., in the discharge. Hence, we are dealing with the total pressure of the working substance and the products of its decomposition in the plasma, which allows us to determine the overall pattern of variation of the CuBr vapour pressure.

Of course, these measurements are made with a certain error. This is mainly due to the fact that the matching between the GDT and the pump generator varies as a result of the supply of vapours of CuBr, and especially HBr. This leads to a variation of the energy input to the GDT which, in turn, affects the total gas pressure. Hence in some experiments we measured the change in the gas pressure in the GDT upon a change in the wall temperature by 20 – 50 °C (e.g., due to the supply of HBr to the working volume). This was then taken into account while determining the pressure of the HBr admixture.

We believe that such a technique allows us to follow the general behaviour of the HBr admixture pressure as well as CuBr pressure. This is also confirmed by the fact that the manometer readings return to their initial zero values when the heating of the HBr generator or of the CuBr containers is discontinued.

3. Experimental results and discussion

The positive effect of HBr (H_2) impurities on the lasing characteristics of CuBr – Ne laser was found by other authors (see, for example [2, 4]) and in our earlier works as well as in the present study in several experiments with tubes of different diameters. The dependence of the average output power on the buffer gas pressure is worth noting. One can see from Fig. 1 that the maximum of the average power for H_2 admixtures (0.25 – 0.45 Torr) is displaced towards lower Ne pressures (15 – 20 Torr) compared to the case of pure neon (20 – 30 Torr). For HBr admixtures (0.22 – 0.28 Torr), however, the maximum of the average power is displaced relative to the maximum for H_2

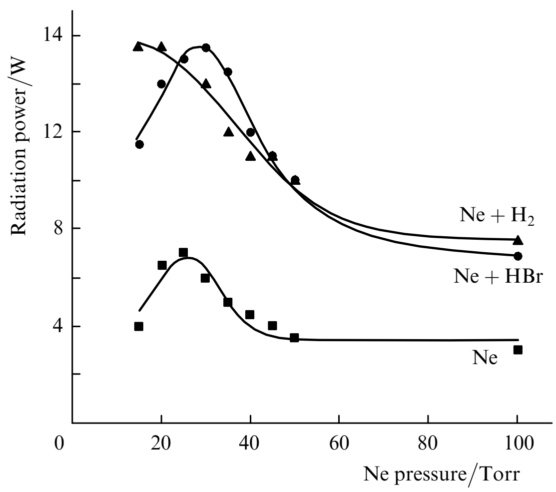

Figure 1. Dependence of the output power of the CuBr laser (gas discharge tube diameter 3.8 cm) operating in a discharge in neon without and with H_2 and HBr admixtures on the Ne buffer gas pressure. The power supply voltage is 7 kV in all cases.

impurities by 10 – 20 Torr towards higher Ne pressures. This fact is interesting for applications because it is known that an increase in the optimal pressure of the buffer gas Ne has a positive effect on the service life of the active element.

Experiments involving a GDT of diameter 3.8 cm show that the increase in the pressure of the buffer gas Ne from 15 to 100 Torr leads to a decrease in the pressure of the optimal admixtures H_2 and HBr (Fig. 2). This is due to the fact that pumping of the GDT was performed under a constant power supply voltage of 7 kV for a Ne pressures of 15 as well as 100 Torr, while the breakdown voltage increases with pressure. Hence the voltage across the GDT and the concentration of the H_2 (HBr) admixture must be increased under such conditions for attaining the highest output parameters. This is illustrated quite well in Fig. 3. The results presented in this figure show that the optimal H_2 admixture pressure and the output radiation power increase with the power supply voltage under high buffer gas pressures. Similar results are also achieved for HBr admixtures.

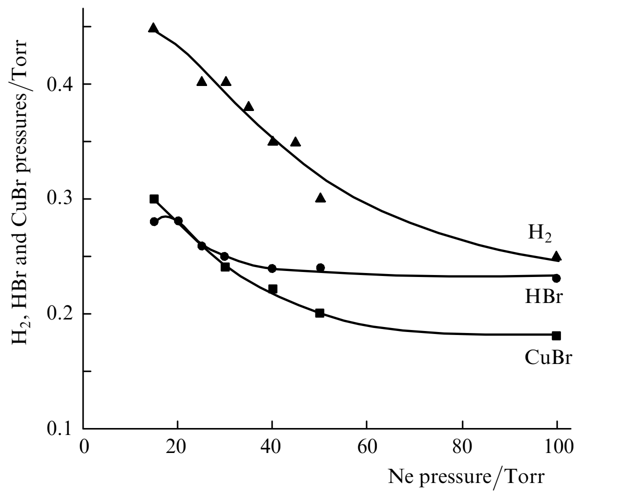

Figure 2. Dependence of the CuBr vapour pressure and pressure of optimal admixtures H_2 and HBr on the Ne buffer gas pressure for a gas discharge tube of diameter 3.8 cm.

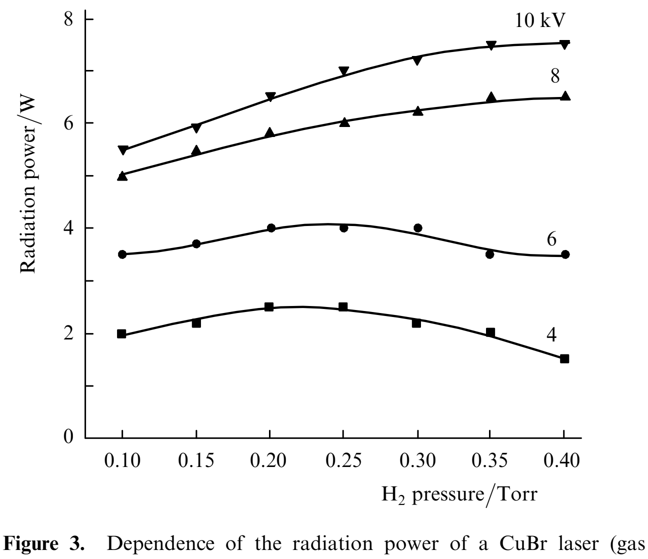

Figure 3. Dependence of the radiation power of a CuBr laser (gas discharge tube diameter 2.6 cm) on the pressure of H_2 admixture for various supply voltages [the buffer gas (Ne) pressure is 100 Torr].

Experiments show that the concentration of the H_2 admixture must be higher than that of the HBr admixture (see Fig. 2). This fact can be attributed to the positive role of the HBr molecules in the kinetics of the given laser. HBr molecule has a high dissociative adhesion cross section, which leads to a delay of the current pulse relative to the applied voltage in the active pump phase [4]. Of course the addition of H_2 to the discharge leads to generation of HBr also. However, in our case, HBr is supplied to the GDT in pure form. When H_2 is introduced, hydrogen has to react not only with bromine to form HBr, but with other plasma components also.

The following observations can be made about the pressure of the working substance, viz., CuBr (it would be more appropriate to write Cu_nBr_n, where n varies from 1 to 3 [1, 2]). Experimental results indicate that the CuBr pressure also decreases upon an increase in the neon pressure, which is apparently due to an insufficiently high voltage across the discharge gap.

It was established earlier during the scaling of the pump power (from 1 to 5 kW) of the $CuBr-Ne-H_2$ laser with a GDT of diameter 2.6 cm and an active zone of length 76 cm [11] that large amounts of H_2 admixtures (0.3 – 0.4 Torr) are required for increasing the energy input to the discharge. In this case, the increase in the input energy is mainly due to an increase in the discharge current, which leads to an increase in the electron concentration as well as its prepulse value. It follows hence that a large amount of hydrogen is required for effective plasma relaxation in the after-glow process.

It should be interesting to study the behaviour of the active admixture concentration upon a variation in the tube diameter. It follows from Fig. 4 that the pressure of the optimal H_2 admixture increases linearly with the GDT diameter. This is apparently due to the fact that in addition to the bulk relaxation of plasma in the period between pulses, relaxation at the wall occurs as a result of diffusion of particles to the GDT wall in narrow tubes. In tubes of larger diameter, higher concentrations of active admixtures are required for accelerating the relaxation process.

A similar picture is also observed upon increasing the pump pulse repetition rate (Fig. 5) because the time interval between pulses becomes shorter and the amount of admixture should be increased to accelerate the plasma relaxation processes (primarily for the electron component). The

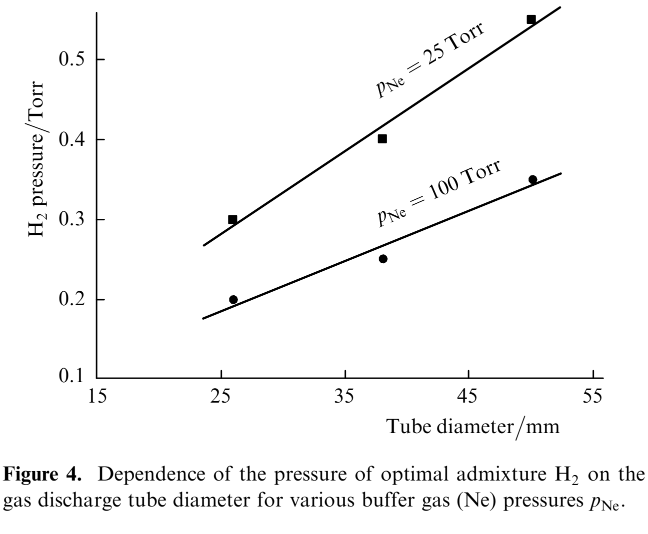

Figure 4. Dependence of the pressure of optimal admixture H_2 on the gas discharge tube diameter for various buffer gas (Ne) pressures p_{Ne}.

optimal concentration of the active substance CuBr decreases upon an increase in frequency. This is apparently due to the fact that not all copper atoms combine with bromine upon a decrease in the interval between pulses, and free copper atoms are accumulated. It is important to note that the voltage must be lowered (e.g., from 6 – 7 to 4 kV at a frequency of 100 kHz) upon a transition to high pulse repetition rates. This means that a further increase in the H_2 admixture pressure can be expected for small working volumes and for maintaining voltage at a preset level. Unfortunately, real switches (tacitrons in the present case) are unsuitable for maintaining high voltages at frequencies exceeding 50 kHz.

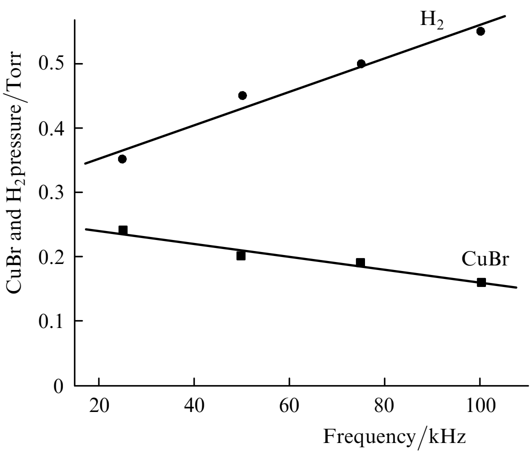

Figure 5. Dependence of the optimal CuBr vapour pressure and pressure of the H_2 admixture on the pulse repetition rate of the CuBr laser (gas discharge tube diameter 2.6 cm).

A comparison of the output parameters of the CuBr – Ne and CuBr – Ne – H_2 lasers (with a working volume of 400 cm^3 [11]) obtained by us with the parameters of the Kristall LT40Cu copper vapour laser of approximately the same volume (350 cm^3) shows that the CuBr laser with the H_2 admixture has a lower output power than the copper vapour laser even for an input power of 12.5 W cm^{-3}. For a specific power input of 11 W cm^{-3} to the discharge, the output power of the standard Kristall LT40Cu copper vapour laser is 40 W [12], which is twice as high as the output power of the CuBr laser. However, an output power exceeding 40 W and a much higher efficiency can be attained for the same pump power (4 kW) in the case of pumping of the active element of the CuBr laser of a much higher volume (up to 4×10^3 cm^3) [13 – 15]. Note also that the output powers for copper vapour lasers presented in [12] were obtained using the Bloomlein scheme with voltage doubling and pump pulse compression.

4. Conclusions

We have shown experimentally that H_2 and HBr admixtures increase the output power of the CuBr – Ne laser, and higher concentrations of H_2 than of HBr are required to achieve the maximum output power.

We have found that under identical pump conditions, the optimal pressure of H_2 being supplied at high buffer gas pressures ($\sim$ 100 Torr) is lower at low neon pressures (25 Torr) due to an increase in the breakdown voltage. An increase in the working voltage and the pressure of the H_2 admixture increases the output power, which approaches the output power at low neon pressures.

To increase the pump power requires high optimal pressures of the active impurity (H_2 or HBr).

Experiments with tubes of various diameters reveal a linear dependence of the admixture being introduced on the tube diameter and the pump pulse repetition rate, which is due to plasma relaxation processes during the time intervals between pulses. At the same time, the optimal pressure of the working substances decreases with increasing pulse repetition rate, which may be due to accumulation of free copper atoms caused by a decrease in the interval between pulses.

The advantages of the CuBr vapour laser with active admixtures over standard copper vapour lasers become more prominent when larger volumes of active elements are used.

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