Optimization of power characteristics in the gas discharge plasma in working mixtures of HgBr laser

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The power and lifetime characteristics of working mixtures in mgBr lasers in the high-frequency discharge plasma are optimized. The average output power of 6.8 mW has been achieved in the combined surface and barrier discharge at the repetition rate of pump pulses of 1900 Hz.

Introduction

To further optimize the power and lifetime characteristics of a HgBr laser, new data on radiation intensity as a function of medium composition, partial pressure of the components, pump pulse repetition rate, energy contribution, and other parameters are needed. Some data were obtained in studying spontaneous emission from the plasma of glow discharge in working (two-component) mixtures of a HgBr laser.[1–3]

In this paper we present some results of our research in multicomponent mixtures and enhanced frequencies.

Experimental setup. Measurement technique

Radiation from HgBr molecules (λ = 502 nm) was obtained in the plasma of glow longitudinal and barrier discharges (occurring simultaneously) in the mixtures of mercury dibromide and gases at atmospheric pressure.

A gas discharge cell (Fig. 1) was close in its design to that proposed in Ref. 4. A 20-cm long coaxial quartz tubes *1* and *2* were sealed at the ends. The outer diameters of the tubes were 15 and 35 mm, respectively. The ring-shaped electrodes *3* were made from a stainless steel and spaced by 18 cm gap. The electrodes of the DRT–240 mercury lamp were used as the leads-in. They were welded in the side surface of the cell. The quartz tube *1* housed a metal tube *4*. The perforated electrode *5* with 72% transmittance was fixed at the outer diameter of the tube *2*. To fill the cell with a gas and to pump it out, the quartz glass inlet connection *6* was welded in the side wall of the cell. It housed a capillary tube about 1 mm in diameter, which served for decreasing the escape of the mercury dibromide from the cell through the evacuation system outside. The thickness of the discharge zone and the length of the glow of the volume discharge were 7.5 mm and 9 cm, respectively. The radiation left the gas discharge cell normally to the surface of the outer quartz tube.

When the working mixture in the vessel *7* was excited by the barrier discharge, the voltage pulse was applied to the gap between the tube *4* and perforated electrode *5*. When both the barrier and surface discharges were used, the high voltage was applied to the metal tube and one of the electrodes *3*, while another one electrode *3* and the grid were grounded.

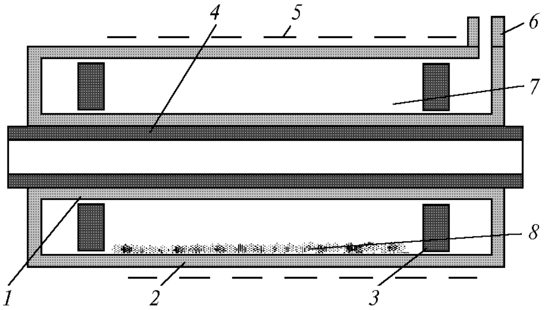

Fig. 1. Design of the excimer lamp.

In contrast to Ref. 1, the partial pressure of $HgBr_2$ vapor in working mixtures was obtained due to dissipation of the volume discharge energy.

The gas discharge plasma in working mixtures was generated and excited by the pump pulses of 100 ns duration with the voltage amplitude of 20 to 40 kV and the pulse repetition rate of 400–2000 Hz. A TGI1–1000/25 thyratron with a forced air cooling was used as a switch in the pulse generator. The charge-storage capacitance of 6.8 nF was build up of KVI–3 low-inductance capacitors. It was recharged through the primary winding of the step-up transformer with the transformation coefficient equal to three. The transformer was fabricated on ferrite rings 12 cm in diameter.[5]

The optical signal (λ = 502 nm, $B^2\Sigma^+_{1/2} \rightarrow X^2\Sigma^+_{1/2}$ vibronic transition of HgBr* molecule), upon passage through the diaphragm with the area of 1 cm^2 and a SZS–16 color glass filter with the transmission

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maximum at λ = 500 nm, entered into the measuring head of the Kvarts–01 device, which measured the mean power of radiation.

Working mixtures were prepared directly in the gas discharge cell as the cell was sequentially filled with a heavy inert gas or nitrogen and a light buffer gas (helium). Mercury dibromide *8* (see Fig. 1) in the amount of 10 mg was first fed into the gas discharge cell. The cell was degassed by warming-up at 50°q and pumping out during 2 hours.

Dependence of radiation intensity on the mixture composition and pumping conditions

The dependence of radiation intensity on the composition was measured at the pump pulse repetition frequency of 1000 Hz and the pulsed voltage of 18 kV. The experiments were conducted in two-, three-, and four-component mixtures: $HgBr_2$:He, $HgBr_2$:N_2:He, $HgBr_2$:Xe:He, and $HgBr_2$:Xe:N_2:He.

In a two component mixture of $HgBr_2$:He an increase in the helium pressure from 141 to 200 kPa resulted in a 1.7 times increase in the mean power of output radiation. In the three-component mixtures (curves *1* and *2* in Fig. 2) the maximum power was achieved at the xenon partial pressure from 2.03 to 4.05 kPa and the nitrogen partial pressure from 12.13 to 47.96 kPa. The mean output power in four-component mixtures was higher than in a three-component mixture with xenon, but lower than that in a three-component mixture with nitrogen. The mean power ratios for the mixtures optimal in the component composition were the following: 1:1.9:4.2:21.5 in the mixtures 1:2:3:4, where 1 is for $HgBr_2$:He (helium pressure of 121.6 kPa), 2 is for $HgBr_2$:u e:He (u e:me = 1:39), 3 is for $HgBr_2$:u e:N_2:He (u e:N_2:He = 1:10:29), and 4 is for $HgBr_2$:N_2:He (N_2:He=1:3).

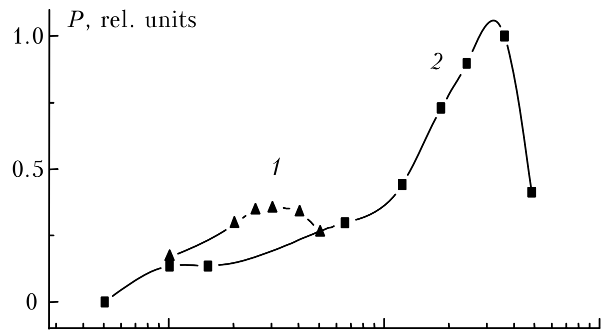

Fig. 2. The mean output power vs. partial pressure of xenon (curve *1*) and nitrogen (curve *2*) in the mixtures of $HgBr_2$:u e:He and $HgBr_2$:N_2:He, respectively. The total pressure of the gas mixture was 121.6 kPa.

Note that in the mixtures with molecular nitrogen the discharge homogeneity retains up to the nitrogen pressure about 48 kPa. At a higher nitrogen pressure, radial spark channels arise. Positions of these channels permanently change. The discharge starts to pulsate. In the mixture with xenon, upon achievement of the upper limit of xenon pressure (~ 4 kPa), the spark channels are directed along the axis of the gas discharge tube.

Figure 3 shows the mean power of output radiation as a function of the number of pulses in one portion of the working medium. The mean power grows faster in the mixture $HgBr_2$:N_2:He (curves *1* and *2*) than in the mixture $HgBr_2$:u e:He (curve *3*). As the maximum mean power is achieved, the mixtures with nitrogen are more stable than the mixtures with xenon. Thus, for the mixture $HgBr_2$:N_2:He (N_2:He = 1:4), upon achievement of the maximum value, the mean output power decreased by no more than 10% for $8{\cdot}10^5$ pulses.

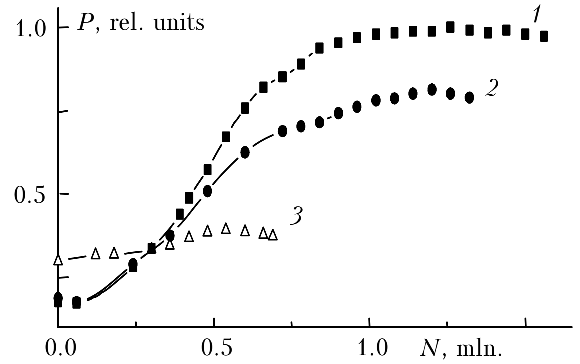

Fig. 3. Mean output power vs. total number of pulses for different mixtures: $HgBr_2$:N_2:He (N_2:He = 1:4) (curve *1*); $HgBr_2$:N_2:He (N_2:He = 1:5.67) (curve *2*); $HgBr_2$:Xe:He (Xe:He = 1:39) (curve *3*). The total pressure was 121.6 kPa. The pump pulse repetition rate was 1000 Hz.

Besides the radiation characteristics as functions of the component composition of the working medium, we have studied the mean output power as a function of pump voltage and the pulse repetition rate. As the energy stored in the 0.06 nF dielectric capacitance (quartz glass) increases from 0.13 to 0.34 mJ/cm^3, the mean output power increases proportionally (Fig. 4). This occurs also as the pulse repetition rate increases from 400 to 1900 Hz. No saturation of the power as a function of the repetition rate was observed in the range under study. For the mixture $HgBr_2$:N_2:He (N_2:He = 1:3) at the total pressure of 121.6 kPa and pulse repetition rate of 1900 Hz, the mean output power of 6.8 mW was achieved. The mean power obtained at pumping of the gas discharge tube by only barrier discharge was 1.5 times lower than that obtained at pumping by the combined (barrier and surface) discharge. The relatively low values of the mean output power in comparison with the data from Refs. 4 and 6 for XeCl* and KrF* molecules can be explained by low concentration of $HgBr_2$ vapor (about 10^{13} cm^{-3}) corresponding to the temperature of the outer wall of the cell about 50°C.

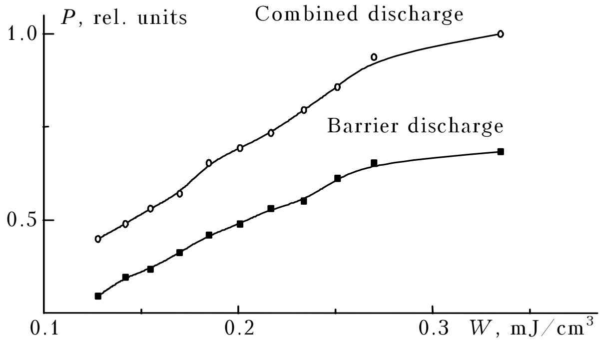

Fig. 4. Mean output power vs. energy stored in the dielectric capacitance.

Conclusion

The study of power characteristics of the gas discharge plasma in the HgBr laser active media of different composition and under different pump conditions allows the following conclusions to be drawn: 1) the linear increase of the mean output power depends on the pump pulse repetition rate within the range from 400 to 1900 Hz; 2) the mixtures $HgBr_2$:Xe:N_2:He and $HgBr_2$:N_2:He are optimal in the mean output power and efficiency; 3) the lifetime of a mixture is more than 12 hours.

The results obtained allow us to look forward to future creation of HgBr laser operating with high (above 1000 Hz) pulse repetition rates of both lasing and pump pulses, which warm up the working medium due to dissipation of the discharge energy, what will increase significantly the mean output power and efficiency.

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