SMALL-SIZE SLAB CO_2-LASER EXCITED WITH A DC DISCHARGE WITH SHORT-PULSE PREIONIZATION

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We have developed and investigated a slab CO_2*-laser with the diffusion cooling excited with a DC discharge sustained by high-voltage high-repetition rate preionization pulses. Volt-ampere characteristic of the discharge was measured under different conditions of preionization, deposited energy, pressure, and content of a gas mixture. We have also studied the dependence of output laser emission power on the parameters of the resonator and conditions in the active medium. At active length of* 22 cm, *cavity width of* 14 mm *and slab height* d = 4 mm *the output power was found to be* 27 W. *This value corresponds to the specific power per* 1 cm^2 *area of the active volume* $S_A \sim 0.9$ W/cm^2 *and to the power in units of* $S_A/d \sim 3.5$ W/(cm^{2}mm^{-1}). *These parameters are comparable with the best parameters of the HF-excited slab* CO_2 *lasers published in literature.*

INTRODUCTION

Recently, the improvement of specific output parameters and decrease of active medium size of CO_2 lasers has become the subject of many studies. The progress in this area is associated, on the one hand, with the use of the wave-guide principle and, on the other hand, with the refusal of linear geometry of the discharge channel.

The highest output parameters were demonstrated with the use of a slab (planar) geometry. Therewith, since the DC excitation can not inherently provide uniform energy deposition, all investigations and constructions are based on a transverse HF-pumping. It is conventional to characterize the slab systems by specific parameters normalized to the unit area of electrodes. The best results reported in literature are as follows: output power is 2 W/cm^2 at pumping power of ~13 W/cm^2 and the gap of 2.25 mm (see Ref. 1). Record results of 2.1 W/cm^2 have been achieved with the participation of one of the author (see Ref. 2). Further progress appears to be quite possible.

In spite of a doubtless promise of the further development of this method its application is to a certain extent difficult. First we should mention the difficulty of matching the generators operating at 10^8 Hz frequency with the load and their high cost. Therefore a search for alternative pumping schemes is quite an urgent problem.

One of possible schemes using a direct current source stabilized by magnetic field is considered in Ref. 3.

We call attention to another one possibility of exciting active media of CO_2 lasers with a DC semi-self-maintained discharge preionized by short high-voltage pulses (see Refs. 4 and 5). In the subsequent works this method has been applied to pump big technological lasers with a convection cooling (see Ref. 6) and diffusion towards the walls of a coaxial laser chamber (see Ref. 7). Therewith specific output power and energy deposition were noticeably higher as compared to those reported in Refs. 4 and 5. Nevertheless, scalability of the parameters when going to small-size slab lasers remains only poorly studied.

The aim of the present paper is to develop an experimental model of a compact slab CO_2 laser with a DC semi-self-maintained discharge sustained by short high-voltage pulses and to investigate its specific energy parameters.

LASER DESIGN

An active medium is formed inside a discharge chamber between Al_2O_3 ceramic plates spaced at 4 mm. Their thickness, length, and width are 1 mm, 22 cm, and 2.4 cm, respectively. The DC discharge occurs between copper plates which serve as side walls of the chamber. One electrode is grounded, another one is coupled to a DC power supply providing voltage of 1000 V and electric current up to 1 A. The ballast resistor in the DC circuit is not used that allows us to avoid power losses characteristic of the DC discharges. High-voltage preionization pulses are applied to hollow duralumin external electrodes which are pressed against the external side of the dielectric plates and have common with DC electrodes water cooling system.

The scheme forming preionization pulses is similar to that described in Refs. 6–8. It is constructed on the base of pulse generator with the

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capacitive energy storage operating in the complete discharge mode. The capacitance of the storage varied from 1 to 3 nF. The capacitor was discharged through a thyratron TGI 1–100/8 controlled by a master generator producing pulses with the duration of 1 μs and amplitude on the order of 200 V and operating at pulse repetition rate from 1 to 30 kHz. Pumping pulses were delivered to the discharge chamber using a step-up pulsed transformer. As a result, 10 kV-voltage pulses with the duration of the order of 100 ns and rise-time of about 20 ns were applied across the electrodes of the auxiliary discharge at a repetition frequency up to 30 kHz.

Stable optical cavity composed of a concave mirror with the radius of curvature of 4 m and a plane output mirror placed 25 cm apart was used for generating laser radiation. Ge-Au photodetector records time behavior of the radiation power with the resolution of 1 μs.

EXPERIMENTAL CONDITIONS

Output laser parameters were recorded at different discharge and preionization parameters, deposited power, composition and pressure of the working mixtures. The frequency and amplitude of the preionization pulses varied from 5 to 30 kHz and from 4 to 12 A, respectively. The peak power deposited into the discharge from the DC power supply was about 500 W, while that from the pulse generator could be changed from 20 to 50 W. The gas mixture was cooled due to the diffusion towards the chamber walls. The measurements were performed at low gas circulation. The pressure range from 20 to 80 Torr was under study. Gas mixtures with different helium content (CO_2:N_2:He = 1:1:M, where M = 4, 5 or 8) were used. The output mirror parameters providing for the lasing effect were as follows: working aperture from 10 to 24 mm, transmittance from 3 to 28%.

RESULTS AND DISCUSSION

Figure 1 depicts the discharge volt-ampere characteristics obtained at different repetition frequencies of the preionization pulses. The voltage and current averaged over time were measured in the circuit of the DC power supply. The characteristics shown in the figure were obtained at pulse repetition rates from 10 to 30 kHz. The pulse amplitude was fixed at 8 A. We used gas mixtures of CO_2:N_2:He = 1:1:8 at a pressure p = 57 Torr. It is seen that the characteristics are typical for the semi-self-maintained discharge. In other words, the discharge current increases with increasing voltage. Besides, Fig. 1 indicates that the conductivity of the discharge gap increases with the pulse repetition rate increase.

Figure 2 presents the laser emission power measured with a calorimeter versus the power deposited into the discharge, the experimental condition being the same as in Fig. 1. One can see that at a fixed energy deposition the output power falls as the pulse repetition rate increases. Most likely this is because certain value of power deposited into the discharge at its lower conductivity is achieved at higher reduced strength of the electric field, E/N. The strength E was determined as a ratio between the average voltage across the DC discharge electrodes and the discharge gap width. When estimating the number density of particles N, variations in the gas pressure with the energy deposition, in accordance with Ref. 9, were taken into account. The output power measured with a calorimeter as a function of E/N parameter for the deposited pump power of 80 and 120 W is shown in Fig. 3. The ratio E/N could be changed by changing preionization pulses repetition frequency. It is seen that for increasing the laser power the reduced electric field strength should be increased. This is achieved by varying the preionization pulses off-duty factor.

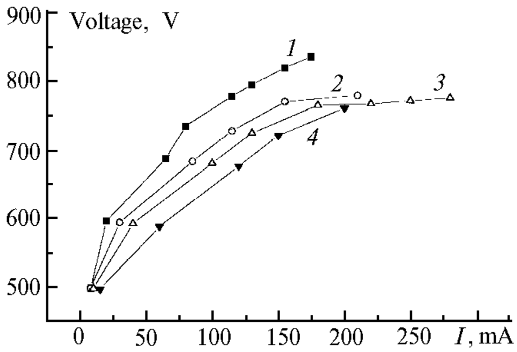

FIG. 1. Volt-ampere characteristics of the discharge obtained at different repetition frequencies of the preionization pulses, f; at f = 10 kHz *(curve 1);* 15 kHz *(curve 2);* 20 kHz *(curve 3) and* 30 kHz *(curve 4).*

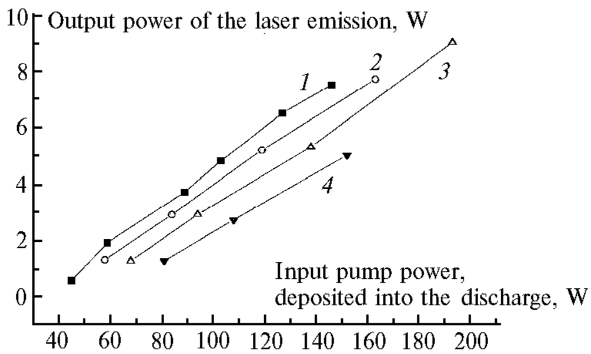

FIG. 2. The output power of the laser emission as a function of pump power deposited into the discharge. Preionization conditions are the same as those shown in Fig. 1.

The effect of gas mixture pressure on the output emission power is well seen in Fig. 4 which demonstrates the average output power measured at different deposited power and gas pressures. Curves *1*, *2*, *3*, and *4* were obtained at $p = 23$, 30, 38, and 57 Torr, respectively. The preionization conditions were fixed, the amplitude of pulses and repetition frequency were 8 A and $f = 20$ kHz, respectively. The gas composition was CO_2:N_2:He = 1:1:8. One can see that the maximum output power is achieved at a pressure of 40 Torr.

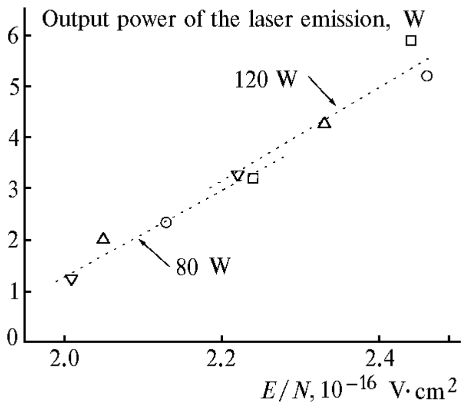

FIG. 3. The output power of the laser emission as a function of the reduced strength of the electric field. $f = 10$ (□), 15 (o), 20 (Δ), and 30 kHz (∇).

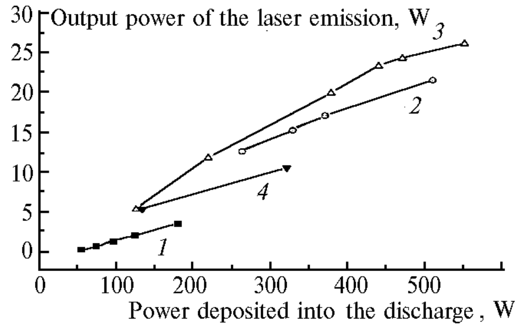

FIG. 4. The output power of the laser emission as a function of the electric power deposited into the discharge at different pressures of the gas mixture.

Investigation of the effect of preionization pulse parameters on the laser emission power performed indicates that the amplitude of pulses providing maximum output power depends both on the gas mixture pressure and on the power deposited into the discharge.

The maximum output power of 27 W was obtained using the mirror 14 mm wide and having the transmittance of 6% that corresponds to the following specific parameters: the power per unit length of the active medium is about 1.2 W/cm, the power per unit square of the active medium involved in lasing $S_A \sim 0.9$ W/cm^2, the power in units S_A/d (d is the slab height) introduced in Ref. 10 from the consideration of scaling the HF-discharges is as high as 3.5 W/(cm^2·mm^{-1}). The discharge parameters are the same as in Fig. 4. It is also seen that the output power – energy deposition dependence is not saturated. In our experiments power deposition was limited by 550 W for technical reasons. The above parameters, though being preliminary, are compared with the best results obtained for a slab CO_2 laser with the HF-pumping available from literature. We hope that optimization of the experimental conditions including the cavity parameters will make it possible to improve the absolute and specific output parameters.

Investigation of the time behavior of the output power demonstrates that laser radiation is modulated at a frequency of the preionization pulses. The percentage modulation m defined as the ratio of the power drop to the maximum power, $m = (P_{max} - P_{min})/P_{max}$, changed from 100% at $f = 7$ kHz to 20% at $f = 30$ kHz. This means that at high repetition frequencies the laser operates in the regime approaching the stationary one. The simplicity of going from that regime to a pulse-periodic one appears to be of a certain technological interest.

CONCLUSION

We have developed and investigated a slab CO_2 laser excited with a DC discharge with the preionization by short high-voltage pulses. The volt-ampere characteristics measured at different preionization conditions, deposited power, composition and pressure of the gas mixtures show that the discharge is semi-self-maintained electric discharge. The output power was also investigated at different optical cavity Q-factor and conditions in the active medium.

The output power of 27 W was obtained at the length of the active medium of 22 cm, the cavity width of 14 mm and the slab height of 4 mm. This corresponds to the power per unit area of the medium used, S_A, of 0.9 W/cm^2 and the power in units S_A/d of 3.5 W/(cm^2·mm^{-1}). Such parameters are compared with the best results for slab CO_2 lasers with the HF-pumping available from literature. One can hope that the optimization of the optical cavity and improvement of the pumping scheme will allow us to increase the absolute and specific output parameters.

Further multiparametric investigation of this laser appears to be useful. In particular, further search for the regimes with a better control over E/N parameter is of interest. It would be important to compare the results obtained using the HF-pumping with those obtained using the above scheme under the same operating conditions. Besides, a sealed-off operation regime deserves a separate consideration.

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