HIGH POWER CO_2 LASER WITH A COMBINED EXITATION SYSTEM

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In this paper we present an experimental model of an industrial CO_2 *laser developed using an original techique of volume discharge formation. In our experiments, discharge volume was* 560 cm^3. *Stable laser operation was obtained under the following conditions:* CO_2:N_2:He = 1: 8:12 *gas mixture at a total pressure of* 40 Torr, *rate of gas circulation of* 75 m/s, *pulse repetition rate of* 3.5 kHz. *Average power deposition on the stage of non-self-sustained discharge was* 4.5 kW *which corresponds to the specific input power of* 8 W/cm^3. *Results of studying laser output in a cw and repetitively pulsed operation mode are presented.*

The problems of high specific output power, high efficiency and advanced reliability of gas lasers are important for such applications as material cutting, surface layer hardening, etc. A number of technological CO_2 lasers with the output power of 1÷10 kW and higher are known to be developed on the basis of different techniques of volume discharge formation.

The main disadvantage of these tecniques is limitation of specific energy deposition and low working time of certain laser elements. Thus, e-beam pumping provides high specific output power, high output energy, and laser efficiency close to the quantum limit, but complicates the laser design and reduces reliability of operation due to the destruction of a separating foil.

Lasers pumped by self-sustained discharge are characterized by high value of electric field strength during energy deposition. This leads to lower laser efficiency and the discharge instability. Combined pumping does not allow high energy deposition.

The most interesting results on combined pumping of CO_2 laser has been published in Ref. 1. In this paper, decoupling of pulsed power supply producing plasma in the discharge gap and power supply of non-self-sustained discharge is realized by means of spatial separation of regions of self-sustained and non-self-sustained discharge. A barrier self-sustained discharge was formed between two vitrified steel tubes and was supplied from a high voltage, high frequency (100 kHz), high power (7.2 kW) source. In this case, we managed to reach a specific power input of 10–15 W/cm^3.

However, the results obtained seem to be the upper limit of this tecnique of excitation. This is related to the fact that when spatial separation of regions of self-sustained and non-self-sustained discharge is used an increase in electron number density in the region of self-sustained discharge results in recombination process faster than electron diffusion to the region of non-self-sustained discharge. Besides, the lifetime of electrodes of self-sustained discharge is not presented in Ref. 1.

Recently, a new method has been found that allows specific energy deposition to be increased at least an order of magnitude than that provided by the above described technique[2]. This method was realized with a model of electrode system composed of two semispherical electrodes with a separating grid[3] (the active volume was 83 cm^3).

In this paper, an attempt to develop experimental model of a technological CO_2 laser based on a combined excitation technique is described.

EXPERIMENTAL TECHNIQUE

The technique of a combined glow discharge formation is proposed to solve the problem of development of efficient CO_2 lasers with large active volume that are able to operate at gas pressures of 10-100 Torr. In addition, electric circuit that allows this regime is developed. High electron number density in the active medium is produced by a short self-sustained discharge whereas the main energy deposition (more than 90%) is provided by a non-self-sustained discharge at an optimal value of the electric field. The excitation diagram is presented in Fig.1.

Combined discharge is formed in the gaps between two profiled electrodes, *1* and *2,* and a middle electrode *3*. Non-self-sustained discharge is supplied by a capacitive storage C_0 charged to voltage U_0 optimal for laser excitation and connected to the profiled electrodes *1* and *2*. Self-sustained discharge that produces plasma with certain concentration occurs in the gaps *3–1* and *3–2*. This discharge is supplied by generators based on capacitors C_1 and C_2 with the common switch F. Capacitors C_3 with points *4* are used for preionization of the active medium.

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The presence of a middle electrode *3* and the use of a separate supply of self-sustained discharges in the gaps *3–1* and *3–2* with a common switch enabled us to decouple electric circuits without any special elements limiting the discharge current.

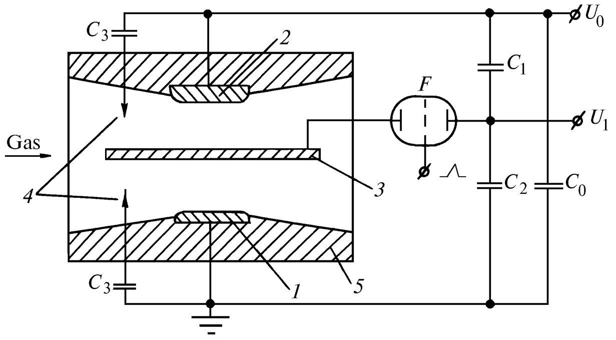

FIG. 1. Block diagram of a combined discharge excitation: are electrodes of the main discharge 1 and 2, the middle electrode 3, the preionization electrodes 4, and the discharge chamber 5.

Formation of a combined discharge is performed in the following way. The storages C_1 and C_2 are initially charged to a voltage U_1 and charging voltage of C_0 is U_0. After the switch is triggered a pulsed voltage is applied to the gaps *3–2* and *3–1*. This voltage is sufficient for self-sustained discharge initiation. Preionization of the gas is produced during the voltage rise by the sparks between points *4* and the middle electrode *3*. Capacitor C_3 limits the current of the preionization discharge.

Main energy loading in plasma produced by self-sustained discharge is provided by the capacitor C_0 during the stage of plasma recombination decay. The value U_0 is determined by conditions of the most efficient population of the upper lasing level (similar to the case of an e-beam controlled discharge).

In our experiments, the total discharge volume was 3.5×2×80 cm^3. Electrode separation was 1.5 to 2 cm. It was chosen to provide equal electric fields in the gaps. Location of the preionization electrodes can be varied with their displacement within 1 to 10 cm along and against the gas flow. The preionization capacitor used was from 1 to 2 nF.

Pulse repetition frequency of self-sustained discharge reached 10 kHz at a peak voltage of 15 kV. Capacity of the energy storage providing self-sustained discharge was 2.2 nF. Power supply for non-self-sustained discharge mantained constant voltage value across the discharge gap of 3 kV providing the electric power consumption about 8 kW.

The rate of gas flow in the discharge chamber varied from 0 to 75 m/s.

Main parts that were in contact with the active medium were made of stainless steel.

EXPERIMENTAL RESULTS

Based on the current waveforms of self-sustained discharge, the electron number density in the plasma prodused is calculated according to the expression:

$$n_e = I/e\,v\,S\ ,$$

here I/S is the current density of self-sustained discharge; e and v are the electron charge and its drift velocity, respectively. The values of drift velocity for nitrogen are presented in Ref. 4.

The energy deposited on the stage of non-self-susteined discharge was obtained by graphic integration of the product of current and voltage values:

$$W_0 = \int_0^t I(t)\ U_0(t)\ \mathrm{d}t\ ,$$

where $I(t)$ and $U_0(t)$ are values of the current and voltage on the stage of non-self-sustained discharge, respectively.

The electron number density and average power of non-self-sustained discharge versus composition of the gas mixture and total pressure are presented in Fig. 2. The electron number density decreases as gas pressure is increased if all other conditions are kept the same. Indeed, in that case the voltage maintained at the stage of self-sustained discharge is higher whereas decrease of discharge current at this stage is observed if the total energy deposition remains unchanged.

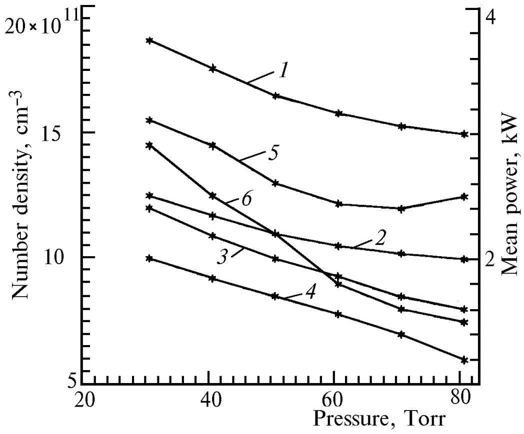

FIG. 2. Electron number density (curves 1–4) and the mean discharge power (curves 5, 6) versus gas pressure and mixture composition. The following mixtures were used: CO_2:N_2:He = 1:1:1 (*1*), CO_2:N_2:He = 1:10:10 (*3*), CO_2:N_2:He = 2:15:25 (*2*, *5*), CO_2:N_2:He = 2:25:15 (*4*, *6*).

Similar explanation is valid if we consider the influence of partial pressure of a molecular gas on the discharge parameters since it strongly affects the current voltage characteristic of a self-sustained discharge.

When analyzing the dependence of the input power on the composition of gas mixture, it is evident that energy loading is almost two times lower in the mixtures containing CO_2 as compared to He-N_2 mixtures. It should be noted that the presence of CO_2 molecules that absorb strongly in the UV range leads to a weaker preionization of the gas. As a result, electron number density is lower and discharge becomes less stable. These conclusions are confirmed by the dependence of electron number density and input power on gas pressure measured at different location of preionization electrodes with respect to the electrodes of the main discharge and on the preionization capacity (see Fig. 3). The closer located are spark gaps to the main discharge, the higher is the energy loading at the stage of non-self-sustained discharge.

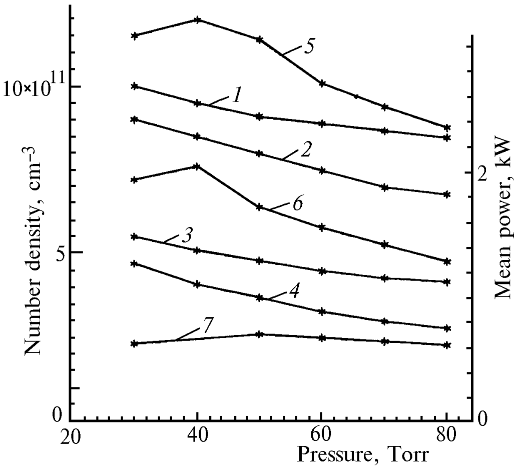

FIG. 3. Electron number density (curves 1–4) and mean discharge power (curves 5–7) versus gas pressure, electrode location and preionization capacity. Curves 1 and 5 were obtained with the preionization electrodes located from the side of a gas flow at a distance of 2 cm, C_3 = 2 nF; *curves 2, 6 correspond to the same conditions but* C_3 = 1 nF; *curve 3 shows results obtained with preionization electrodes located from both sides of the main gap at a distance of* 10 cm, C_3 = 2 nF; *curves 4 and 7 correspond to the data obtained with the preionization electrodes located from the opposite sides of the gas flow at a distance* 4 cm, C_3 = 2 nF.

When the gas flow reaches first electrodes of the main discharge and then electrodes of the preionization, the electron number density produced in self-sustained discharge is lower than that observed in the opposite case. This can be explained by the fact that plasma produced in the previous preionization pulses does not come into the discharge region. If the preionization capacity is increased, higher intensity of UV radiation is observed. This leads to higher initial electron number density, higher n_e in self-sustained discharge, improvement in discharge stability, and, as a result, to the possibility of operation at high pulse repeating rate.

In the course of our experiments, examination of maximum energy loading as a function of pulse repetition rate at different velocity of gas flow was performed (see Fig. 4). For given electrode configuration, maximum input power at the stage of non-self-sustained discharge can be reached if the fluorescence excited by self-sustained discharge is brighter from the side of the gas inflow. It should be pointed out that intensity distribution of the fluorescence depends both on pulse repetition rate and on the velocity of a gas flow. It is apparently related to specific configuration of electrode system and discharge chamber. Therefore, though no basic limitations for energy loading was established, the average power deposited on the stage of non-self-sustained discharge obtained at stable laser operation (without discharge constriction) is lower than the expected value. In a gas mixture without CO_2 it was 7.8 kW corresponding to specific energy loading of 14 W/cm^3 . In the presence of CO_2 a reduction of the mean power by a factor of two was observed. Maximum energy loading was obtained under the following experimental conditions: gas mixture was CO_2:N_2:He = 1:8:12 at a total pressure of 40 Torr , velocity of the gas flow in the discharge region was 75 m/s, and pulse repetition rate was 3.5 kHz.

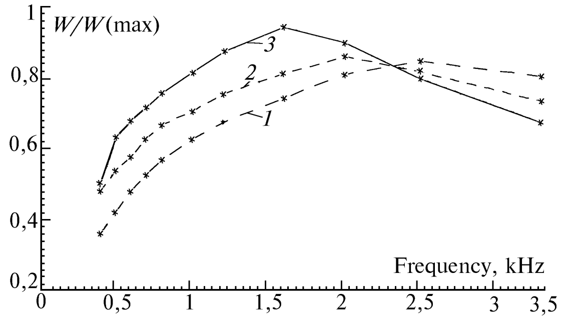

FIG. 4. Energy loading as a function of self-sustained discharge pulse repetition rate and velocity of the gas flow. Curves were obtained at a velocity of gas flow of 75 *(1),* 60 *(2), and* 40 m/s *(3).*

It should be mentioned that no wear of both main and preionization electrodes was evident after laser operation during about 1000 hours. Hence, no additional treatment of electrode surface was needed.

Experimental data obtained demonstrate the efficiency of excitation technique used and possibility of developing efficient technological lasers using it.

REFERENCES

1. H. Nagai, M. Hishii, M. Tanaka, et al., IEEE J. Quant. Electron. **29**, No 12, 2898–2909 (1993).

2. V.V. Osipov and V.A. Tel'nov, *"Discharge laser"* Inventor's certificate No. 713468 (USSR).

3. V.A. Tel'nov, *"Investigation into the output characteristics of* CO_2 *laser with high level of pumping,"* Candidate thesis, Sverdlovsk (1988), 153 pp.

4. R.A. Sierra, H.L. Brooks, A.J. Sommers, S.R. Foltin, and K.J. Nygaard, J. Phys. D: Appl. Phys. **14**, 1791–1801 (1981).