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To cite this article: A S Kiselev and E A Smirnov 2018 J. Phys.: Conf. Ser. 1058 012020

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Investigation of amplifying and electrical properties of plasma carbon dioxide lasers

A S Kiselev and E A Smirnov
Department of electronic instruments and devices, Saint Petersburg Electrotechnical University “LETI”, 197376, Saint Petersburg, Russia

E-mail: alex.kiselev.epu@gmail.com

Abstract. In this work devices to study the electrical and amplifying properties of the plasma of gas mixtures corresponding to carbon dioxide lasers were designs. The devices to a vacuum system that allows them to be pumped out and filled with a working gas mixture are connected. Experiments to study the current-voltage characteristics of the discharge at various pressures of the gas mixture and the diameters of the discharge gaps were carried. The discharge voltage decreases with increasing discharge current, which is characteristic of a discharge with a longitudinal positive column. Large number of experiments to study the enhancement of the emission of carbon dioxide laser in the discharge of various gas mixture were carried: CO$_2$, CO$_2$ : N$_2$, CO$_2$ : N$_2$ : He. The obtained dependences have a maximum at a certain pressure. The three-component mixture has the greatest amplification. The results of the studies were used when replacing the active gas mixture of a carbon dioxide laser, as well as in the educational process when studying the amplifying properties of plasma.

Gas-discharge lasers form the most extensive class of lasers. Gas-discharge lasers currently occupy a leading position in the fields of application. Gas-discharge lasers are beyond competition in terms of the degree of coherence of radiation, the developed ranges of generation wavelengths and output power levels. The unique properties of radiation from gas-discharge lasers, and the prospects for their development, allow maintaining relatively high volumes of production, development and application in such areas as metrology, recording, processing and transmission of information, technology, medicine and other [1, 2]. Gas-discharge lasers, including glow discharge lasers (GDL), are not only widespread but also quite complex devices in structure and manufacturing technology. From this point of view and taking into account the economic reality, it is quite logical to find ways to increase the service life of the gas-discharge lasers used, and to restore active elements in the event of complete loss of generation. The relatively short life of lasers makes this problem even more urgent. Possible reasons for the complete or partial failure of gas-discharge lasers are: a disturbance in the operation of the power source; increase in the level of losses in the optical resonator; reduction of amplifying in the active element of the laser. The service life of power supplies is much higher than that of active elements. In optical resonators, the main causes of a noticeable reduction in radiation power are the degradation and contamination of mirrors and Brewster’s windows. The main reason for the failure of the active element is the degradation of the active medium due to the leakage of atmospheric gases, gas desorption by elements of construction, the absorption of the working gas by the shell, by the electrodes and their spray products, and the diffusion of the working gas through the envelope.
The effect of the leakage process on the electrical parameters of the laser was studied experimentally and theoretically by comparing the potential gradient $E_z$ in the positive column for the pure active media of a CO₂-laser and media containing additives of atmospheric gases [3]. An automated calculation of the electron temperature $T_e$ required to find $E_z$ was carried out for recombination conditions on the walls of a longitudinal cylindrical tube with an internal radius $R$. In this work was assumed Maxwell distribution electron velocity, and approximation of the ionization cross section was a linear [4].

For multicomponent gas mixtures [5], on the left side of the ionization balance equation, the sum of the frequencies $\nu_j$ of ionization of all sorts of gases $j$ entering into the mixture was recorded:

$$\nu_i = \frac{h k (2.405)^2 T_e}{R^2 e}, \quad (1)$$

The average mobility of gas ions was calculated using the Blank law [6]:

$$\frac{1}{b_i} = \sum_j \frac{p_j}{b_{i0}}, \quad (2)$$

where $p_j$ is the partial pressure of the gas of type $j$; $b_{i0}$ is the unit (for $p = 1$ Pa) mobility of ions of a gas of type $j$ in its own gas.

To calculate the electron temperature $T_e$, expression (1) was transformed to the form:

$$\sum_j \nu_j(j) - \frac{23.1 h k T_e}{e d^2} = 0, \quad (3)$$

The longitudinal gradient of the potential in the positive column was found to be [7]:

$$E_z = \frac{3 k T_e \sqrt{\chi}}{2 e \lambda_e}, \quad (4)$$

where $\chi$ - coefficient of accommodation of electrons; $\lambda_e$ is the mean free path of electrons in a mixture of gases.

In the case of an GDL, the quantity $\chi$ can be determined from the experimental data. The average mean free path of electrons in the gas mixture with sufficient accuracy for practice can be determined from the expression:

$$\frac{1}{\lambda_e} = \sum_j \frac{p_j}{\lambda_{e0j}}, \quad (5)$$

where $\lambda_{e0j}$ is the unit (for $p = 1$ Pa) the mean free path of electrons in a gas of type $j$.

In the case of strong leakage of atmospheric gases into the active medium of the laser, there remains a cardinal solution-replacement of the gaseous active medium. Of all the ways to increase the life of active elements of gas-discharge lasers, the replacement of the gas active medium is the most laborious solution, since it assumes the depressurization of the active element. This raises a number of problems: the need for a vacuum pumping system and a set of working gases, the selection of optimal gas ratios in the working mixture for each model of the laser, the search for an optimal operating mode for the new mixture and others [8].

The regeneration of the generation ability of active elements of CO₂-lasers was carried out by the method of replace the gaseous medium. Preliminary, with the help of a specially designed layout (figure 1), were investigated the dependences of the amplifying $k_{amp}$ on the discharge current and pressure for different gas mixtures [9]. The voltage on the discharge decreases with increasing discharge current. The layout had length of active medium 0.33 m with a discharge channel diameter of 10 mm [10]. The ends of the layout were covered with Brewster windows of gallium arsenide. Below are the results obtained for pure CO₂ (figure 2), double (figure 3) and triple (figure 4) gas mixtures.
mixtures. All dependencies were obtained at a constant cooling water flow rate (0.53 gallons in minute).

Figure 1. Scheme of investigation of the amplifying properties of the active medium of a carbon dioxide laser

![Scheme of investigation](image)

Figure 2. Dependence of the amplifying on the pressure of carbon dioxide at different discharge currents.

![Dependence on pressure](image)

Figure 3. The dependence of the amplifying on the total pressure of the double gas mixture CO$_2$ : N$_2$ = 1 : 1 at different discharge currents.

![Dependence on total pressure](image)
Figure 4. The dependence of the amplifying on the total pressure of the triple gas mixture \( \text{CO}_2 : \text{N}_2 : \text{He} = 1 : 1 : 6 \) at different discharge currents

The study of the current-voltage characteristics was carried out on a layout having 4 discharge tubes of different diameters. Current-voltage characteristics have a falling character, which corresponds to lasers of a glow discharge. Figure 5 shows the CVC of the discharge for different diameters of the discharge gap and pressures of gas mixture.

Figure 5. 3D-plots of current-voltage characteristics of the discharge: (a) in a carbon dioxide; (b) in a gas mixture \( \text{CO}_2 : \text{N}_2 : \text{He}=1:1:6 \)

The dependences of \( k_{\text{amp}} \) on the pressure have a maximum. The maximum value of \((0.2 \ldots 0.3 \, \text{m}^{-1})\) increases with the transition from pure \( \text{CO}_2 \) to a mixture of \( \text{CO}_2 : \text{N}_2 : \text{He} (0.6 \ldots 0.7 \, \text{m}^{-1}) \). Similar results are useful both in the selection of the gas mixture of the \( \text{CO}_2 \)-laser, and in the study of the \( \text{CO}_2 \)-amplifier itself, for example, in the educational process. Connecting the amplifier to the vacuum system facilitates periodic over-filling with the active mixture in the event of its leakage. In order to ensure the maximum time between overflows in the laboratory version of the layout, it is possible to avoid using expensive helium and use either pure \( \text{CO}_2 \) or \( \text{CO}_2 \) with a \( \text{N}_2 \) [11].
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