Investigation of current-voltage characteristics of a glow discharge in molecular gases

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Abstract. In this work current-voltage characteristics of a glow discharge flowing in narrow long tubes are investigated. The studies were carried out on a specially developed layout, which includes discharge tubes of various diameters. The model was connected to the pumping and filling system, which allows varying the gas content and working pressure. The discharge was excited in pure carbon dioxide gas, as well as mixtures based on it: carbon dioxide with nitrogen in the ratio 1:1, carbon dioxide with helium in the ratio 1:8, and also carbon dioxide, nitrogen and helium in the ratio 1:1:8. An approximating expression is obtained for the CVC in the form of a power function including the discharge current, the length of the discharge gap, and the longitudinal potential gradient calculated in the automated mode.

The glow discharge is widely used in various fields of science and technology. One of the possible variants of using a glow discharge is the excitation of the active gas medium of lasers. The parameters of radiation of glow discharge lasers are significantly influenced by the electrical characteristics of gas-discharge tubes. First of all, this refers to the type of current-voltage characteristics (CVC) of extended discharge gaps of lasers. The current-voltage characteristic of glowing lasers makes it possible to judge the state of their active medium, including the degree of leakage of atmospheric gases [1]. The impedance of the plasma, which affects the dynamic stability of the glow discharge lasers current circuit, depends to a considerable extent on the values of the static and differential resistances determined by the CVC. In addition, the form of the current-voltage characteristic has a significant effect on the dynamic properties of the discharge, which determine the stability of the current-carrying chain of glow discharge lasers [2].

Knowledge of the behavior of the CVC of the discharge tubes of the glow discharge lasers makes it possible to control the deviation of the parameters of the active elements of lasers from the nominal values and to carry out the necessary correction. However, the individuality of technical solutions implemented in the glow discharge lasers makes it difficult to assess and predict the effect of changes in the discharge conditions on the CVC of lasers. To exclude the need for additional experiments for the specific discharge conditions of a laser, it is proposed to use approximating expressions for the current-voltage characteristic of a glow discharge lasers, taking into account the variety of discharge conditions for different types of lasers.

Layout for the study of discharge characteristics is four discharge tubes with immobile molybdenum anodes (figure 1). The length of the positive column is fixed and is 350 mm. The internal diameters of the tubes are 3; 5; 10; 15 mm. Such dimensions are typical for CO$_2$-lasers. Before filling
the tubes with a working gas mixture they were carefully pumped out. The pressure control during evacuation was made by a thermocouple sensor connected to a vacuum gauge [3].

Experiments to study the discharge were carried out for different gas contents: pure carbon dioxide, carbon dioxide with nitrogen in the ratio 1:1, carbon dioxide with helium in the ratio 1:8, and also carbon dioxide, nitrogen and helium in the ratio 1:1:8. The pressure of the gas mixture ranged from 0.5 to 10 Torr and was controlled with an oil U-shaped manometer.

![Diagram of discharge setup](image)

**Figure 1.** Layout for the study of discharge characteristics.

![Current-voltage characteristics](image)

**Figure 2.** Current-voltage characteristics: (a) – mixture CO₂:N₂:He=1:1:8, tube diameter 3 mm; (b) – CO₂:N₂ =1:1, tube diameter 15 mm; (c) – pure CO₂, tube diameter 5 mm; (d) – CO₂:He =1:8, tube diameter 10 mm.

In the ranges of working currents, the current-voltage characteristic of a glow discharge in long tubes is of the same type of falling character. Figure 2 presents examples of the current-voltage characteristic for various fillings and diameters of discharge tubes. The general tendency is an increase in the discharge voltage with an increase in the total pressure $p$ and a decrease in the diameter of the discharge tube $d$. This is due to the increase in the gradient of the potential of the positive column $E_z$ [4].
For the approximation of the working sections of the falling CVC, the functional relationship between the voltage drop across the tube $U$ and the discharge current $I$ are expediently displayed in the form of a power law:

$$U - U_k = aE_zLI^b,$$

(1)

where $U_k$ is the cathode potential drop; $a$, $b$ is approximation coefficients calculated on the basis of a set of experimental current-voltage characteristics; $E_z$ is the longitudinal gradient of the potential in the positive column; $L$ is the length of the positive column. When choosing the form of expression (1), it was assumed that the near-anode potential drop is close to zero [5]. The cathodic drop in the potential depends on the material and design of the cold hollow cathode and the kind of gas. In the normal glow discharge mode, typical for glow discharge lasers conditions, $U_k$ is 100–250 V and is not a current function. In the narrow extended discharge capillaries used in the glow discharge lasers, $E_z$ turns out to be high and amounts to a few–tens of kilovolts per meter [6]. Therefore, the main part of the total voltage drop falls on the positive column, the longitudinal gradient of the potential in which depends on the discharge current.

The value of $E_z$ in the approximating expression was determined as:

$$E_z = \frac{3\chi T_e}{2e\lambda_e},$$

where $\chi$ is coefficient of accommodation of electrons; $\lambda_e$ is the mean free path of electrons in the gas mixture; $T_e$ is the electron temperature; $k$ is the Boltzmann constant [7].

During the experiments under certain discharge conditions, standing striations were observed in the tubes. They are alternating regions in which either gas excitation or ionization predominates. Strata were predominantly observed at low pressures. The spatial period of the stratum (the distance between the luminous regions of the discharge) depended on the diameter of the tube, and also on the discharge current. Under certain conditions (the growth of the discharge current, the heating of the tube), there were situations when the strata ceased to fill the entire discharge gap, or disappeared altogether. The conditions for the existence and appearance of strata are certainly of interest and require the carrying out of separate full-scale studies.

![Figure 3. The emergence of striations in the discharge of pure carbon dioxide.](image)

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