Normal glow discharge investigation in inert gases and nitrogen between flat electrodes with 20 mm of discharge gap

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Abstract. Experimental studies of normal glow discharge (NGD) phenomenon have been carried out in the NGD facility at the Institute for Problems in Mechanics RAS. For helium, argon and nitrogen at the pressure values of 1-10 Torr, the dependences of the characteristic dimensions of the discharge current glow region are obtained. The results of the measurements were compared with calculations performed according to the formulas of Engel and Steinbeck's theory [1, 2]. Spectral measurements of radiation from different regions of normal glow in nitrogen for a pressure of 10 Torr are carried out.

1. Introduction

Glow discharge is the most used type of discharge in various applications, such as gas-discharge light sources, lasers, microelectronic technologies (etching, spraying thin films). It also belongs to the most studied gas discharges [1, 2]. However, the computational and theoretical description of the glow discharge is still insufficiently developed. This is due to the complex structure of the glow discharge and in practice the absence of unified calculation models that allow describing all elements of the glow discharge structure [3].

The Institute for Problems in Mechanics RAS (IPMech RAS) has significant experience in theoretical and numerical study of different types of discharges [3, 4]. This work continues the cycle of experimental studies of the normal glow discharge for the so-called “infinite” plane electrodes described in [5, 6]. The term "infinite" electrode is used to emphasize that the boundary effects on the electrodes do not affect the discharge structure. This allows to provide more accurate comparison of experimental data with theoretical models and numerical two-dimensional calculations of stationary discharge in a wide range of currents (spot sizes), taking into account diffusion [5].

Registation of electrical parameters, discharge form and spectral properties of radiation from in various regions is the main purpose of this investigation. The results of the study of the discharge shape and current-voltage characteristics for nitrogen, argon and helium were present for pressures $P = 1, 3, 5, 6$ and 10 Torr. Radiation spectra’s from different regions of glow discharge were obtained in nitrogen for a pressure of 10 Torr.

2. Experimental setup

Detailed description of the experimental setup and methods for measuring current and glow discharge voltage, pressure parameters in the discharge chamber, types of emission spectra are described in [5, 6].
In contrast to [5, 6], changes were made in the scheme of the installation, increasing the accuracy of the experiment. Namely, the ballast resistance equal to 300kOhm was selected; dividers (up to 5 kV) were manufactured and calibrated to measure the voltage of the power supply and the voltage on the electrodes; baratron in the pressure range $P = 0.1\div11$ Torr was shielded; the leakage of the discharge chamber was brought to the onset no worse than $10^{-3}$ torr/min. A window with a diameter of 50 mm and KU–1 glass was installed for spectral measurements in the range up to $\lambda = 200$ nm in the central part of one of the acrylic windows.

3. The results of the experiments

The methodology of the experiments is similar to that set out in the [5, 6]. For a fixed pressure ($P = 1, 3, 5, 6$ and 10 Torr) in the investigated gases (Ar, He or N$_2$) the discharge current varied from 1 to 10 mA. Voltage source ($E$), the discharge current and the voltage across the electrodes were recorded with a digital storage oscilloscopes. At the same time video recording of the glow discharge category was carried out.

After synchronization of the video and oscillograms of the current, a number of video frames were processed. With the help of the Universal Desktop Ruler program [7] the characteristic dimensions of the luminous region at the cathode were determined. These measurements allow to construct the dependence of the cathode spot diameter on the magnitude of the discharge current and to compare them with the calculations performed by the formulas of the theory of Engel and Steenbeck [1–3].

Empirical constants and mobility for different gases in [2] are shown in table 1.

| s   | A    | B    | $\mu_i$(Gas)/$\mu_i$(N$_2$) |
|-----|------|------|----------------------------|
| N2  | 8.8  | 275  | 1 P>1 Torr                 |
| N2  | 12   | 342  | 1; P=1 Torr                |
| Ar  | 12   | 180  | 1.1                        |
| He  | 3    | 34   | 5                          |

Experimentally measured (symbols) and calculated dependences (solid lines) for the characteristic size of the luminous pre-cathode region for gases Ar, He and N$_2$ for different pressures and distance 20 mm between the flat electrodes are shown in figures 1, 2.

The dependence of the power of the discharge and the volume of the luminous discharge region on the time for nitrogen at a pressure of 3 Torr present on figure 3. Voltage - current characteristics for the series of experiments presented in Fig. 1 are show in figures 4, 5.

![Figure 1](image1.png)

**Figure 1.** Discharge characteristic size dependence of the luminous pre-cathode region in Ar (left), He (right).
**Figure 2.** Discharge characteristic size dependence of the luminous pre-cathode region in N₂.

**Figure 3.** The dependence of the power of the discharge and the volume of the luminous discharge region on the time for nitrogen at a pressure of 3 Torr.

**Figure 4.** Current-voltage characteristics in Ar and He for different pressures.
Figure 5. Current-voltage characteristic in N\textsubscript{2} for different pressures.

The dependence of the EMF of power supply and the discharge current for the ballast resistance of 300 kOhm are shown in table 2.

Table 2. The dependence of EMF and discharge current for ballast resistance of 300 kOhm.

| Gas  | P, Torr | \( \mathcal{E} = V + R*I \)     |
|------|---------|---------------------------------|
| N\textsubscript{2} | 10      | \( 752 + 255000*I \)            |
| N\textsubscript{2} | 6       | \( 577 + 269000*I \)            |
| N\textsubscript{2} | 5       | \( 515 + 275500*I \)            |
| N\textsubscript{2} | 3       | \( 423 + 283000*I \)            |
| N\textsubscript{2} | 1       | \( 351 + 293000*I \)            |
| Ar   | 10      | \( 311 + 292000*I \)            |
| Ar   | 6       | \( 296 + 291500*I \)            |
| Ar   | 5       | \( 284 + 292000*I \)            |
| Ar   | 3       | \( 279 + 292500*I \)            |
| Ar   | 1       | \( 267 + 296600*I \)            |
| He   | 10      | \( 318 + 291000*I \)            |
| He   | 6       | \( 311 + 292000*I \)            |
| He   | 5       | \( 316 + 292000*I \)            |
| He   | 3       | \( 303 + 305000*I \)            |

4. Spectral measurements

Spectra of different regions were obtained for the discharge column in nitrogen at a pressure of 10 Torr and a current of 5.3 mA. The distance between the electrodes was 20 mm. While the diameter of the positive column did not exceed 10 mm, the measurements allowed us to obtain spectra of the cathode layer and positive column. Emission spectra were obtained at different distances from the cathode are shown in figure 6.

Spectrum analysis showed that the cathode has radiation of N\textsubscript{2} molecular bands (C B). The spectra also allow one to estimate the vibrational and rotational temperatures of the gas in the discharge. The blue regions of the experimental studies of normal glow discharge at the IPMech RAS have been carried out.
Figure 6. Emission spectra received from different regions of the discharge. The numbers to the left of the spectra and the photo indicate the distance in mm from the cathode. Relative intensities are indicated on the right side.

Conclusion
For helium, argon and nitrogen at the pressures of 1÷10 Torr, the dependences of the characteristic dimensions of the glow region on the discharge current were obtained. Spectral measurements of radiation from different regions of normal glow discharge in nitrogen for a pressure of 10 Torr were carried out. Further experiments will make it possible to validate the computational models describing this phenomenon.

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