Normal glow discharge in nitrogen and inert gases between flat electrodes with distance of 10 mm

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Abstract. Experimental study of normal glow discharge in the installation of IPMech RAS is continued. For problem formulation of discharge behavior between "infinite" electrodes investigations were carried out at a distance of 10 mm between flat electrodes with much greater diameter in the pressure range 1÷10 Torr. Dependencies of the characteristic size of the glow region on the discharge current in helium, argon and nitrogen were obtained. Spectral characteristics were constructed. Rotational and vibrational temperatures of the discharge were estimated.

1. Introduction
Experimental study of normal glow discharge (NGD) in the installation of IPMech RAS between "infinite" electrodes (flat round electrodes with diameter much greater than distance between them) continues [1]. In the paper the processes occurring between the "infinite" electrodes at a distance of 10 mm at pressures of 1÷10 Torr in helium, argon and nitrogen are investigated.

Research continues on the generation, existence and behavior of a normal glow discharge on flat "infinite" electrodes. Fundamental theoretical studies [2] of the molecular picture of this phenomenon in the framework of physic-chemical kinetics of gas discharges are devoted to this problem. In [3], complex structures of the normal glow range, spectral properties of radiation, and volt-ampere characteristics were experimentally obtained.

As a continuation of experimental studies [1–3], a cycle of works on "infinite" electrodes with a changed distance between the electrodes up to 10 mm was performed with comparison of experimental data, theoretical models and numerical two-dimensional calculations of the stationary discharge in a wide range of currents (spot sizes) taking into account diffusion, as well as to estimate the vibrational and rotational temperature of the gas in the discharge.

2. Installation possibilities for experimental studies
Description of the experimental setup and methods for measuring the current and NGD voltage, pressure in the discharge chamber, emission spectra are presented in [1–3]. The scheme contains a vacuum chamber with "infinite electrodes", the distance between which, in the present experiments, is reduced to 10 mm. The scheme contains a high-voltage calibrated power supply with adjustment of the applied voltage and current level to the electrodes, baratron in the pressure range from 0.1 Torr to 11 Torr, spectrograph with CCD line in the range of 480÷1100 nm, current meters ($I_{NGD}$) and voltage ($U_{NGD}$) in the discharge plasma using ballast resistance. The method of processing the video of the discharge and the current waveforms registered by the digital storage oscilloscope, their synchronization and processing with the help of the Universal Desktop Ruler program is given in previous works on this installation [1–3].

The construction of the dependence of the cathode spot diameter on the discharge current and their comparison with the calculations are performed according to the formulas of Engel and Steenbeck theory [4].
3. The results of the experiments

The diameter of the cathode spot on the magnitude of the discharge current was calculated by the formulas of the theory of Engel and Steenbeck in [4].

The empirical constants of the studied inert gases (Ar, He and N2) are given in table 1[1].

The dependences (solid lines) of the characteristic size of the luminous near-cathode region for gases (Ar, He and N2) for different pressures, measured experimentally (symbols) and calculated by formulas, are shown in figure 1.

![Graphs showing the dependence of the cathode spot diameter on the discharge current for Ar, He, and N2 gases.](image)

**Figure 1.** Dependence of the cathode spot diameter on the discharge current.

Frame-by-frame measurements in all sizes of the near-cathode luminous region of the discharge in nitrogen at a pressure of 3 Torr and at a distance between the electrodes of 10 mm were investigated. This made it possible to determine the volume of this area and compare it with the power invested in the discharge. The dependence of the power invested in the discharge and the volume of the luminous region of the discharge on time for nitrogen at a pressure of 3 Torr is shown in figure 2. Current-voltage characteristics (CVC) for a series of experiments presented in figure 1, are shown in figure 3.

For a series of experiments the dependence of the EMF $E$ of the source of current $I$ in the discharge for ballast resistance $R = 300 \text{ kOhm}$ is shown in the table 1.
Figure 2. The dependence of the power invested in the discharge and the volume of the luminous region of the discharge on time for nitrogen at a pressure of 3 Torr (10mm).

Figure 3. CVC in Ar, He and N\textsubscript{2} for different pressures at a distance of 10 mm between electrodes.
Table 1. The dependence of EMF and discharge current for ballast resistance of 300 kOhm.

| Gases | P, Torr | $\mathcal{E} = V + R*I; \ d = 10\text{mm}$ |
|-------|--------|------------------------------------------|
| N\(_2\) | 10     | $\mathcal{E} = 534 + 280000*I$          |
| N\(_2\) | 6      | $\mathcal{E} = 430 + 288000*I$          |
| N\(_2\) | 5      | $\mathcal{E} = 403 + 291000*I$          |
| N\(_2\) | 3      | $\mathcal{E} = 384 + 291000*I$          |
| N\(_2\) | 1      | $\mathcal{E} = 337 + 294000*I$          |
| Ar    | 10     | $\mathcal{E} = 312 + 295600*I$          |
| Ar    | 6      | $\mathcal{E} = 295 + 292000*I$          |
| Ar    | 5      | $\mathcal{E} = 292 + 293000*I$          |
| Ar    | 3      | $\mathcal{E} = 291 + 293000*I$          |
| Ar    | 1      | $\mathcal{E} = 271 + 295000*I$          |
| He    | 10     | $\mathcal{E} = 283 + 293000*I$          |
| He    | 6      | $\mathcal{E} = 283 + 294500*I$          |
| He    | 5      | $\mathcal{E} = 282 + 296500*I$          |
| He    | 3      | $\mathcal{E} = 276 + 301600*I$          |

4. Spectral measurements

Emission spectra of different regions of NGD: spectra from the cathode layer and the positive column were removed at a distance between the electrodes of 10 mm with the diameter of the positive column not exceeding 10 mm, at a pressure of 10 Torr and a current of 5.3 mA. Analysis of the spectra showed that the cathode has radiation of molecular bands N\(_2\) (C–B) blue region of the spectrum and N\(_2\) (B–A) red region of the spectrum. The radiation of the molecular ion N\(_2^+\) (B–X) is also present, the radiation of which is not observed in the positive column (figure 4).

![Figure 4. Radiation spectrum.](image)

Conclusion

Experimental studies have confirmed the computational and theoretical conclusions about the behavior of the normal glow discharge under specified conditions: a pressure of 10 Torr and a current of 5.3 mA. The shape of the discharge and the minimum spot (10 mm width) was resulted, when the distance between the flat electrodes 10 mm. Parameters of the current in the discharge plasma,
removed volt-ampere characteristic were measured. The radiation spectra are obtained. The greatest interest in the conducted research is the experimental measurement of vibrational and rotational temperatures on the radiation spectrum.

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