The spectral characteristic investigations of normal glow discharge

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Abstract. Description of experimental installation created for investigation of the normal glow discharges in different gases at pressures of ~ 1 Torr is presented. It is assumed that systematic research of the current-voltage characteristics, spatial configuration of the normal glow discharges, as well as their spectral emissions will be investigated with the use of the installation.

Preliminary experimental investigations of the spectral emission in helium, nitrogen, and argon of the normal glow discharge have been conducted.

1. Introduction

The phenomenon of the normal glow discharge (NGD) has been open about 100 years and until the present is the significant object of the basic physics. Schematic of the normal glow discharge is shown in figure 1. Here ε and R0 are e.m.f. of power supply and ohmic resistance of the external electric circuit.

Normal glow discharge exists between the two "infinite" flat electrodes. The term "infinite" electrodes used in order to emphasize that the boundary effects on the electrodes do not affect the structure of the NGD. As a rule, such discharges permanently exist with parameters close to the minimum of the Paschen breakdown curve. As an example, for molecular nitrogen N₂, voltage drop between electrodes reaches only a few hundred volts, and the total current through the discharge gap is measured by several milliamps.

Law "normal current density" states: with the increase of the total current through a glow discharge the current density in the center of the current spot remains practically unchanged. Simple, but very effective, the one-dimensional method for calculating of the parameters of the normal glow discharge was created by Engel and Steenbeck [1]. The two-dimensional hybrid fluid-dynamic model [2] has demonstrated the real physics of the phenomenon.

The paper presents preliminary studies of the spectral characteristics of normal glow discharge which were performed on the new experimental installation. The installation is shown in figure 2. It includes the cylindrical vacuum chamber with internal diameter of 230 mm and with height of 195 mm. This chamber is mounted on the laboratory table together with Baratron capacitance gauge and Vacom pressure sensor to control rarefaction level. Spectrograph is installed in front of acrylic
window to register discharge emission spectra. Vacuum pump and the gas supply pipes are connected to the chamber via the valve system. High Voltage Power Supply is mounted under the laboratory table.

**Figure 1.** Schematic of the normal glow discharge.

**Figure 2.** The normal glow discharge (NGD) experimental facility.

As it was mentioned above the general goal of the experiments is the investigation of the normal glow discharges. But it is well known that channel of current (or several channels) of the normal glow discharge between flat electrodes is unstable. As a rule it can stochastically change their location. To provide a stabilization of location of investigated channel of current the slightly convex electrodes are used (see figure 3).
Figure 3. Gas discharge electrodes with diameter of 100 mm for creation of the normal glow discharge. Observation window diameter is of 320 mm.

2. Research methodology at the NGD facility

Figure 4 shows schematic of the experimental installation.

Laser device and spectrograph with collimating lens can be moved in parallel relative to the discharge gap. To register discharge emission spectra the Horiba spectrograph CP140-1824 with the gated CCD line Hamamatsu S11156-2048 of spectral resolution 1.25 nm is used. The spectra registration was carried out in the range of 374-1000 nm, the short-range boundary was determined by emission passing through the acrylic window, which allows alignment laser to monitor the spatial position of the area between the electrodes and take the discharge pictures (figure 3).

Figure 4. NGD facility schematic.
As a source of high-voltage discharge power the Spellman SA10PN4 is used (with constant and regulated voltage and current: 0.4A 10kV). The discharge voltage information was shot through the divider directly from the electrodes, and the current information from the reference point of power supply. The ballast resistance (1-100 kΩ) is connected in the discharge power supply circuit.

The experimental procedure includes the initial evacuation of the discharge chamber oil-free fasting to $10^{-5}$ Torr pressure control wide-range vacuum gauge type Atmion (Pirani method to $10^3$ Torr, technique Bayard-Alpert to $10^{-11}$ Torr). This is followed by filling the investigated gas (argon, helium or nitrogen) through inlet valve. To monitor the test gas pressure in the discharge chamber in the range of Torr units the Baratron capacitance gauge type is used (limit of 10 Torr, accuracy 0.2% of the maximum measured pressure).

Further, high voltage is applied to the electrodes, and when an ignition of the discharge occurs the Spellman changing form of the discharge by adjusting current that is fixed by camera. At that the time, voltage and current are registered, which builds the current-voltage characteristic.

Registration of the spectral characteristics of the glow discharge in the test gas along the discharge column depends on the spatial resolution of the optical circuit perpendicular to the observation axis and is determined by pixel CCD line height (1 mm). Along observation axis the resolution collimating lens with $f=75$ mm and 15 mm diameter placed on the double focal distance from the axis of the discharge gap was ~ 3.2 mm. Changing the depth of field along the axis of observation can change by the collimating lens diaphragm.

Spectrograph with CCD line used in experiments was calibrated using the SI-10 tungsten lamp. Figure 5 shows dependence calibration of the spectrograph sensitivity with filter ZHS17 and without it in relative units. ZHS17 filter is used to exclude the effect of radiation influence from the spectral range 374-500 nm from the second-order diffraction grating for spectrum in the range of 750-1000 nm.

Figure 5. The curve of the spectral sensitivity of the spectrograph with a CCD receiver without filter ZHS17 and with it.

For the measurement of the temporal behavior of the discharge emission photomultiplier tube (PMT) Hamamatsu R1547 is used. Before the PMT the adjustable slit was set. To measure the time evolution of the discharge emission PMT with slit are on the spectrograph position. The time resolution of the PMT was better than 20 ns with the load resistance of 50 ohms.

Discharge’s current and voltage, the signals from the photomultiplier and the Baratron gauge are fed through analog-to-digital converter L-Card E20-10 (10 MHz, 14 bits) to the computer. Special programs are used to build CVC, the current and voltage waveforms in time, as well as spectra.
3. Experimental results

Test experiments at the NGD facility are carried out in air, nitrogen, argon and helium at pressures of 0.2 - 10 Torr. Initially, the discharge circuit has no ballast resistance. Analysis of the time behavior of discharge’s current and voltage under these conditions indicates a quasi-periodic nature of the discharge. The oscillation frequency varies from a few to thousands of Hertz, and depends on the maximum current value at the power supply and the pressure and type of gas. Figure 6 shows a typical waveform view of current and voltage of the discharge in nitrogen at a pressure of 1 Torr at quasi-periodic mode. From these waveforms current-voltage characteristics (CVC) of discharge are constructed of discharge. Examples of CVC of the discharge in argon and air at different initial pressures for the quasi-periodic mode are shown in figure 7. The behavior of the current and voltage for discharges in all the investigated gases without ballast resistance is similar.

Examples of discharge forms in quasi-periodic mode in argon and helium are shown in figure 8. As the pressure in the discharge chamber increases the discharge is usually compressed to the electrode axis. Changes the shape of the discharge in nitrogen, air and argon at change of pressure and discharge current are similar in nature. A typical feature of the discharge in helium is bending the edges of the discharge near the cathode to the anode with increasing pressure.

![Figure 6. Current and voltage oscillogram without ballast resistance in air at a pressure of 1 Torr](image1)

![Figure 7. Current-voltage characteristics of the discharge without ballast for argon and air](image2)

Evolution in time of discharge development in argon at a pressure of 1 Torr without ballast is shown in figure 9. The emission from the cathode region increases in a time of no more than 0.1 µs and has duration of 0.5 µs. During the next ten microseconds emission is practically absent, and then it increases in a time of microseconds to a constant level of duration of 500-800 µs. The development character could mean that the first the streamer breakdown occurs at the discharge gap, and thereafter the Townsend one. Study of the nature of discharge occurrence is the subject of further researches.

By increasing the ballast of more than 10 kOhm discharge current becomes stationary, which corresponds to the theoretical calculated data [1]. The shapes of the discharge becomes more stable and of all areas typical for glow discharge are clearly visible: aston dark space, the cathode glow cathode dark space, negative glow, Faraday dark space, positive column glow and anode dark space.

Preliminary results of the study the spectral composition of a glow discharge in argon and nitrogen are shown in figures 10-13. The spectra were obtained from the brightest part of the discharge. Figure 11 illustrates the suppression of emission from a second order grating using ZHS17 filter. Emission intensities are given in relative units, taking into account the spectral sensitivity of the spectrograph with a CCD receiver, but the intensity ratio in each experiment corresponds to a real ratio.
Figure 8. Photos of discharge in Ar at pressure 5 Torr (a); 1 Torr (b) and He at 5 Torr (c); 1 Torr (d).

Figure 9. Current, voltage and emission waveforms registered in the PMT at 5 mm above the cathode without ballast resistance in argon at a pressure of 1 Torr.
At low pressures and small discharge currents the line Hα is observed in the emission spectra of the hydrogen, both for nitrogen and for argon, due to hydrogen-containing impurities in the cylinder. The discharge emission spectra of nitrogen identified vibronic transitions molecular nitrogen (C–B) and (B–A) and a positive nitrogen ion (B–X).

![Emission spectra in nitrogen](image)

**Figure 10.** The emission spectra in nitrogen (2 Torr; 6 mA, 14 mA).

![Emission spectra in nitrogen](image)

**Figure 11.** The emission spectra in nitrogen (3 Torr, 103 mA).
Figure 12. The emission spectra in argon (1 Torr, 5 mA).

Figure 13. The emission spectra in argon (2 Torr, 6 mA).

The emission spectra of the discharge in argon identified all the main line transitions of singly-ionized atom. The average CVC (3–6 Torr) in Ar is shown in figure 14.

After analyzing data on the spectra of the corresponding to atomic line positions the full convergence of Ar gas were obtained. In the analysis of the emission spectra on the N2 molecular emission lines were found positive with the transitions of the first group of B–A, C–B of the second group of positive and negative of the first group of B–X. The energy values of atomic transition lines
in test gases obtained by spectral analysis will be used in the calculation of physical models of glow discharge.

![Figure 14. The averaged CVC at pressure 3±6 Torr in Ar.](image)

4. Conclusion
The experiments carried out at the NGD facility of a glow discharge at a constant pressure allowed to establish the existence of the glow discharge normal regimes. Discharges were obtained in various gases (nitrogen, argon, helium, and air). Quasi-periodic glow discharge modes are investigated. In the future it is planned to continue to study the characteristics of the discharge with simultaneous recording of current-voltage characteristics, pressure and emission spectra in absolute units in different parts of the discharge.

It is planned to investigate the nature of the initial stage of occurrence of discharge in its time evolution. Adding a small amount of hydrogen (less than 1%) in the future will allow determine the concentration of electrons using the Stark broadening. The experimental data on the electrical parameters of the discharge distribution of concentration and temperature in the space between the electrodes will allow in the future verify the theoretical models.

The results will be used in experiments with normal operation of a glow discharge in a high speed gas stream for the GFDST facility.

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