Heat transfer in a longitudinal glow discharge

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Abstract. This article is devoted to the experimental study of heat transfer in a longitudinal glow discharge. The discharge was ignited in the discharge chamber (DC), consisting of a glass tube 10 mm in diameter and two electrodes. Copper electrodes were placed in the side branches, so that the average distance between them was 9 cm. The discharge pressure was varied in the range of P = (2.5 – 8.5) kPa. The air flow rate was varied from zero to G = 0.06 g / s. Current was varied in the range of I = (30-80) mA. Current-voltage characteristics of the discharge had falling form, and the voltage was varied in the range of U = (1-2) kV. The temperature of neutral particles in the plasma glow discharge was measured by six thermocouples, which were insertedon radius of DC.The aim of the article was to compare achieved experiment data with theoretical studies: recombination and diffusion plasma models.

1. Introduction
A plasma glow discharge is widely used in gas-discharge light sources, as the active medium of gas lasers [1-9], modern technologies for production of various coatings, nanotechnology methods for obtaining unconventional materials [10-24]. The study and research of glow discharge plasma parameters is of great scientific and practical interest. An important feature of glow discharge plasma is its thermal non-equilibrium: the electron temperature can be several times higher than the temperature of neutral molecules. For many applications it is important to know the heat transfer processes that occur in the gas discharge. Heat transfer in the gas discharge can be regarded as heat in the gas stream with internal heat sources. For theoretical analysis of these tasks, it’s required to obtain the spatial distribution of the power heat sources. In the above works the potential distribution, the electron density, electric field strength, temperature of neural particles in the case of longitudinal glow discharges were obtained theoretically. The purpose of this article is a further study of heat transfer processes in a longitudinal glow discharge using experimental methods.

2. Experiment
Measurements of the neutral gas temperature in glow discharge plasma has certain difficulties related to the lack of balance between the neutral and charged particles, the possibility of chemical processes, etc. Definition of methodological error of temperature measurement is part of the general problem of the heat exchange system of bodies of research that are in contact with the environment or bodies. In case of radial thermocouple temperature measurements, the error sources are: the heat exchange by radiation between the thermocouple and the wall of the DC, the heat transfer by conduction from the sensor through the wires and thermocouple protection shield, heating of the thermocouple due to heterogeneous processes. Taking into account all the factors, the neutral gas temperature measurement error does not exceed 8%, which is consistent with the available data.

The circuit design and the DC for studying the processes of heat exchange is shown in Figure 1. Copper electrodes located at a distance ofl = (0.08 – 0.1) m on the side branches of the glass tube diameter of 0.01m. On the outer surface of the DCthere are nine capillaries for directing the thermocouple insertion and pressure measurement.The DC is connected to the pumping system using vacuum hoses. Current and discharge voltage were controlled by pointer-type instruments.Current-voltage characteristics were recorded using plotter model H-306.The temperature of the outer surface of the DC was measured at eight points chromel-alumel thermocouples of 0.2 mm diameter. The working ends of thermocouple were pressed against the surface of the DC by means of four thin rings. The average temperature of the surface of the DC was determined by the measurements of thermocouples. The temperature of neutral particles was measured after the establishment of steady state, as determined by the stability of the input and output parameters. In each mode of measurements, the following parameters maintained constant: pressure in the DC, the gas flow rate, current and voltage discharge. Measurements in every mode were carried out 5 - 10 times. Thermo-emfthermocouple was measured using the compensation method by potentiometer model PP-63 (accuracy class of 0.05). The thermocouples shared a cold junctioninserted into constant-temperature (0^oC/ 32F) container.

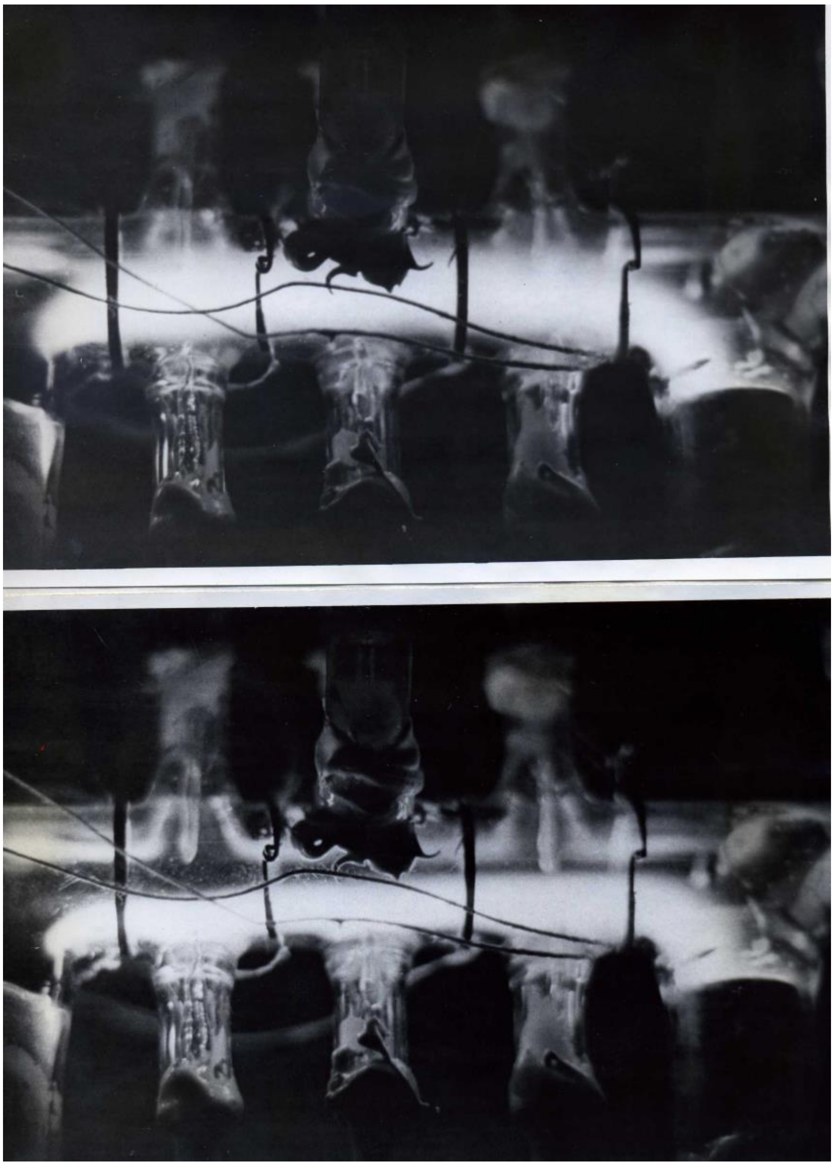

Figure1. Photographs of the discharge in the air flow

3. Results

The experiments showed that the air temperature in the longitudinal glow discharge increases linearly with increasing current, discharge capacity and pressure. The temperature increases approximately linearly with speed 6.5K / W on axis and 4K / W near the wall of the DC,when discharge power increases.Detected that temperature field of neutral particles essentially depends on the form of luminous discharge. A glow discharge glow between the two electrodes is shown on Figure 1. It also shows six capillaries, through which the vitrified thermocoupleswere inserted inside of the DC. The top photo corresponds to a small air flow rate G = 0.007 g/s, when the glow fills the entire cross-section of the discharge tube. The bottom photo corresponds to a higher air flow rate G = 0.035 g / s, in which the discharge is contracted to the bottom of the discharge tube, and can be clearly seen that the upper ends of the thermocouples are in the non-luminous discharge.Measured distributions of temperature along the length of the DC are shown in Figure 2.

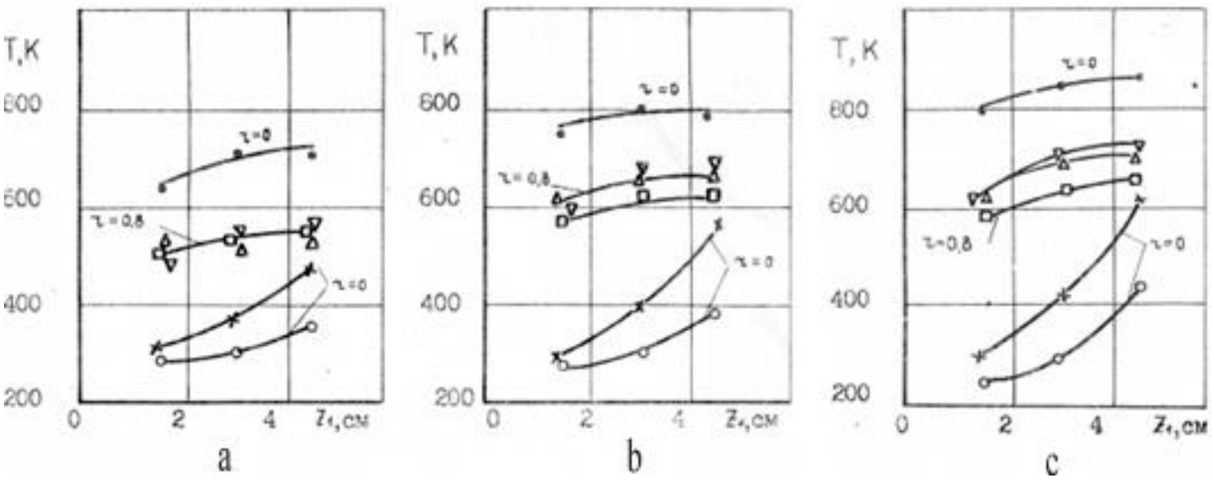

Figure2.The neutral particle temperature distribution along the length of the DC at P = 2.5 kPa: ●, □ - G = 0.007 g/s; △, × - G = 0.017 g/s; ∇, ○ - G = 0.035 g/s; a - I = 30mA, b- I = 50mA, c- I = 70 mA.

The gas temperature at the outlet of the discharge chamber is increased by (50 - 400) Kon the axis of the discharge at a current I = 30 mA airflow range G = (0.007 -0.017) g/s. Under the same conditions of temperature increase of the gas at the radius r = 0.8 cm is 250K and weakly depends on the flow rate. When current increases, the gas temperature also increases, but the nature of its distribution along the length of the discharge chamber is not changed. Influence of air flow is particularly noticeable for the gas temperature at the discharge axis. When the air flow rate changes in the range G = (0.017 – 0.035) g/s (figure 2.a) on the discharge axis, the temperature decreases nearly to a room temperature. It happens because the flow of air causes a contraction of the discharge to the inner wall of the DC.

4. Discussion

In theoretical works [1-9] formulas were derived for calculating the temperature field of neutral particlesby solving the system of equations consisting of the charge continuity equation, Ohm's law in integral form and the energy equation. Calculations using these formulas were compared with the experimental temperature measurements, the results are shown in Figure 3.The recombination model has best agreement with experiment on the discharge axis, while the diffusion modelshows more accurate results near the wall of DC.

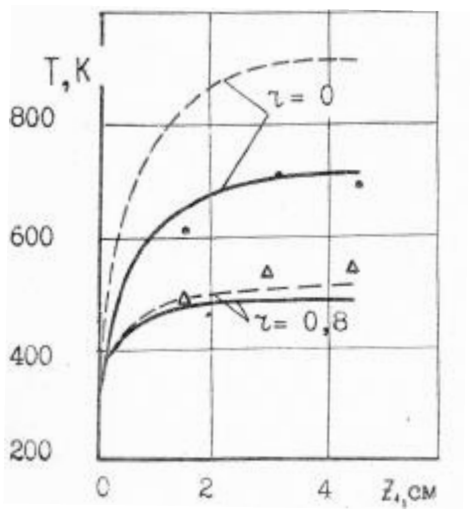

Figure3.The neutral particle temperature distribution along the length of the DC at P = 2.5 kPa, G = 0.007 g/s, I = 30 mA, ● - r = 0, Δ - r = 0, 8 cm. Dashed line – diffusion model, solid line – recombination model.

5. Conclusions

The aim of the article was experimental research of the temperature field of neutral particles in the plasma of a longitudinal glow discharge.The discharge was observed visually and photographically.Detected dependence of the temperature of the discharge current and gas flow rate. The experiment showed thatincrease of discharge power produces linear increase of temperature with speed 6.5K / W on axis and 4K / W near the wall of the DC.It has been found: the glow discharge is compressed to the boundary of the DC, when the air flow rate reaches a certain value equal to G = 0.035 g/s. Comparison of experimental and theoretical data was performed. It showed that the experimental temperature measurement results are in better agreement with the plasma recombination model on the discharge axis, while data near the wall of DC better fit in diffusion model.

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