Peculiarities of the development of ionization instability of various scales in the air gas discharge

T A Lapushkina
Ioffe Institute, Politekhnicheskaya str. 26, 194021, St Petersburg, Russian Federation
tanyusha@mail.ioffe.ru

Abstract. In this work, the air gas discharge of constant voltage, organized in an unlimited chamber without the side walls, is experimentally studied, which leads to a stratification of the discharge region due to the development of ionization instability. Depending on the conditions of the discharge (pressure or magnitude of the gas discharge current), the scale of the ionization striations changes, which leads to the layered structure of the plasma medium and the possibility of creating layers of different thicknesses, where not only the electronic temperature, but also the gas temperature are different. Various types of discharge were obtained in the work, from large-scale structured ones (3-5 striations per discharge length) to small-scale ones (20-25 striations per discharge length), and the conditions for their occurrence and development were investigated. The main diagnostic parameters are gas pressure, the magnitude of the gas discharge current, which is changed by a change in the load resistance, the size and frequency of the ionization waves, estimation of electronic and gas temperatures at different points of the discharge. Gas discharges of this kind can be used to structuring the air environment, gas mixing and supersonic flows control.

1. Introduction
Gas discharge physics includes a wide range of research areas, both fundamental and applied. One of the topical issues is the stability of the discharge, the ability of a stationary uniform glow. The development of various kinds of instabilities in a discharge is usually regarded as a negative phenomenon. This work is aimed at considering the possibility of creating and using a spatially inhomogeneous discharge. In this work, an air gas discharge of constant voltage, organized in an unlimited chamber by the side walls, is experimentally studied, which leads to a stratification of the discharge region due to the development of ionization instability. Ionization instability develops due to a fluctuation excess of the ionization rate over the recombination rate in a certain region of the discharge, which leads to a buildup of the ionization process and the formation of ionization waves (striations), standing or moving from the cathode to the anode [1]. Strata are areas with increased electron concentration and temperature. In experiments, strata are well observed as zones of increased luminescence in the discharge region, their shape is close to spherical. In most research papers, discharge stratification is observed at glow discharge in gas discharge tubes with inert gases as working media [2-5]. In narrow gas-discharge tubes, sphericity and regularity of strata are clearly seen [1]. The striations are curved towards the anode, can be located separately from each other or with a vertex located inside the front sphere. In this work, ionization striations were obtained in air, which makes the work relevant in terms of the possibility of structuring the air environment, including air flows and gas mixing chambers.
2. Experiment arrangement
A gas discharge was organized in a vacuum chamber from plexiglass with square cross section $5 \times 5$ cm$^2$, 50 cm long, with dielectric inserts 8 cm wide mounted in the upper and lower walls. Pin electrodes 3 mm wide were used, which regularly were mounted in the inserts and protruding 2 mm from the surface of the insert. The electrodes were supplied with power from a constant voltage source $U = 600$ V, as shown in Figure 1, which did not change during discharge organization in different experiments. The studies were carried out at different load resistances $R$ in the range of 1–5 kOhm, while the value of the gas discharge current changed. All pin electrodes were connected simultaneously to the same load. Gas discharge ignition was made by means of high frequency Tesla generator. The discharge itself chose the propagation path and closed through arbitrary electrodes, mainly in the central part of the electrode insert, which are given in the work. In the experiment also, a current closing was observed in the diagonal direction, including with ionization striations, the diagonal current closing does not affect the shape of the discharge. The shape of the discharge could be observed and fixed to the camera through the side windows.

![Figure 1. Power supply connection diagram for arrangement of a gas discharge.](image1)

The inlet of the working gas into the gas discharge chamber was carried out after preliminary pumping to a pressure of $10^{-3}$ Torr. Air was used as a working gas, the gas pressure in the discharge chamber was controlled by monometer. The value of the gas discharge current was recorded in the experiment, and changes in the shape of the discharge were investigated depending on the conditions of its organization. The unboundedness of the discharge by close walls and the spontaneous selection of pin electrodes to close the gas discharge current created an opportunity for the development of ionization instability in the discharge region.

3. Types of ionisation unstable discharge
During the experiment, at a fixed air pressure of 7 Torr, it was found that, depending on the magnitude of the gas discharge current, the shape of the discharge changes, and at currents in the range of 100-400 mA, ionization strata appear in the discharge region. The magnitude of the striations and their repetition rate depends on the magnitude of the gas discharge current. Figures 2 and 3 show possible variations in the shape of the discharge obtained in the experiment when the magnitude of the load resistance changes. Photos of the discharge are presented sequentially as the discharge current increases. The cathode in the photographs is located on the top wall of the chamber, the anode is located on its bottom wall.
Figure 2. The structure of the gas discharge at currents of 10-200 mA.

At low currents up to 100 mA, the discharge is homogeneous (Figure 2a), barrel-shaped, with a cross-sectional width of about 3 cm. An increase in current in the range of 100-200 mA leads to the development of ionization instability with large-scale striations. The number of striations per discharge length increases from 2-3 (Figure 2b) to 5-6 (Figure 2e) with increasing current, moreover, with an increase in the number of striations, the structure becomes more regular and stable. The strata movement stops, the discharge burns stationary.

Figure 3. The structure of the gas discharge at currents of 300-500 mA.

A further increase in current in the range of 300–400 mA leads to an increase in the repetition rate of striations, 10–20 striations per discharge length, as can be seen from Figures 3a, 3b, 3c. The structure remains regular, stable with standing striations. The duration of the stationary glow of this form of discharges can continue a few minute. The width of the striations reaches 5 cm (Figure 3a). With an increase in the frequency of striations, the discharge region narrows. With a further increase in current, the striations disappear, the discharge becomes uniform and begins to contract, as can be seen from Figure 3d.

It should be noted that the same type of discharges can be obtained with a fixed load resistance, but by a change in pressure in the discharge chamber in the range of 1-10 Torr. At more high working gas pressures, the discharge goes out. Studies have shown that the magnitude of the gas discharge current increases with increasing pressure, and the structure of the ionization-unstable discharge arising from this way of the formation of the discharge corresponds to the structure arising at the same current magnitude as in experiments with a fixed pressure in the gas discharge chamber, shown in Figures 2
and 3. It can be concluded that the shape of the discharge depends on the magnitude of the gas discharge current, regardless of how this current is achieved.

According to estimates, in strata the electron temperature reaches 3000–5000 K, the electron concentration is $10^{12}$–$10^{13}$ cm$^{-3}$. The region of the discharge with developed ionization instability in the stationary state is a layered structure with regularly following regions of elevated temperature and electron concentration regularly along the axis of the discharge. The thickness and number of such layers can be changed by changing the magnitude of the gas discharge current. In the above experiments, the layer thickness varied in the range from 2 to 15 mm. In the case of standing striations, these layers occupy a stationary position in the region between the electrodes, which leads to an increase in the temperature of heavy particles in the striation region due to Joule heating. Thus, the gas-discharge region of the ionization-unstable discharge obtained in the experiment has a regular structure that is layered with respect to the temperature of the gas, and with the possibility of changing the scale of the layers in a wide range.

4. Possible applications
The gas discharges obtained in the experiment with the development of ionization instability can be used to control supersonic flows and shock-wave configurations by creating a stratified energy source, also can be used for temperature structuring of the medium, including the medium of propagation of shock waves with the aim of changing their shape and intensity [6, 7], mixing the flows in the combustion chambers, as well as structuring the kinetic energy of supersonic flows by pumping it into separate areas at shock wave passing [8].

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