SYMmetrical Forms of Striated Glow Discharge in Molecular Gases

O.A. Nerushev, S.A. Novopashin, V.V. Radchenko, G.I. Sukhinin

Institute of Thermophysics, 1 Lavrentyev Ave., Novosibirsk 630090, Russia
rvv@itp.nsc.ru

Abstract

In this paper, there are presented several types of a stratified low-pressure (<1 Torr) glow discharge, which have highly symmetrical forms. Namely, these are a spherical or quasi-spherical discharge, a plane (flat) and volume discharge with a ring-form cathode. A specific feature of (quasi-) spherical and “ring” glow discharges is a small-size anode surrounded by a large surface cathode or ring-like or hoop-like cathode.

1. Introduction

The instability of gas discharge connected with the stratification of a positive column is well known and described phenomenon [1]. In the paper [2], spherical stratification of low-density gas discharge (p ~ 0.1 Torr) was observed and described for the first time. Experiments were carried out in a steel cylindrical chamber. In the center of the chamber, a steel ball, whose diameter is much smaller than the characteristic dimension of the chamber, was placed. A positive potential was fed through a ballast resistor from a high-voltage power supply. Grounded walls of the chamber served as the second electrode, i.e. (Fig. 1.a).

Fig. 1. Three types of studied discharge gaps: a) quasi spherical with point-like anode; b) ring-like cathode and central anode; c) plane discharge with ring-like cathode and central point-like anode.
After the ignition of the discharge, steady state glowing spherical layers (striations or strata) appeared around the central electrode. In experiments, there were observed from one to more than ten striations. A photograph of a stratified discharge with five striations is presented in Fig. 2.

![Stratified spherical discharge](image)

Fig. 2. Stratified spherical discharge in air+acetone. Cathode - steel chamber and the spherical anode in the center.

This work is a continuation of the study of stratification origin in low-pressure gas discharge, in which there is spherical or cylindrical symmetry with respect to central anode. A comparative analysis of results obtained in a different kind of spherical discharge is carried out.

2. **Summary of experimental results**

In addition to the described above, we have studied discharges in two geometries of a discharge gap.

![Stratified discharges](image)

a) b)

Fig. 3. Stratified quasi-spherical discharge air+acetone. Copper ring cathode and spherical anode in the center of the ring plane.
1. A volume ring discharge was formed in a glass spherical bulb 30 cm in diameter. In the centre of the bulb there was an anode (~0.3 cm in diameter). A copper ring (25 cm in diameter) placed in the equatorial plane served as a cathode (Fig. 1.b). Surprisingly, under some conditions striations appeared to be a set of spherical shells (Fig. 3.a) and under other conditions they were cylindrical closed sheets surrounding the anode (Fig. 3.b).

2. A plane ring discharge was created between two plexiglass (transparent) plates placed at the distance of 1-2 cm from each other, with a central anode (~0.2 cm in radius). A ring-like steel cathode (30 cm in diameter) served as a grounded wall (Fig. 1. c). A number of bright circle striations (from one to more than ten) around the anode were observed. An example of a volume ring discharge is presented in Fig. 4.

![Image of a volume ring discharge]

Fig. 4. Stratified quasi-cylindrical discharge in air+acetone. Steel ring cathode and the spherical anode in the center of the ring plane.

Before starting all the experiments, discharge chambers were pumped out till the residual pressure ~ 0.1 Pa and then were filled by working gas at pressure p. A discharge was initiated by applying positive voltage to the central electrode, the value of which is higher than the breakdown potential. After the discharge was initiated, the characteristic voltage drop $U_d = 600+500$ V was settled between the central anode and grounded cathode. In Fig. 5, two curves are presented: 1. Dependence of the breakdown potential $U_d$ on gas pressure; 2. Steady-state discharge potential $U_d$ for the discharge gap is shown in Fig. 1.a.

In the above-mentioned example, the discharge took a stratified form only at pressures lower than $p_0 \sim 50$, i.e. close to the minimum at the breakdown curve that is marked by the abbreviation Str. in Fig. 5. For two other discharge gaps, this border was higher respective to pressure, which corresponds to Paschen-Back law: if $p_0$ is the minimum at the Paschen-Back curve, and $d$ is characteristic distance from the anode to cathode, then $\phi \cdot d = C$, where $C$ is a constant. Besides, it was discovered that voltage-current characteristics in these discharges (for the above mentioned pressures) correspond to the normal glow discharge.

961
the wide range of discharge currents \((J = 10 + 70\, \text{mA})\), the potential between the anode and cathode practically did not change (Fig. 6).

There was found one more common feature in these discharges: the existence of striations depends on the chemical composition of gas medium. All three types of symmetrical stratified or striated glow discharges were realized in a number of high-

![Graph 1](image1.png)

![Graph 2](image2.png)

Fig. 5. Dependence of breakdown potential, \(U_b\), and potential of discharge, \(U_d\), on the pressure, \(p\).

Fig. 6. Voltage–current characteristic of a spherical discharge at different gas pressures.

molecular gases (mixtures of nitrogen, oxygen, and argon with vapors of acetone, alcohol, and so on) [3]. In pure noble gases, such a pronounced symmetrical stratification was not observed. In stratified discharges, the number of striations is decreasing with the time of burning. The conducted investigations show that it is connected with the changing of the chemical composition of gas medium at the time of discharge burning. The time evolution of emission spectra from the discharges was supports this fact. Simultaneously, the increase of gas pressure in the discharge chamber was observed, which was proportional to the initial concentration of high-molecular admixture. It can be accounted for the decomposition of complex molecules into several particles by collisions with discharge electrons in the cathode sheath or in striations, where high strength of electric field can be expected [4].

3. Discussions and conclusion.

The problem of a spherical or symmetrical discharge is associated with the problems of double layers in a variety of plasmas, in which a small anode is used (plasma contactors, electro-dynamic tethers, plasma chemical reactors, and light sources). What is the cause of the appearance of these bright structures in low-pressure high-molecular gases? Is the role of striations harmful in electro-ionization laser devices? Can the volume-filled up structures of
high electric fields in a striated discharge be used in technological applications with a benefit? Can they be turned into an advantage?

At present, the stratification of discharges described above gives more questions than answers.

In all the considered above discharge gaps, only non-moving (standing) striations were observed, while moving striations were not observed. It can probably be explained by permanent non-uniformity of "positive columns" of discharges operating with a small (point-like) anode. It is well known that in discharge tubes, standing striations are observed when one introduces some mechanic or electric disturbance in the tube [1].

In discharge tubes, a traditional explanation of stratification lies in the mechanism of diffusion-drift and ionization instability [5]. However, this approach corresponds to rather high gas pressures (p>1Torr). Under low-pressure conditions, stratification is explained on the basis of non-local electron kinetics [6,7]. Electrons acquire kinetic energy from an electric field until they reach the molecule excitation threshold \(U_{ex}\), and then undergo an inelastic collision. After the loss of energy \(U_{ex}\), the electrons again start to gain energy from the field, and the picture is repeated. These processes should be considered with the help of non-local Boltzmann equation for electron distribution function in the electric field preset in a model form or taken from the probe measurements [6]. Theoretically, to receive striations, one presets a spatially periodic striation-like field [7,8]. Such a situation cannot be admitted as satisfactory even in the best-studied case of discharge in tubes.

In highly non-uniform conditions of a glow discharge with a point-like anode, the problem of a self-consistent description or even interpretation of stratification becomes more complex. For example, Fig. 3.a and Fig.3.b illustrate the fact that a striated discharge can suddenly change its structure after a slight change of discharge conditions. Striations can look like closed spherical glowing shells or sheets surrounding the anode. What is the cause of this instability? Is there a sudden change of electric fields around the anode? What is the role of plasma chemical processes in such transformation?

A possible explanation of these complex phenomena is connected with the instability that is typical only of high-molecular gases, i.e. of plasma behavior in gases with non-monotone dependence of electron drift velocity on a reduced electric field, see for detail [9].

References

[8] F. Sigeneger, G. I. Sukhinin, and R. Winkler, Plasma Chemistry and Plasma Processing, 20,