Volume discharge in Helium nearby atmospheric pressure: uniformity and stability

Kurbanismailov V.S.[1], Omarov O.A.[1], Ragimhanov G.B.[1], and Aliverdiev A.A. [1,2]

[1] *Dagestan State University, Gadjieva Str. 43A, 367025, Makhachkala, Russia*
[2] *Institute for Geothermal Researches DSC of Russian Academy of Sciences*
- Pr. Shamilya 30A, 367030, Makhachkala, Russia, aliverdi@mail.ru

We have experimentally studied electric and time-spatial characteristics of volume discharge and transition from a volume burning stage to a channel stage nearby atmospheric pressure. We have shown that in conditions of strong preliminary ionization the discharge has a volume structure of the current in a wide range of initial voltage, and the duration of this stage decreases with the growth of current density and gas pressure.

Keywords: discharge formation, volume discharge, streamer discharge, high-pressure, plasma

1 INTRODUCTION

Volume discharges in inert gases are widely used for a gas lasers pumping. To increase the power characteristics of gas lasers we need (i) to improve the pumping methods and (ii) to optimize the excitation conditions. [1-3] The problem of pumping optimization consists in reception of certain electric characteristics of discharge plasma with the constant spatial uniformity during a pumping. Instability of the discharge results in transition from stage of volume burning to channel stage (contracted discharge). The physical mechanisms, which are responsible for the discharge instability, can be various and depends of the gas (or the gas mixture). [4-9]

Thereby the study of volume discharge properties in pure gases has both fundamental and practical interest. Toward this aim we have experimentally investigated the plasma characteristics of volume and contracted discharges, as well as the processes of a discharge counteraction and a plasma torch creation in helium at atmospheric pressure in a wide range of initial conditions.

2 EXPERIMENT AND METHODS

The experimental setup and methods of research were similar to ones described in [7-10]. The gap under study (about 1 cm length) irradiated by either a spark discharge through the grid anode or an ultraviolet source placed in the same gas at a distance of 5-7 cm from the main gap axis. Diameter of electrodes was 4 cm. We have used electrodes with various shapes (planar and hemispherical, $R = 30$ cm) made of different materials: aluminium, stainless steel and copper. The pulsed voltage source generated voltage pulses with a variable amplitude of up to 30 kV and front duration ~10 ns.

The discharge voltage and current were measured with the application of digital oscilloscopes. Frame photographs of the discharge glow were obtained using the FER-2 streak camera with the UMI-92 image tube and were synchronized with the electrical characteristics by simultaneously supplying of the triggering voltage pulse to the FER-2 and the signal of the discharge current (or voltage) pulse to a double-beam storage oscilloscope. Streak images of the discharge glow were synchronized by applying the signal of the current (or voltage) pulse to the deflecting plates of the UMI-92 image tube simultaneously with the scanning of the discharge. [8] The time shift between the glow and electrical signals was taken into account. Thus, the images of the discharge glow taken with spatial and temporal resolutions allow tracing the spatiotemporal dynamics of the discharge and, on the other hand, together with oscilograms to determine the durations of the characteristic stages.

3 RESULTS AND DISCUSSION

A homogeneous volume discharge burns at small external fields ($E_0 < E_{critical} = 6$ kV/cm) and the development of uncompleted anode channels adhered to cathode spots with high conductivity (plasma channels) begins at density of a current about 40 A/cm^2. The increase of a current density up to 60 A/cm^2 leads to the further promotion of the uncompleted anode channels, the anode spotting, and also the appearance of uncompleted cathode channels. When the current density overcomes 100 A/cm^2, the anode and cathode channels merges (see fig. 1).

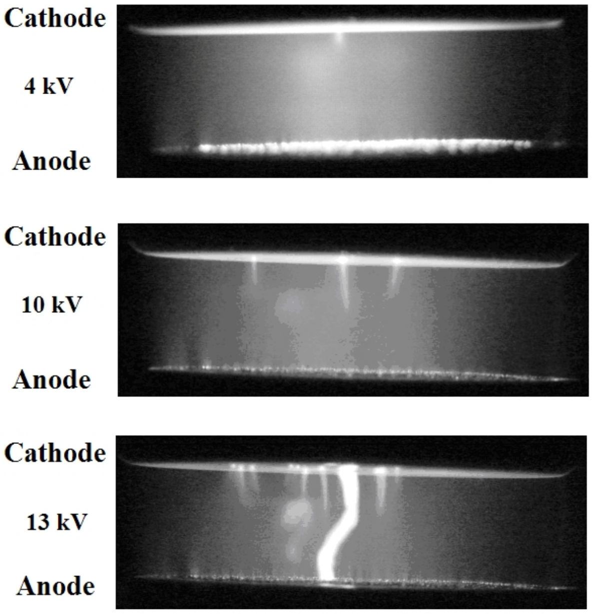

Fig.1: Time-integrated photos of the discharge glow at atmospheric pressure. Planar electrodes (the solid cathode and the grid anode) were used

If a gas pressure increases the discharge uncontracts and burns homogeneously at fields $E_0 \le E_{\text{critical}}$ =7,5 kV/cm. At fields $E_0 > E_{\text{critical}}$ the large density of cathode spots (from which formation of the uncompleted channels begins) is observed, and the discharge column has a high degree of uniformity. In the coordinated pump mode it is realized a specific heat input ~ 0.1 J/cm^3, being maximal in a stage of homogeneous burning.

The duration of volume stage τ_b can be adjusted by the reduction of a current density or by the increase of a gas pressure. The step on a pulse voltage is practically not authorized at the pressure 5 atm. In this case the duration of the volume discharge stage is defined by the time of switching of a discharge current, thus a voltage pulse on a discharge interval smoothly falls down up to arc value. On the other hand, the reduction of the duration of the volume discharge burning stage with the pressure growth is based on the non-compensated growth of ionization processes relative to recombination ones. Time-differentiation of volume and channel stages of the discharge burning is well visible on oscillograms (look at fig. 2).

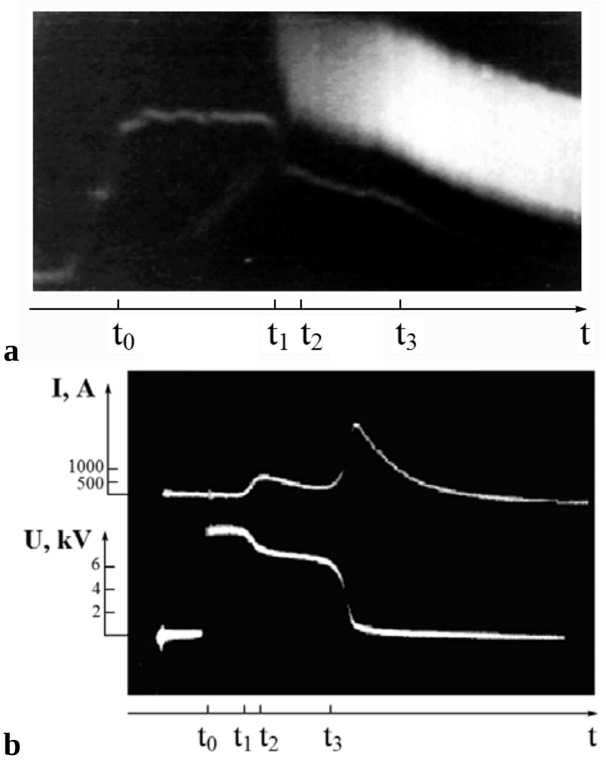

Fig.2: a) typical streak image of the discharge in He synchronized with a voltage pulse (U_0=10 kV, P = 1 atm, the time scale is 300 ns per screen); b) typical oscillogram of current (up) and voltage (down) (U_0 = 9 kV, P = 3 atm, the time scale is 2000 ns per screen). Here, t_0 is the beginning of the applied voltage growth; t_1 is the beginning of the first voltage drop; t_3 is the beginning of counteraction of a volume discharge in a spark channel; $\tau_b = t_3 - t_2$ is a volume phase duration. Hemispherical electrodes were used

The increase in a gas pressure results to the increase of voltage at the discharge column. It, for one's turn, results to a growth of ionization processes both due the shock ionization that is caused by strong dependence of factor α from E_0, and due the step ionization. Then the rough uncompensated growth of electron concentration results in growth of conductivity and the recession of voltage up to arc value. Afterward the discharge passes in a recombination mode and dies. The increase of overvoltage up to 300 % brings to the appearance of a large number of plasma channels having rather large diameter.

At the volume stage of the discharge burning the voltage U_b is constant. Its value depends on pressure and corresponds to the minimal voltage of breakdown with the fixed product of gas pressure on the interval length *(P d)*.

For the obtaining of a sparkless mode, it is necessary to obtain the full dispersion of a storage element energy ($C = 1{,}5\cdot10^{-8}$ F) for the time τ_b [1]. For the volume discharge in helium this requirement is reached if $U_0=2U_b$, where $U_b \approx 3$ kV is the voltage of a volume discharge burning at $P = 1$ atm, $d = 1$ cm. The spark channel in this case is initiated by instabilities in near-electrode areas [8-10]. These instabilities define a binding of narrow diffusive channels and cause the process of the transition from the volume discharge to the spark.

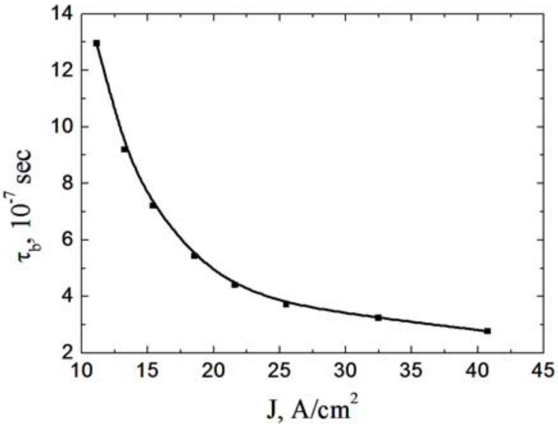

Fig.3: Characteristic dependence of the duration of the volume stage of discharge burning on a current density (P = 1 atm.). Planar electrodes (the solid cathode and the grid anode) were used

The basic energy is entered in the discharge on quasi-stationary stages. Then for the energy density it is possible to write:

$$W = P\tau_b / V = IU\tau_b /(Sd) = jU\tau_b / d ,$$

where τ_b is the volume stage duration, j is the current density.

The energy, entered into gas before the spark channel formation, grows at increase of power, although the burning duration τ_b exponentially decreases with the field growth (see fig. 3), and the volume discharge counteracts in the spark channel at the critical current density $j \ge j_{critical} \approx 40$ A/cm^2 and the extreme specific inputs $\approx 0{,}1\text{-}0{,}2$ J/cm^3 [8].

4 CONCLUSION

From our experiments we have a clear sequence of occurring events: 1) the occurrence of cathode spots in an initial stage of the discharge, 2) the development of uncompleted anode channels, 3) the formation of uncompleted cathode channels, and finally 4) the merge of counter channels and the growth of their conductivity. In the case of the extreme specific heat input ≈ 0.1 J/cm^3 and the critical current density $j_{critical} \ge 40$ A/cm^2 the discharge contracts to a spark channel. The burning voltage U_b tends to such value at which U_b/Pd is constant. At the same time the ionization ability of electrons $\eta = \alpha/E_0$ is maximal and optimal for electron multiplication.

Acknowledgements

The work was partially supported by RFBR (12-02-96505, 12-01-96500, 12-01-96501) and within the framework of the State task № 2.3142.2011 Ministry of Science and Education of Russian Federation for 2012-2014.

REFERENCES

[1] Korolev Yu D, Mesyats G A, Physics of Pulsed Gas Breakdown, Nauka, Moscow 1991.

[2] Mesyats G A, Korolev Yu D, Sov. Phys. Usp. 29 (1986) 57-69

[3] Woodard B S, Zimmerman J W, Benavides G F, et al., J. Phys. D: Appl. Phys., 43 (2010) 025208.

[4] Meek J M, Craggs J D (ed), Electrical Breakdown of Gases, Chichester Wiley 1978.

[5] Raizer Y P, Gas Discharge Physics, Springer, Berlin 1991.

[5] Bologa A, Paur H-R, Seifert H, Woletz K, International J. on Plasma Environmental Science & Technology 5 (2011) 110-116.

[6] Kurbanismailov V S, Omarov O A, Teplofiz. Vys. Temp. 33 (1995) 346.

[7] Bairkhanova M G, Gadzhiev M H, Kurbanismailov V S, et al., Prikl. Fiz. 5 (2009) 62-66.

[8] Kurbanismailov V S, Omarov O A, Arslanbekov M A, et al.. Plasma Physics Reports 38 (2012) 22-28.

[9] Kurbanismailov V S, Omarov O A, Ragimkhanov G B, et al., Plasma Physics Reports 37 (2011) 1166-1172.

[10] Efendiev A Z, Aliverdiev A A, Radiophysics and Quantum Electronics 20 (1977) 850-855.