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INFLUENCE OF PARAMETERS OF THE ELECTRODE DESIGN ON A LUMINESCENCE FORM OF THE PULSED DISCHARGES IN OVERVOLTAGE GAPS

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Abstract- Present article is devoted to discharge processes in solid air under influence on discharge gap the high voltage nanosecond pulses. Are considered the different types of potential electrodes with dielectric nozzles and their influence on luminescence volume form of powerful discharges in high pressures. Is shown a conversion of diffusive volumetrically discharge to constricted discharge on different interelectrode distance and electrodes geometry and the accompanying physical processes are analyzed.

Keywords: Potential Electrode, Volume Discharge, Run Off Electrons, Electron Beam, Streamer, Propagation Speed, Interelectrode Distance, Dielectric Nozzle, Fluoroplastic, Luminescence, Plasma Clots, Microcraters.

I. INTRODUCTION

Last time is given enormous attention to development of high voltage pulsed technique for realization of the different researches and applied purposes. At the most fields of industry and technique is observed transition from microsecond high voltage pulses to nanosecond ones. Nanosecond electrical pulses with a big power up to TVt are used in a number of the most areas, such as relativistic microwave electronics, super wide-band radio-location, electromagnetic reaction, research of electromagnetic compatibility of the complex systems, underground radio-location, lasers and accelerators power systems, research breakdown processes in water, purification and disinfection of drinking water and wastewater and etc. [1-4]. Powerful short pulses are also used in a number of modern developmental physics areas such as controlled nuclear fusion and other large-scale physical experiments.

Development of nanosecond pulsed discharge process is accompanied by infraction of electrons distribution function by energy and appearance of run off electrons capable to realize a collision ionization. The run off electrons phenomenon in plasma is known a long time ago [5], were carried out the numerical computations [6, 7] and analytic treatment for low fields [8]. This phenomenon has an essential importance for diagnostics and admixture's energy-balance in plasma of tokamacs [9].

Researches of characteristics of nanosecond discharges in dense air cause a particular interest owing to getting the very short fronts of pulses and not identity of the physical processes happening in classical physics of discharges. Physical processes around the electrodes (cathode and anode) at a big overvoltages lead to emergence of the high energy electrons capable to cause X-ray radiation there. Configuration of electrode systems in these processes also can play an important role.

This article is devoted to researches of influence of a surface and configuration of electrode systems on a form and luminescence of nanosecond discharges in air on various atmospheric pressures.

II. EXPERIMENTAL PART

For initiation of nanosecond pulse discharge the high voltage pulsed generator, designed by Arkadiyev-Marx scheme, is used. At exit of generator the pulse by amplitude 100 kV, duration and front 350 ns and 18 ns respectively is formed.

In Figures 1-5 the luminescence photos of the discharge gaps at different interelectrode distance - d and configurations of cathodes are shown. As the anode and cathode the flat copper foil and the metal core with various radius of curvature - r_c are respectively used. As shown on Figure 1 the volume diffuse discharge in atmospheric pressure and d=10 mm, r_c = 6 mm on U_{gen} = 100 kV is realized.

Figure 1. r_c = 6 mm, anode-copper foil, U_{gen} = 100 kV, P = 760 Torr, interelectrode distance, d = 10 mm

On the cathode are formed the plasma bunches by visible dimension $l_p \sim 2$ mm << d, but remaining space up to anode is filled up by diffusive glow. The cathode plasma formations are substantially non-uniform.

With reduction of interelectrode distance up to d = 5 mm at the invariable radius of curvature of potential electrode (cathode) we observe transition from diffusion volume discharge to spark one, as shown on Figure 2. There are some plasma bunches on the cathode and constricted channels and their quantity is equal to plasma bunches on cathode.

Figure 2. r_c = 6 mm, anode-metal screen, U_{gen} = 100 kV, P = 760 Torr, interelectrode distance, d = 5 mm

We will note that with reduction of air pressure, the plasma bunches dimension on cathode is grown and luminosity is decreased. In case of low pressure, P < 0.5 Torr and planar electrode system, when we have developed working surface of potential electrode, the discharge phenomena is not observed. But with replacement of the flat electrode on a metal rode with different radiuses of curvature we are witnesses of formation of plasma clots which sizes are decreased with reduction of air pressure below atmospheric, P = 760 Torr.

With reduction of radius of curvature of the potential electrode up to r_c ~1 mm and change of the anode surface on a metal grid at pressure, P = 760 Torr and interelectrode distance, d = 10 mm, an intergrowth of the bright constricted channel and overlap of whole discharge gap is observed, as shown on Figure 3.

Figure 3. r_c = 1 mm, anode- metal grid, U_{gen} = 100 kV, P = 760 Torr, interelectrode distance, d = 10 mm

Under the identical conditions given on Figure 3, but with reduction of interelectrode distance up to d = 3 mm, we observe an expansion of luminescence area discharge channel (Figure 4). Diffusive cover in that case is not appeared.

We will note, that in case of sharply non- uniform field is fixed only one bright channel and plasma bunch. By increase of the field's uniformity the channels and plasma bunches quantity are grown. By increasing of pressure up to P = 3.5 Atm and putting on potential electrode (with diameter r_c = 1 mm) dielectric fluoroplastic nozzle, we can get the white bright volume luminescence of discharge gap like shining sphere (Figure 5).

Figure 4. r_c = 1 mm, anode-metal grid, U_{gen} = 100 kV, P = 760 Torr, interelectrode distance, d = 3 mm

Figure 5. r_c = 1 mm, anode-metal screen, U_{gen} = 100 kV, P = 3.8 Atm, interelectrode distance, d = 10 mm

Throughout experiments we also researched an influence of various dielectric nozzles from porcelain and fluoroplastic put on potential electrode at "pin-plane" electrode system on a form and volume of the discharge luminescence depending of their promotion distance relatively the end of the "pin" electrode at the different air pressures, P = 1-5 Atm. The end of "pin" electrode is sharpen under a cone [12] with various radiuses of curvature, r ~ 1÷4 mm. The cylindrical dielectric porcelain tube was put on the "pin" electrode and moved relatively its end on l ~ 1÷5 mm.

It is used here for getting a strong longitudinal electric field. The porcelain tube is used for focusing of the charged particles, forming under action of super strong electric field. In some experiments the hydrophobic fluoroplastic nozzle was put on porcelain tube and moved relatively its end face on d ~ 1÷5 mm. In view of water hydrophobic surface of fluoroplastic nozzle, the leakage charges resistance on its surface practically didn't depend on air humidity.

As the anode, the steel grid by step 1.5 mm with moving mechanism for changing of the interelectrode distance between the electrodes was used. Interelectrode distances varied in range l ~ 3÷15 mm at various configurations of the "pin" electrode - cathode.

The luminescence photos of discharge channels were made for single pulses. Below under the anode the digital video camera Samsung S500 Digimax 5.1x was placed. On that camera position it is possible to observe an expansion of the luminescence area of discharge zone in presence of dielectric nozzles on cathode. Then by Sony Vegas Pro8 computer editing program the available video files to integrated photos are transformed.

The technique of registration of X-ray radiation was based on traditional registration methods of runaway electrons [13-16]. At 5 cm distance from a discharge zone the DP5V dosimeter was located. On opposite side the cartridge with a high contrast X-ray film (CP-BU) was installed. The films were cut by size: 5×7 cm and into the

cartridge were inserted. The autographs of X-ray radiations were got at continuous following pulses with frequency about 50 kHz.

As it was noted above, the experiments were carried out for cathodes with various radiuses of curvature, r ~ 1-8 mm with porcelain and fluoroplastic nozzles. They were fixed at different positions relatively end of the "pin" electrode. At r = 1 mm (radius of curvature) the porcelain nozzle in combination with fluoroplastic one was used. But at r = 4 mm the plexiglas nozzle on "pin" electrode was put and fixed on l ~ 1÷5 mm relatively its end. In some experiments as the cathode the steel sphere by r = 8 mm was applied. In this case the round fluoroplastic nozzle moved rather working end face of sphere on l ~ 1÷5 mm. By using the various configurations of potential "pin" electrode the integrated stages of nanosecond pulse discharges were photographed and given in Figure 6.

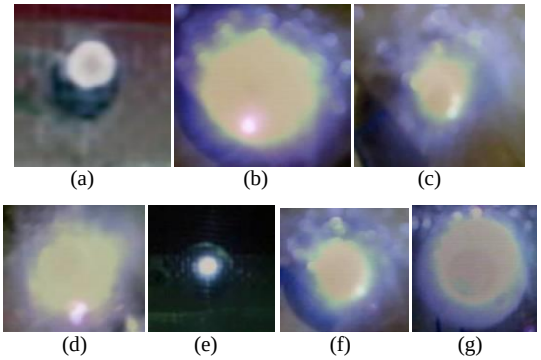

Figure 6. Luminescence photos of the nanosecond discharges at negative tension polarity on potential "pin" electrode with various radiuses of curvature (r = 1-8 mm), interelectrode distances - l and dielectric nozzles at high air pressures (P = 1-5 Atm.):
(a) P = 1 Atm, r = 1 mm, l = 5 mm, without nozzles;
(b) P = 5 Atm, r = 1 mm, l = 5 mm, porcelain tube - nozzle is put forward relatively the "pin" electrode end on l ~ 3 mm;
(c) P = 1 Atm, r = 4 mm, l = 5 mm, without nozzles;
(d) P = 5 Atm; r = 4 mm, l = 5 mm, Plexiglas nozzle is put forward relatively the "pin" electrode end on l ~ 4 mm;
(e) P = 1 Atm, r = 8 mm, l = 5 mm, without nozzles;
(f) P = 3 Atm, r = 8 mm, l = 5 mm, without nozzles;
(g) P = 2 Atm, r = 8 mm, l = 5 mm, the fluoroplastic nozzle basis is in one plane with the sphere basis

The general in photos (Figure 6) is an existence of a bright white luminescence nearly cathode, covered by diffusion luminescence area with violet color. The violet luminescence, most likely, corresponds to highlighting of the excited nitrogen molecules (the second positive system of strips) [17]. The observed white luminescence is, probably, a plasma radiation in area, closed to cathode, with rather high temperature.

Really, it is possible to estimate the role of porcelain and fluoroplastic nozzles on "pin" electrode with various radiuses of curvature in expansion of the luminescence area of pulse discharge and increase of the X-ray radiation dose at high air pressure. The luminescence area of the nanosecond discharge in existence of both dielectric nozzles in case (r = 1 mm) is much wider, than at their absence. It is well visible on integrated luminescence photos (Figure 6).

It should be noted, that with deepening of potential electrode in dielectric nozzle on l = 1-4 mm the luminescence area of discharge is more extended. Here the focusing effect of the charged particles is taken place, about what it was mentioned above. By simultaneous use of both nozzles we can considerably increase of luminescence area. For example, by fixing of "pin" electrode (r = 1 mm) in porcelain nozzle on 3 mm relatively its end we get an expansion of luminescence area up to 10 mm (twice). With putting on the fluoroplastic nozzle and its fixing relatively porcelain one on 1 mm, we can get an expansion of luminescence area up to 27 mm (by 5.5 times).

With deepening of "pin" electrode in porcelain nozzle on 4 mm, the width of luminescence area is reached up to 62 mm. At the same time by increase of air pressure (up to 5 Atm.), the luminescence area of nanosecond discharge is more extended. For example, by fixing of porcelain tube on one plane with the end of "pin" electrode (r = 1 mm) at P = 1 Atm. the width of luminescence area is increased from 8 mm to 15 mm at P = 5 Atm, and in case of r = 8 mm, up to 30 mm. It should be noted the greatest expansion at simultaneous use of the both dielectric nozzles.

Registration of X-ray radiation on films showed, that on negative tension polarity on potential "pin" electrode an intensity and energy of quanta of X-ray radiation is sufficient for the film flare, placed in black paper [18, 19].

Considering, that during formation of nanosecond pulse discharge at high air pressures there are the intensive ionization and explosive processes on cathode, we also investigated the changes on cathode micro reliefs before and after discharge at various radiuses of curvature of "pin" electrode (r = 1-8 mm). Before discharge the cathode surface was electrochemically treated.

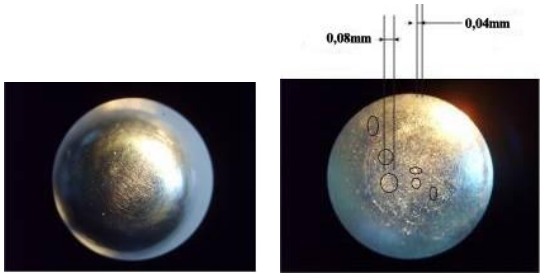

Figure 7. Microphotos of surface parts on cathode (a, b) before and after discharges in air pressure 3 Atm:
(a) "pin" electrode (r = 4 mm), before discharge;
(b) P = 3 Atm, "pin" electrode (r = 4 mm), after discharge

In photos (Figure 7) the microcraters, formed, as a result of explosive processes on cathode during formation of the nanosecond discharges in solid air, are noted. Their sizes can reach 40-80 mcm. Microcraters on the surface are distributed separately. It should be noted, that with pressure increase the number of microcraters is also grown. The spot size on the anode (copper plate) after pulsed discharge makes 1.13 mm. By pressure increase it can be extended on some tens microns, as well as the microcraters sizes on the cathode [20].

III. RESULTS AND DISCUSSION

From results of experimental researches and known works, it is possible to offer the following development mechanism of the nanosecond pulse discharge in non-uniform electric field in air on high pressures. By affect of high pulsed voltage with short front on solid gases an electric field concentrates on microinhomogeneities of the "pin" electrode-cathode.

The mechanism of discharge development in solid gases on big overvoltages can be described by following way. As a result of auto electronic emission the initial electrons from the cathode form a bunch, that on pulse front and length Z_{cr} ~ 100 mcm are transformed into anode streamers. Before the voltage impulse reaches the maximum value, intensity of electric field at the front of streamer reaches the critical value E_{cr}. On that time on streamer front are formed the run off (high power) electrons. At the same time the mechanism of polarizing self-acceleration, reducing to generation the powerful electrons with anomalous energy is operated.

These electrons ionize a gas and form the volumetrical discharges on discharge gap in relatively weak non-uniformity field. In strongly non- uniform electrical fields the volume discharge is formed only as a result of gas ionization by running-away electrons bunch. Because an interelectrode distance, $d >> Z_{cr}$ the cathode discharge is caused only by photoelectric effect. The local field, strengthening on cathode by positive volume charge, during the time $t_d < 1$ ns which reduces the formation of plasma bunches. From this moment the formation and development of cathodic spots and exploding processes on it by transition to exploding electronic emission are begun.

On sufficiently small interelectrode distance the plasma bunch can constricted and advanced over ionized gas by run off electrons. As result the high local intensity of electrical field on the channel head, where is concentrated a negative volume charge, is increased and this channel is accelerated as a single whole. In spite of the power density, input in discharge gap is ~ 100 MVt/cm^3, plasma is remained low-temperature, weakly ionizated in all discharges development stages because between electrons and gas there is an insignificant interaction and electrons almost completely keep the energy.

Thus on big overvoltages the run off electrons effect plays a fundamental role in breakdown mechanism of pulsed discharges in solid gases. Participation of run off electrons in breakdown process in solid gases is determined by displacement of minimum on Pashen's curve $U(pd)$ to right by overvoltage growth (shortening the pulse front τ_{gen}) for big pd.

At the same time the energy of part of runaway electrons dissipates on gas molecules, causing the X-ray radiation there. The volume positive charge, forming nearly cathode, as a result of formation of avalanches, promotes to strengthening of electric field on cathode and leads to explosions [21, 22]. All these processes are developed very fast on pulse front. In turn, a negative charge on the avalanches front and the increasing tension on an interelectrode distance lead to increase of electric field intensity. When it reaches the value above critical one, an acceleration of electrons energy up to tens keV and participation in ionization and excitement of gas molecules in remain distance between electrodes and advance of ionized plasma to anode is taken place.

The high-energy electrons promote to expansion of plasma channel and formation of the volume pulsed discharge. They cause the soft X-ray radiation in gas volume, which plays an important role in further ionization and excitement of neutral gas molecules. At approach of ionization front to anode, the critical field intensity between it and plasma channel forms the heavy-duty bunches of runaway electrons with nanosecond duration, bombarded the anode with total kinetic energy. The mentioned above treats a case when dielectric nozzles on the cathode are absent.

At existence of dielectric nozzles on the cathode the process of formation of the nanosecond discharge is differed a little. We have here not only the gas area nearly cathode, but also the dielectric surfaces. Therefore, it is necessary to consider the possible physical processes, happening in solid dielectrics during formation of nanosecond pulsed discharges. An expansion of luminescence area of the pulsed discharge, observed in photos in existence of dielectric nozzles on the cathode, can be explained by several physical mechanisms.

One of them can be connected with accumulation of the inactive positive ions on the fluoroplastic surface, formed as a result of ionization processes nearly cathode. They, in turn, lead to change of electric field configuration in "cathode-porcelain-fluoroplastic" zone and to advance of the high-speed discharge processes far from initial ionization centers. Secondly, an expansion of luminescence area can be a result of the processes, developing in solid dielectrics at impact of high voltage nanosecond pulses.

In both cases an expansion of ionization processes is connected with emergence of runaway electrons in strong electric field. There is a bombing of valent zone of dielectrics by high-energy electrons and further narrowing of forbidden zone and rough injection of electrons from the valent zone to conductivity one during impact of sharp front pulses. It is possible to assume, that as a result of accumulation of electrons in conductivity zone of dielectric, its surface becomes conductive and the high tension can be transferred from the cathode to nozzle surface. In this case the nanosecond discharge is developed not only from the "pin" electrode, and also from a dielectric surface. All these processes lead to expansion of the discharge luminescence area.

In case of r = 1 mm (radius of curvature of "pin" electrode) X-ray radiation is registered at the cathode and anode (as in the existence and at absence of dielectric nozzles on the cathode) in atmospheric air pressure. When using a porcelain tube, the more rigid X-ray radiation is registered, than at their absence. It should be noted, that with change of r, the dose of X-ray radiation is also changed.

An electric field near the "pin" electrode with r = 1 mm is more non-uniform, than around electrode with r = 4 mm. Because of the small working area of "pin" electrode with r = 1 mm the quantity of microinhomogeneities is less in comparison with r = 4 mm. Therefore at r = 1 mm, there are less explosions, where the most field intensity is concentrated. By increase of air pressure the luminescence area of pulsed discharge (because of intensification of ionization processes at a potential electrode) is more extended. It should be noted, that at "pin" electrode with r = 4 mm even in absence of dielectric nozzle on cathode the X-ray radiation is registered.

Change of microrelief of the cathode surface can be explained by explosions of microinhomogeneities under the effect of critical currents of thermoautoelectronic emission. Besides, in gas discharges the microemitter warming up owing to bombing by high energy ions is essential.

Thus, using of various dielectric nozzles on a potential electrode on high air pressures allows to expand of luminescence area of the pulsed discharge and extend the discharge processes far from initial ionization centers and can be effectively applied for solution of various actual tasks of applied physics. An increase of the luminescence volume of pulsed discharge leads to increase of concentration of chemically active products in interelectrode space and can be effectively used for purification of contaminate gases from harmful impurities. At the same time, the growth of X-ray radiation dose nearly cathode and anode with using dielectric nozzles on the cathode testifies to formation of big concentration of runaway electrons, actively taken part in formation of powerful super short avalanche electron beams.

We will note that ionization emission in air at multiple overvoltages in volumetrical discharges reaches the light speeds and the current pulse with a high rate of pulse rises up to ~ 10 TA/s value. In that case a pulse front is τ_f < 0.5 ns and upper bound of current is I_m ~1.5 kA. By decrease of the interelectrode distance - d the volumetrical discharges pass into constricted channels and the current amplitude I_m and channels conductivity are considerably grown.

Also we have to note the importance of the breakdown delay time t_d relatively to moment of voltage pulse supply from generator that characterizes a speed of ionization processes development.

On d < 10 mm and U_{gen} > 180 kV independently from cathode geometry in solid gases a big conduction current is already appeared on the front of voltage pulse and $t_d < \tau_I < \tau_{gen}$ < 0.6 ns, where τ_I is an acceleration time of voltage pulse at the discharge gap.

So, ionization propagation speed $V_I > d/t_d > d/\tau_{gen} > 2.5\times10^9$ cm/s that is more than a speed of streamers distribution [10, 11]. When U_{gen} < 180 kV in relatively uniform field we can register the breakdown delay time ~ t_d ~ 2 ns for cathodes with radius of curvature r_c ~ 20 mm. By decrease of pressure this parameter t_d is grown.

IV. CONCLUSIONS

In presented article are considered the physical processes in pulsed nanosecond discharges in solid air. Are shown the local and non-local criterions of run off electrons (high power) in air at different pressures..

Are given the various luminescence photos of pulsed discharges on different electrodes geometry and interelectrode distance and etc. Is shown transition of volumetrical diffusive discharge to constricted discharge formed due to run off electrons created on cathode plasma bunches.

It iss shown an influence of dielectric nozzles on a potential electrode, distances of their promotion relatively the end of pin electrode, surface state and parameters of potential electrodes and interelectrode distance on luminescence form and volume of the nanosecond pulse discharge.

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BIOGRAPHY

Elchin Jalal Gurbanov was born in Kurdamir city, Azerbaijan on 12.02.1963. He graduated from school No. 151 in Baku, Azerbaijan in 1980 and entered to Faculty of Electronic Equipment, Moscow Power Engineering Institute, Moscow, Russia. He successfully graduated that institute by specialty "Electronic Devices" in 1986 and start to work in High Voltage Laboratory in Physics Institute of Azerbaijan National Academy of Sciences, Baku, Azerbaijan. He successfully defended a candidate dissertation regarding the high voltage treatment of compositional materials and received a scientific degree, Ph.D. in Physics and Mathematics Sciences in 1995. He studied in doctorate level in high voltage department of Moscow Power Engineering Institute (Technical University) in 2006-2010. From 2013, he work in Science department of "Azersu" Open Joint Stock Company of Azerbaijan. He have above 65 scientific articles in different journals, 1 author certificate and 2 patents.