# ELECTRICAL AND OPTICAL INVESTIGATIONS OF TRANSIENT HIGH PRESSURE DISCHARGE PHENOMENA

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## 1 Introduction

The object of our study is the induced formation of streamers (thin current filaments with radius of the order of several hundreds of μm) and spark in steady-state positive corona. It is well known, there are three main current modes (1-diffusive Hermstein glow, 2-streamers, 3-spark) for a centimeters gap positive pin-plane corona in ambient air, which follow in that order with increase of applied voltage. It is common, a critical value of corona current for 1→2-transition equals to 50-70 μA. Streamers start from a tip of pin towards the plane. Streamer mode is characterized by almost periodical splashes in current. In general, both the frequency of streamer occurrence and amplitude of current splashes increase with average corona current from units to tens of kHz and from tens to hundreds of mA, respectively. If the average corona current is in excess of some value, streamers (more precisely, streamer trains) induce periodically the sparks. A quantity of streamers in train inducing a single spark (2→3-transition) is diminished with increase in average corona current (see Fig. 1).

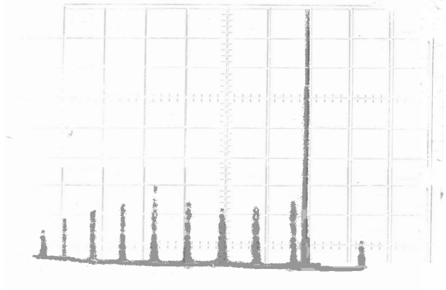

Fig. 1
Waveform of a positive corona current oscillogram under self-running streamers and regular the streamers-to-spark transition. (Horizontal and vertical scales are 50 μs and 10 mA in square. Air, pin-plane gap 17 mm).

Previous experimental studies on physics of the spark formation in pin-plane geometry were performed predominantly under a pulsed high voltage applied across non-ionized inter-electrode gap (see [1-2] and literature cited therein). In this case the breakdown into spark occurs during each pulse and the streamer-to-spark transition takes very short time typically no more than several hundreds of ns (see Fig. 2 taken from paper [1]).

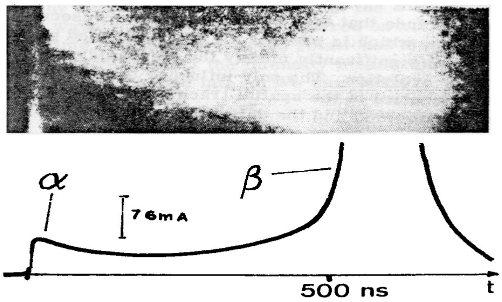


Fig. 2
Streak photograph and corresponding current evolution of the whole transition between the primary streamer and the transient arc. Air. Pin-plane gap length 18 mm.

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Although great data on the streamer-to-spark transition are already obtained in previous works mentioned above, a lot of important details associated with a generation of streamers in glow mode of steady-state positive corona and development of pre-spark channel are remained still non-cleared. For instance, it is well known, a streamer will occur in air gap under high electric field if the famous Meek's criterion has been reached:

$$M \equiv \int_0^d (\alpha_i - \alpha_a)dx \geq 18 - 20\,,$$

where M is the resulting coefficient of ionization multiplication of electron avalanche across inter-electrode gap; $\alpha_i, \alpha_a$ are the ionization and attachment coefficients, respectively. However, the value of M that ensures a self-sustained regime for steady-state glow corona is always kept much lower (M $\leq$4-5) at any current of this discharge. Therefore, it is not clear from the point of view of the received Meek's criterion how it is possible to induce streamer in steady-state glow mode of a positive corona under low value of M.

Further, there is a scanty experimental information on transverse size of pre-spark channel and its spatial-temporal behaviour from initiation up to bridging the inter-electrode gap. Also the detailed experimental information on the streamer-to-spark transition in a positive pin-plane corona in $N_2$ at atmospheric pressure is practically absent.

## 2 Experimental set-up

Some part of special experiments on observation of luminosity emitted from generation zone of corona in glow mode was carried out with use of wire-cylinder electrode geometry. The radii of wire and cylinder were and  mm respectively. These experiments were made predominantly in air at low pressure of several tenths of Torr.

The most part of experiments on spark formation was made with a positive corona in pin-plane geometry. Experimental set-up is shown in Fig.3. An inter-electrode distance of pin-plane corona is equaled to 17 mm. A radius of pin cap equals to 0.5 mm. A resistance of the ballast resistor in external circuit is equaled to 5 MΩ. Ambient air and pure nitrogen (99.999%) at atmospheric pressure are chosen as the background gases separately.

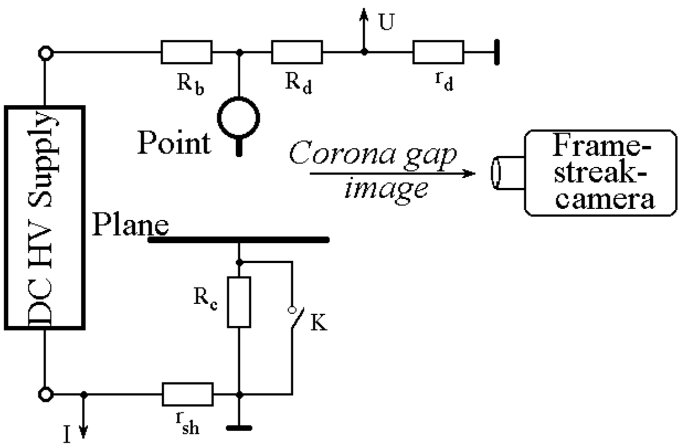



Fig. 3
Layout of experimental set-up on streamer- and spark initiation and observation

We used two approaches to induce sparks. First of them is in slow increase of steady-state voltage applied across corona gap up to the critical value, which results in seldom sparks at almost regular intervals between them. Second is in a fast increase of applied voltage for a small value (ΔU<<U) in a stepwise manner. Here ΔU is amplitude of step, and U is a background steady-state applied voltage corresponding to glow corona *with absence of self-running streamers* (!). So, second approach allows the initiating of sparks immediately from a diffusive background of steady-state corona. Such smart regime of streamer and spark initiation results in strong increase in time of a total transient process that makes a detailed observation of different stages of the glow-to-streamers-to-spark transition much easier.

## 3 Results and discussions

### 3.1 On difference between physical factors, which are responsible for appearance of streamers in non-ionized gas gap and within bulk of steady-state corona discharge.

Generation zone of steady-state positive glow corona appears with the naked eye as homogeneous and stationary. We have taken the pictures of anode glow with use of high-speed frame camera and revealed that glow is not in fact uniform. Local light emission emitted from each piece of glow generation zone is non-stationary. A noise intensity of local luminosity increases with corona current. The experiment shows that glow generation zone is broken into a lot of small non-stationary current spots, which are clearly observed (see Fig.4) if the total corona current exceeds over some critical value. This critical current decreases with pressure and is close to the threshold current for the 1→2-transition at atmospheric pressure (nearly 50 - 70 of $\mu$ A for corona in air). The characteristic size of current spots decreases with pressure. In the case of pin anode rounded like a hemisphere cup, the maximum frequency in appearance of current spots correlates always with a tip of pin. The anode spots become more intensive and appear more frequently if the total corona current increases.

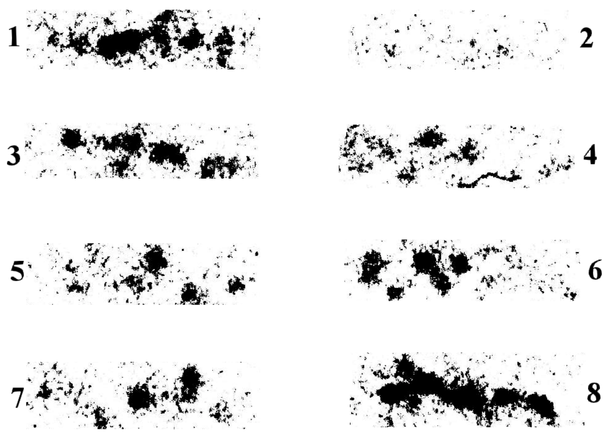



Fig. 4
Frame pictures illustrating the chaotic dynamics of high-density current spots on the anode surface of a glow positive wire-cylinder corona. Air, P = 30 Torr, $r_a$ = 0.5 mm, $R_c$ = 10 mm, I= 80 μA/cm, U= 1.6 kV.
Time exposition of each frame is 5 μs. Time interval between neighboring frames is 5 μs.
Typical diameter of current spot is 0.5 mm.

In our opinion, the most likely physical reason that is responsible for appearance of small anode current spots is the local development of ionization instability. A positive feedback resulting in a drastic enhance of the rate of ionization can be associated with increase in time of a local accumulation of $N_2$-metastable molecules produced in the generation zone.

The anode spots arise spontaneously and abruptly. Each current spot corresponds to the local breakdown of glow generation zone. This breakdown releases a voltage drop about of 1 kV, which results in a strong increase of the local reduced electric field that is sufficiently large to induce a streamer at the anode. So, our findings show that a crucial role in provocation of streamers in a positive corona at atmospheric pressure belongs to the high-density current spots on the anode.

### 3.2 Experiments on study of the streamer-to-spark transition in air

**Self-sparking.** Experiment in air with use of our first method for spark initiation shows that 2→3-transition can result from a sequence of streamers the amplitude of which does not necessarily increase in time (Fig.1). In the most cases more importantly for spark to happen, the time interval between two streamers in train has to be less than nearly 100 μs. This small interval ensures that the local energy deposited by the foregoing streamer into gas volume of tiny size (of the order of streamer diameter) does not dissipate due to diffusion before the subsequent streamer is happened. So, it means that a local accumulation of energy within small gas volume near the top of pin will enhance in time. High level of the deposited energy per $cm^3$ will result in a strong increase the rates of ionization and detachment processes and creation of a critical plasma embryo of the pre-spark current channel, which will elongate and propagate towards cathode plane up to spark formation. Our estimation gives the minimal value of the reduced energy deposition of the order of 1 $J/cm^3$.

**Formation of the induced streamers.** The representative step-by-step frame-camera picture and waveform of corona current under 1→2- and 2→3-transitions initiated by our second approach are shown in Fig.5, 6. A step change in applied voltage results in triggering of numerous streamers, which exhibit themselves like branches of tree (Fig.5). The maximum radius of this streamer bush at the cathode plane equals nearly to length of inter-electrode gap.

The streamer in air is self-limiting their lifetime that is of the order of several tenths of ns because of intensive electron attachment processes decreasing rapidly a conductivity within body of streamer. There are therefore several generations of the induced streamers (generally, 4-5 ones under our test experimental conditions), each of them correlates with appropriate pick in the current oscillogram presented in Fig.6. The most contribution of each generation to current pick is associated with bridging the inter-electrode gap by axial streamer travelling perpendicular to cathode plane. Some delay of the order of several tenths of ns exists in appearance of the first generation of streamers after applying of the triggering step voltage. We believe this time is spent on development of high-current anode spot inducing thereafter the first streamer.

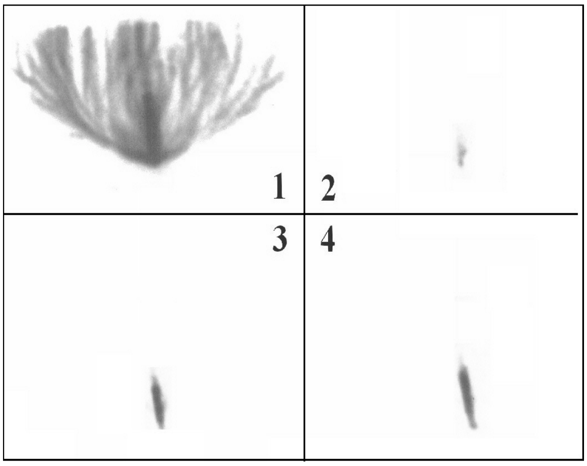



Fig. 5
Typical temporal evolution of a positive pin-plane corona morphology under the induced sparking.
Time exposition for first and second frames is 0.2 μs. Time exposition for third and forth frames is 0.5 μs.
Time interval between neighboring frames is 1μs. Gap length 17 mm. Air. U= 20.7 kV, I= 55 μA, ΔU= 1.8 kV.

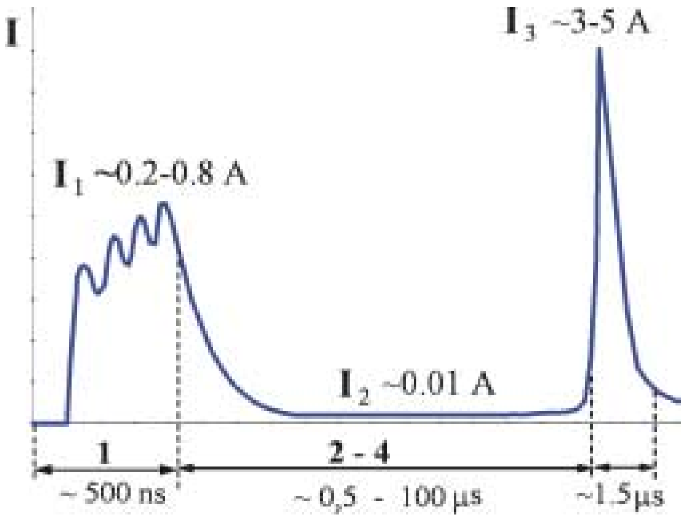



Fig. 6
Generalized behavior in time of corona current under the induced sparking. Scale is an arbitrary one.

At given length of inter-electrode gap, a total duration of the streamer induction period $T_1$ depends slightly on amplitude of the triggering step $\Delta U$ and background voltage $U$ across the gap. A typical value of $T_1$ under the test conditions is about of 0.5 μs. After this term, the induced streamers disappear in corona gap. The corona current drops down from $I_1$ ~ 0.2 – 0.8 A to $I_2$ ~ 0.01 A (these current amplitudes are not correct but typical ones).

It should be noted, a characteristic magnitude of discharge current at the induction stage $I_1$ is much in excess of steady-state corona current under total applied voltage equaled to U + ΔU. Taking into account a vast value of resistance in external circuit (R=5 MΩ), it means that transfer of current $I_1$ through external circuit is provided due to charging of stray capacitance in this circuit. As a rule, typical value of stray capacitance equals to several tenths of pF.

Additional important information on dynamic behavior of the induced streamers was obtained from streak photos. The streak photo is formed in photo film by linear scanning the image of some dynamic process. The following essential circumstances should be taken into account to decipher correctly these photos. First, a head of streamer emits high intensive luminosity but the body of streamer is much fainter. Therefore the tracks on streak photo are pictured with the moving bright point sources corresponding to the streamer heads. Second, the streamers travel in different directions from anode pin towards the cathode plane (see the bush of streamers in Fig.5), and not just along the axis of pin-plane system. Therefore the streamer heads exhibit different magnitudes for components of velocities parallel to direction of linear sweep. In this case the contemporaneous events will not already correspond to the points disposed on vertical line in streak photo as it usually is supposed.

Two streak photos obtained for short time domains of 75 ns and centered around first and second current picks (see Fig. 6) are presented in Figs. 7a) and 7c) respectively. One can see the first generation of streamers is poor enough and consists mostly of a single fast axial streamer that has already finished the shunting of inter-electrode gap, and slow streamers, which are travelling yet along the peripheral trajectories. Second generation is much richer and includes new fast axial streamer and a lot of slow streamers filling the bulk of the dome with radius at the cathode plane equaled to nearly of 0.8 d (d is inter-electrode distance).

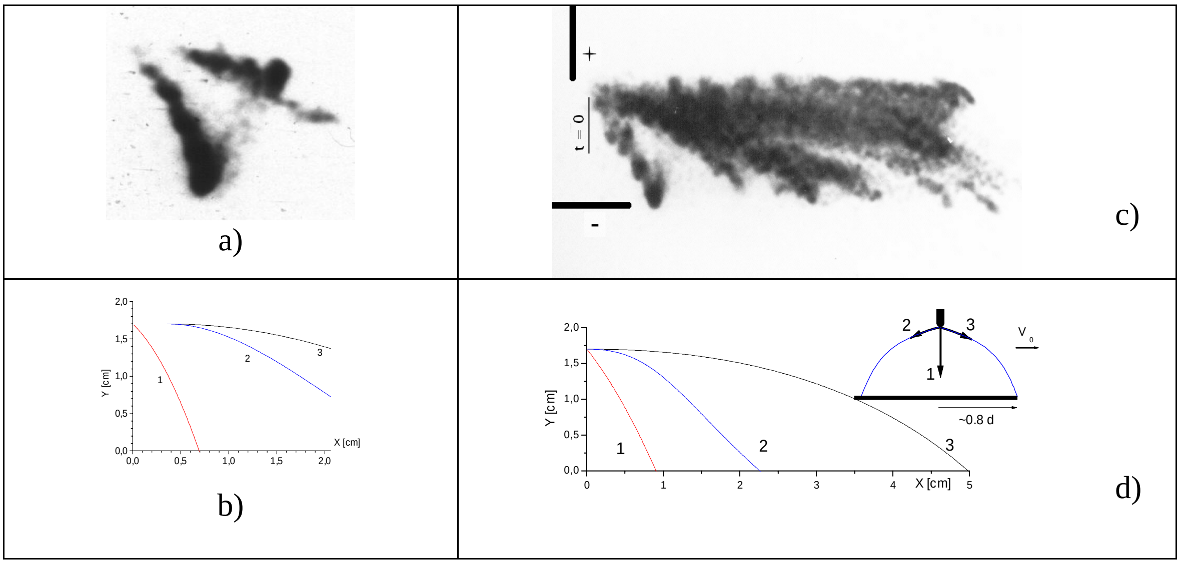



Fig. 7
Experimental streak photos of the induced streamers
and calculated tracks for axial (1) and peripheral streamers (2, 3).
Ambient air, d=17 mm, r=0.5 mm. I = 65 μA, U = 21.2 kV

A proper processing of streak photo allows to determine the velocities of the fast axial (1) and slow peripheral (2, 3) streamers and radius of the streamer bush at the plane. According to explicative sketch inserted in Fig. 7d), the x,y-coordinates of appropriate streamer heads can be written in the following form:

1) $X_1=V_0\cdot t$; $Y_1=d-(V_1+\alpha\cdot t)\cdot t$;
2) $X_2=V_0\cdot t-\varepsilon\cdot d\cdot\sin((\omega_0+\beta\cdot(t-\Delta t))\cdot(t-\Delta t))$; $Y_2=d\cdot\cos((\omega_0+\beta\cdot(t-\Delta t))\cdot(t-\Delta t))$;
3) $X_3=V_0\cdot t+\varepsilon\cdot d\cdot\sin((\omega_0+\beta\cdot(t-\Delta t))\cdot(t-\Delta t))$; $Y_3=d\cdot\cos((\omega_0+\beta\cdot(t-\Delta t))\cdot(t-\Delta t))$;

Here $V_0$ is a speed of linear sweep; $V_1$ is a velocity of axial streamer at the start; α is acceleration of axial streamer; $\omega_0$ is angular velocity of peripheral streamers at the start; β is angular acceleration of peripheral streamers; d is length of inter-electrode gap; ε·d is radius of a streamer dome (or streamer bush) at the plane; Δt is time delay in between start of axial streamer and peripheral ones; t is real time.
The fitting parameters used in this calculations are listed in table below.

| | |
|---|---|
| Fig. 7b)<br>$\omega_0$=4·$10^7$ $s^{-1}$;<br>$\beta$=0 $s^{-2}$;<br>$V_0$=8.2·$10^7$ cm/s;<br>$V_1$=1·$10^8$ cm/s;<br>$\alpha$=1.2·$10^{16}$ cm/$s^2$;<br>d=1.7 cm;<br>$\Delta$t=4.4·$10^{-9}$ s;<br>$\varepsilon$=0.4; | Fig. 7d)<br>$\omega_0$=2.5·$10^7$ $s^{-1}$;<br>$\beta$=2.4·$10^{14}$ $s^{-2}$;<br>$V_0$=8.2·$10^7$ cm/s;<br>$V_1$=1.1·$10^8$ cm/s;<br>$\alpha$=4·$10^{15}$ cm/$s^2$;<br>d=1.7 cm;<br>$\Delta$t=0 s;<br>$\varepsilon$=0.8; |

We can state that calculated tracks are quite similar to the experimental ones. Experimental and calculation data show that all streamers move with acceleration towards the cathode plane. The average characteristic velocities of fast axial and slow peripheral streamers are $V_1 \cong 1.5{\cdot}10^8$ and $V_{2,3} \cong 5{\cdot}10^7$ cm/s respectively. More precisely, the streamer velocities decrease gradually in each subsequent generation. In contrast, the radius of streamer bush (or dome) at the cathode plane increases in each succeeding generation from 0.4 d up to 1.0 d (d is gap length).

It is interesting to note the trajectory of left peripheral streamer is pictured in streak photo at the right side with respect to trajectory of fast axial streamer. The reason is that $V_2 < V_0$. This is a typical relation between $V_2$ and $V_0$ in all experiments on the streak photo registration of streamers in air. As the Fig.7a) illustrates, there is likelihood of some delay in between triggering of the first fast streamer and slow peripheral streamers. In this situation the tracks of slow peripheral streamers could be mistaken for so-called secondary streamer.

**Formation of spark.** The frame picture 1 in Fig. 5 shows clearly a formation of pre-spark channel along pin-plane axis in the course of the induced streamer stage. However, the current-decay at the end of this stage results in strong diminishing in length and brightness of pre-spark channel but not in full its disappearance. The small reminder of pre-spark channel located in the vicinity of the pin top continues to be in progress (the frames 2-4 in Fig. 5). The development of this pre-spark embryo manifests itself in elongation of current filament towards the cathode. In contrast to streamer, the current filament emits a bright luminosity along the whole its length. The elongation of filament is supported by corona current approximately of 0.01 A (Fig. 6). This current is almost constant in time and much in excess of the initial background corona current about several tenths of μA.

The duration of the pre-spark stage associated with current filament elongation tends to diminish with the background corona voltage U and ranges over 0.5-100 μs at U = 18.5-22.5 kV. The appropriate results are presented in Figs. 8, 9.

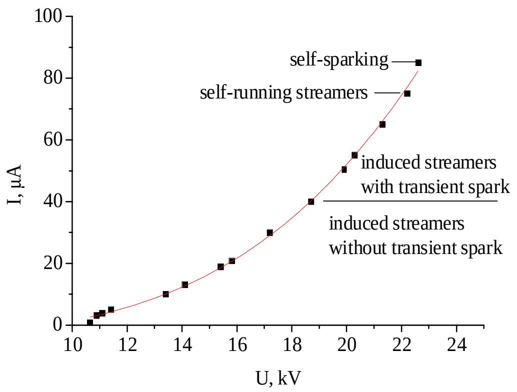



Fig. 8
Volt-ampere characteristic of steady-state positive corona in ambient air. Gap length d = 17 mm, radius of anode pin r = 0.5 mm

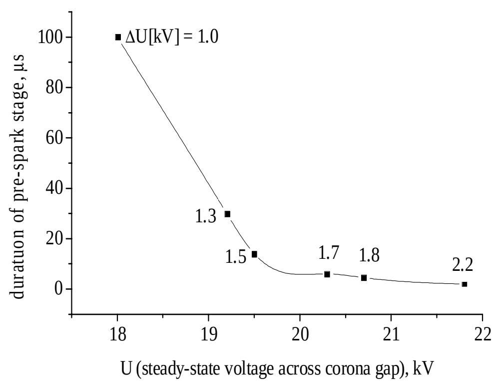



Fig. 9
Duration of pre-spark state vs applied voltage on corona gap. Amplitude of a triggering step ΔU is variable parameter. Ambient air. Gap = 17 mm, radius of anode pin r = 0.5 mm.

These data enable to calculate the average velocity of current filament at the pre-spark stage. It is found out that this velocity is smaller in comparison with the velocity of induced streamer and varies over range $2{\cdot}10^6$ - $2{\cdot}10^4$ cm/s. Under the test conditions our observations show the maximum lifetime of current filament is not in excess nearly of 100 μs. Under low value of applied voltage V < 18.5 kV the average velocity of current filament is too low, and it therefore has no time to arrive at the plane prior to being died. This value of critical time (≈100 μs) correlates with the maximum allowable time interval between two self-running streamers that assures self-sparking of steady-state corona.

It should be noted the pre-spark channel almost does not change its own radius at the propagation stage. The light radius of pre-spark channel determined from frame pictures is equaled to nearly 0.5 mm, which is 1.5 times more than that for the induced streamer. When current filament arrives at the plane and bridges inter-electrodes gap, both the corona current and brightness of current filament increase drastically. It means the spark is formed. The light radius of spark current filament increases in size up to 1.0 mm. The spark current about of 3-5 A in amplitude is determined, like the current of the induced streamers, by the charging of stray capacitance in external circuit. Therefore the induced spark exhibits a transient behavior. This high-current spark regime lasts for nearly of 1.5 μs only.

It was observed that spark current oscillates with high frequency about 10-30 MHz. Besides, our experiments revealed yet another interesting feature of transient spark mode in air. The frame pictures show the spark filament emits luminosity for a long time (nearly 300 μs) upon completion of the spark current.

## 3.3 Experiments on study of the streamer-to-spark transition in nitrogen

Self-sparking of a positive corona in nitrogen occurs at lower current and applied voltage in comparison with corona in air. The induced streamer-to-spark transition in $N_2$ can be realized under lower magnitudes of U and ΔU. Appropriate information illustrated this statement is presented in Figs. 10 and 11. We believe the absence of oxygen molecules in background gas causes the worst stability of corona in pure $N_2$. Indeed, as it well known, the $O_2$ molecules quench effectively metastable states of nitrogen and suppress therefore a development of ionization instability, which results in appearance of high-current density anode spots triggering the streamers.

In general, the waveform of current oscillogram relevant to transient process at spark formation in $N_2$ is identical qualitatively to that for corona in air. However there are essential quantitative distinctions in their pieces. First, the current splash associated with the induced streamer stage is lower in amplitude ($I_1 \approx 0.1$ A) and longer in duration ($T_1 \approx 800$ ns). Its shape is almost smooth and has only one sharp picks correlated with bridging of corona gap by the axial streamer. It means there is only one generation of streamers in $N_2$. A reason of this is associated again with absence of oxygen molecules, which restrict strongly the lifetime of streamer in air because of intensive electron attachment processes. In the case of pure $N_2$, the conductivity in body of streamer is held on high level for a long period exceeding the induced streamer stage. Second, the characteristic amplitudes of current $I_2$ at the pre-spark stage and $I_3$ associated with transient spark in $N_2$ are also lower in comparison with that for corona in air ($I_2 \leq 10$ mA and $I_3 \leq 1$ A). Third, at given U and ΔU the pre-spark stage duration varies essentially from experiment to experiment within range of ± 30 % from average magnitude pointed in Fig.11.

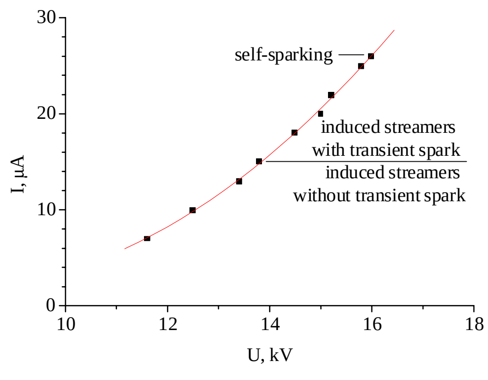



Fig. 10
Volt-ampere characteristic of steady-state positive corona in nitrogen. d = 17 mm, r = 0.5 mm

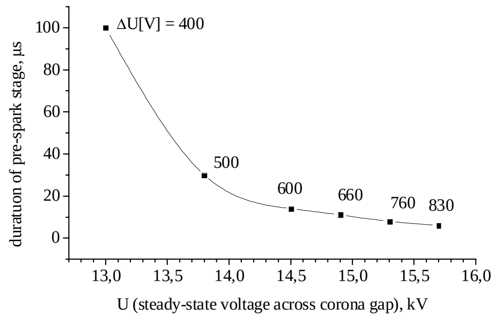
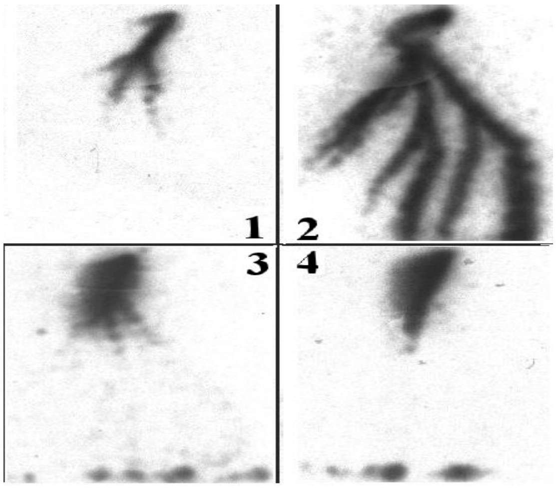
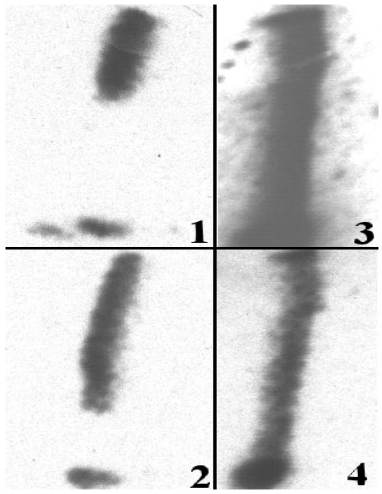



Fig. 11
Duration of pre-spark state vs applied voltage on corona gap. Amplitude of a triggering step ΔU is variable parameter. Nitrogen.
Gap length d = 17 mm, r = 0.5 mm.

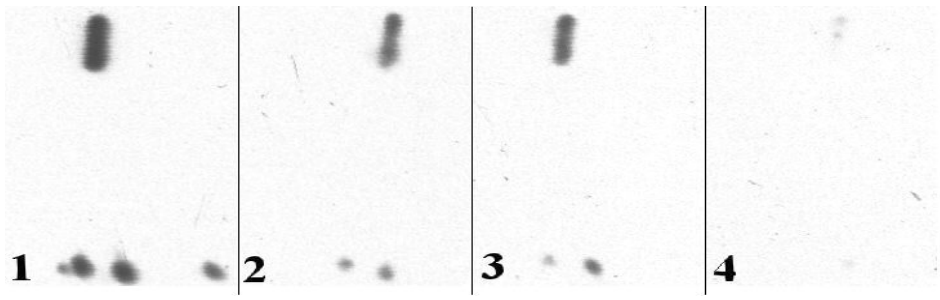
The representative sequence of the frame photos relevant to the induced streamer stage in $N_2$ is shown in Fig.12a). In contrast to corona in air, it is common a single streamer starts from the anode pin. Under most part of the test conditions the branching of this induced streamer occurs once the streamer elongates itself for some millimeters. As it was observed, several induced streamers can start simultaneously from anode pin under high values U and ΔU. The velocities of newly formed streamers after branching of initial streamer are lower in comparison with the last-named. A quantity of the induced streamers in corona gap in $N_2$ is not so high as with corona in air. Besides, the induced streamers in nitrogen look like as narrow sparse bush and travel within dome having a small diameter at the cathode plane in comparison with that for corona in air.




a)




b)




c)

Fig. 12

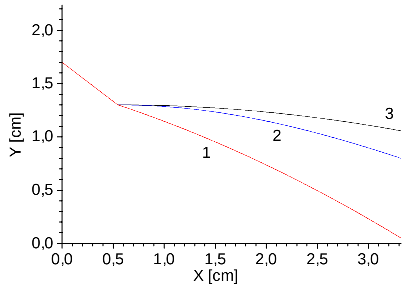
Spatial-temporal behavior of the induced streamers a) and pre-spark channel b)
in a positive steady-state corona in nitrogen. d=17 mm, r=0.5 mm.
The set of photographs c) illustrates a decay of the induced pre-spark channel at low values of U and ΔU.
Time intervals corresponding to shots in Fig. 12 are following (t=0 correlates with the applying of the step):

a) 1 – (0, 30); 2 – (30-80); 3 – (380-430); 4 – (650-700); [t] in ns.
b) 1 – 5.4 μs; 2 – 14 μs; 3 – 17 μs; 4 – 21 μs; exposition is 50 ns
c) 1 – 3 μs; 2 – 6 μs; 3 – 9 μs; 4 – 12 μs; exposition is 1 μs.

After bridging of corona gap with streamers, the image of streamer bush in frame photo disappears. One can see only luminosity emitted from several cathode spots and small piece of current filament originated from anode, which looks like as the rest of initial induced streamer. This piece of current filament serves as an embryo of pre-spark channel, which elongates itself in the course of pre-spark stage and forms spark after its bridging of inter-electrode gap. The dynamics of elongation of pre-spark channel is presented in the set of frame photos in Fig.12b). One can see that light diameters of pre-spark channel and spark channel in $N_2$ are equaled nearly to 1.0 and 1.5 mm, which are larger in comparison with those for corona in air. After bridging the light diameter of spark channel decreases in time (see frame 4 in Fig.12c)). Intensity of its luminosity drops in time also but more slowly in comparison with a speed in current-decay. It was observed luminosity from post-spark channel after 500 μs. It means that energy deposited into spark channel is kept for a long time in the course of post-spark stage. Characteristic velocity of pre-spark channel elongation depends on values of U and ΔU and ranges from $2{\cdot}10^4$ to $2{\cdot}10^6$ m/s.

The characteristic velocities of the initial induced and after-branching streamers were obtained from streak photos with use of the calculation processing mentioned above. Appropriate streak photo of streamers and their calculated tracks are presented in Figs.13a) and 13b) respectively.

a)




b)

Fig.13
Experimental streak photos of the induced streamers
and calculated tracks for axial (1) and peripheral streamers (2, 3) in nitrogen; d=17 mm, r=0.5 mm.

The calculation procedure for nitrogen is identical to that for air.

1) $X_1=V_0\cdot t$; $Y_1=d-(V_1+\alpha\cdot t)\cdot t,\ t < t_1$;
$Y_1=y_1-(V_2+\alpha\cdot t)\cdot(t-t_1),\ t > t_1$;

2) $X_2=V_0\cdot t-\varepsilon\cdot y_1\cdot\sin(\omega_0\cdot(t-t_1))$; $Y_2= y_1\cdot\cos(\omega_0\cdot(t-t_1)),\ t > t_1$;

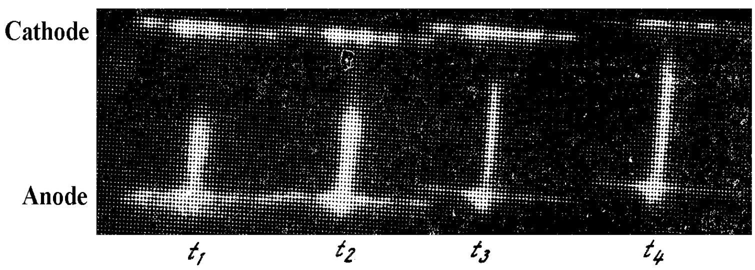
3) $X_3=V_0\cdot t+\varepsilon\cdot y_1\cdot\sin((\omega_0\cdot(t-t_1))$; $Y_3= y_1\cdot\cos(\omega_0\cdot(t-t_1)),\ t > t_1$;

$V_0=4.1\cdot10^7$ cm/s; $V_1=3\cdot10^7$ cm/s; $V_2=1.2\cdot10^7$ cm/s; $\alpha=8\cdot10^{13}$ cm/s$^2$; $\varepsilon=0.6$, $\omega=1.1\cdot10^7$ s$^{-1}$; d=1.7 cm, $y_1$=1.3 cm;
Here, $t_1$ and $y_1$ correspond to the moment and y-coordinate of branching of the initial induced streamer.

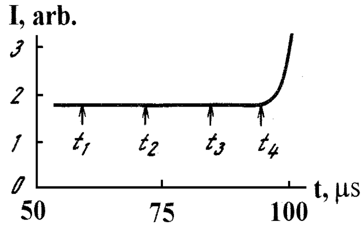
One can see the velocities of the induced streamers in nitrogen are lower in comparison with those for air. We believe this is because the values of the background U and the triggering $\Delta U$ in corona in $N_2$ are lower than those for corona in air. So, we can state, on the obtained results, that streamers can be initiated under low background value of the replenishment criterion M $\cong$ 4-5, and the induced streamers travel with much lower velocities in comparison normal streamers generated at the breakdown of non-ionized gas gap under high over-voltage. It is important to note the propagation of slow cathode-directed streamers under steady-state corona conditions does not require the existence of any photoionization processes in gas gap filled with air or nitrogen.

## 4. Spark formation in corona and constriction of uniform glow discharge

We would like to attract a reader's attention to similarity between formation of spark channel in corona gap and the non-uniform constriction of homogeneous glow discharge at middle pressures. As in the case of corona, high-current density anode spot triggers constriction of initially uniform plasma column. This spot generates locally a small plasma disturbance with high conductivity, which elongates itself in form of current filament towards cathode. Characteristic velocity of filament ranges from $3\cdot10^3$ - $3\cdot10^5$ cm/s. Like pre-spark stage, total discharge current practically does not increase in the course of the filament propagation stage. After bridging of gap with the filament, a transient arc occurs. Appropriate experimental information is presented in Fig.14.




a)



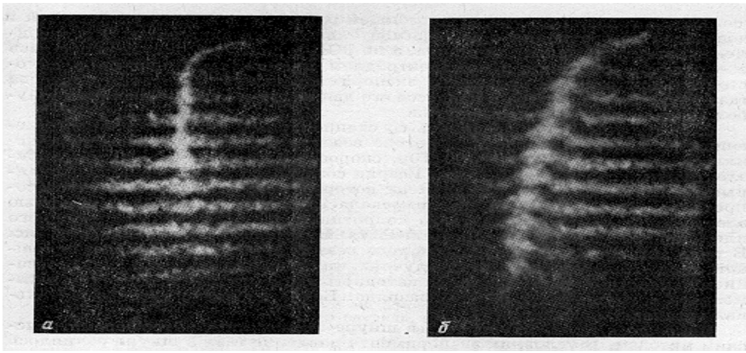

b)

Fig.14

a) Frame-camera shots of a propagating filament (air, p=50 Torr, d= 2,5 cm, j= 40 mA/cm$^2$ (this is current density in the background plasma), exposure time=0.2 μs) (from [3]).
b) Time behaviour of total discharge current during non-uniform constriction (from [3]).

By this is meant that physical processes associated with local increase of ionization in current filament at the pre-spark stage in corona and under non-uniform constriction of middle-pressure glow discharge are closely analogous. Therefore it would be reasonable to use information obtained in experiments on constriction for description of the spark formation. For instance, one of the important questions is a speed of extrusion of neutral gas from a pre-spark channel. We obtained answer on this question from the interferometer measurements of glow discharge under its constriction. These measurements allow to determine a characteristic time for decrease in gas density within lengthening current filament. The experiments were made in nitrogen at pressure of 60 Torr.

It was find out (see Fig. 15), the gas-dynamic extrusion of neutral gas from a current filament was not essential in the course of its propagation. Both the gas heating within lengthening filament and the gas extrusion from its body had too low pace in comparison with a speed of filament propagation across gap. Extrapolation of these data to the pre-spark conditions of a positive pin-plane corona at atmospheric pressure allows the concluding that gas-dynamic extrusion of neutral gas could likely not be important process for propagation of pre-spark channel.



a) b)

Fig.15

Frame-camera shots of filament interferogramms under filament propagation a), and after its bridging the gap b). $N_2$, P=60 Torr, d=2,5 cm, j=30 mA/cm$^2$ (current density in the background plasma), exposure time=0.5 μs.

One can see that gas-dynamic extrusion of neutral gas from current filament occurs after bridging the gap only.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