Influence of the sign and magnitude of a surface charge on the breakdown voltage of a barrier corona discharge in Ar

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Abstract. The topic of this article is related to the breakdown phenomena in the surface dielectric barrier discharge (SDBD). The surface charge, locally deposited on the dielectric barrier, changes markedly the configuration and intensity of the electric field both on the barrier and in the gas gap. In turn, a change in the local electric field affects the rate of ionization multiplication of electrons in this area and, accordingly, influences the breakdown conditions of both volume and surface barrier discharges. In the case of sinusoidal SDBD, the first breakdown in each next half-cycle will be controlled by the charge deposited on the barrier during the previous half-cycle. Contrariwise, if there are several successive breakdowns in the half-cycle, each next breakdown after the first one will be controlled predominantly by the charge and plasma created by the previous breakdown in this half-cycle but not only by the charge deposited in the previous half-cycle. These features of the SDBD breakdown were investigated by the example of the barrier corona in argon at atmospheric pressure in the pin-to-plane configuration. This discharge allows us the controlling of the location of the deposited charge. Surface charge was deposited in advance and by the SDBD itself.

1. Introduction

The monopulse or periodic gas discharges created in electrode systems with one or two electrodes covered with a thin dielectric (for example, corona discharge in the gap between a metallic pin and a flat dielectric barrier or the discharge between two dielectric barriers), are widely used in scientific research and numerous practical applications as well [1-3]. Barrier discharges are the self-extinguished ones. A reason is that the electric current arising after every breakdown of the gap deposits on the barrier(s) the charge(s) creating the additional electric field $E_{\text{opposite}}$ directed against the initial $E$-field in the gap. The $E_{\text{opposite}}$ quickly grows with time and, eventually, reduces the resultant field in the gap down to such low magnitude which is not able further to support the discharge. The new current pulse can arise if the voltage across the gap continues to increase and the resultant electric field between electrodes will increase again to the breakdown magnitude. For this reason, in many cases (especially in gases at atmospheric pressure and with the use of AC voltage of high amplitude) barrier discharges exhibit themselves in the form of irregular current pulses (microdischarges) arising one after another in each half-cycle on a phase of the increasing voltage [4-7].
One of the important questions in physics of the microdischarges formation in the periodical barrier discharge is the question about the influence of the amount and sign of the surface charge deposited in the previous half-cycle on the first breakdown in each subsequent half-cycle of the sinusoidal voltage. At the qualitative level, it is a well-known fact that the surface charge, locally deposited on the dielectric barrier, changes markedly around the configuration and intensity of the electric field both on the barrier and in the gas gap. In turn, a change in the local electric field affects the rate of ionization multiplication of electrons in this area and, accordingly, influences the breakdown conditions of both volume and surface barrier discharges. In the case of sinusoidal DBD, the first breakdown in each next half-cycle will be controlled by the charge deposited on the barrier during the previous half-cycle. However, if there are several successive breakdowns in each half-cycle, all breakdowns being happened in the half-cycle after the first breakdown will be controlled by the charge and plasma that were created by the previous breakdowns just in this half-cycle but not by the charge deposited in the previous half-cycle. These features of the DBD breakdown were investigated experimentally by the example of the barrier corona in argon at atmospheric pressure in the pin-to-plane geometry. This discharge allows us controlling the location of both the microdischarges and charges deposited by them. Besides, the manipulation of the value of the electric charge pre-posedited on the barrier surface was done in the experiments; this charge was formed by an auxiliary discharge.

2. Experimental setup
The pin-to-plane electrode system consists of the following elements. The plane electrode, a copper disc with a diameter of 110 mm, was covered with a thin dielectric film (lavsan, 80 µm thick, $\varepsilon = 3.5$) (Figure 1). High-voltage (HV) electrode (the pin) is the stainless steel wire with a diameter of 1 mm, the end of which was sharpened on a cone with a radius of 0.1 mm. The distance between the wire tip and the film is 1 mm (at smaller distances, there was an electric breakdown of a thin film by a high voltage being applied to the pin electrode). Before applying the sinusoidal voltage powering the barrier corona, an electric charge $Q$ was deposited in advance on the film. It was done by applying a DC high voltage to the pin. This voltage initiates a short-term discharge both in the tip-film gas gap and on the film surface as well. Variation of both the amount and sign of the pre-posedited charge $Q$ was performed by changing the amplitude and polarity of the auxiliary DC voltage. The $Q$ amount was being determined from the measured voltage on the capacitor $C$ connected between the copper disk and the ground (Figure 1). After the charge deposition, the auxiliary DC voltage was disconnected, and the sinusoidal generator was connected to the HV pin.

![Figure 1. The scheme of the experimental setup.](image-url)
the breakdown in the corona gap. Second, the generator sharply dumped the output voltage after each corona breakdown but after that, the output voltage slowly was increased. On the one hand, the voltage sharp dumping stops quickly the corona current after the breakdown. On the other hand, the subsequent slow increase of the output voltage gives the opportunity for the next breakdown to happen.

The voltage applied to the HV electrode was measured by a high voltage probe (1:2000). The voltage and current of the barrier corona were recorded with an oscilloscope (C8-17). The breakdown moments were identified by the appearance of the sharp pulses on the voltage and current waveforms. The images of the barrier corona during its breakdown development are taken by a fast multi-frame intensified camera (LV-03). The images were synchronized with the voltage and current waveforms. Before each deposition of a pre-charge Q, the surface of the dielectric barrier was being "cleaned" from the residual charges of the previous experiment. The charge erasing was done with the use of the grounded soft brush made of many thin copper wires. All experiments were conducted in the gas discharge chamber under argon pressure slightly exceeding the ambient atmospheric one and with weak pumping of gas.

Close examination of the parameters characterizing the first and subsequent breakdowns in each half-cycle allowed us to reveal the role of the surface charge and plasma covering the charge in the development of primary and all other secondary breakdowns in the barrier corona.

3. Results and discussion

Figure 2 presents the results on the first corona breakdown when the sinusoidal voltage was being switched on starting from zero magnitude. The polarity of the chosen half-cycle (positive or negative) was opposite in sign to the sign of pre-posedit charge (negative or positive). As expected, in such a case the pre-posedit surface charge Q decreases the breakdown voltage $U_b$. One may see in Figure 2, this effect exhibits itself the stronger, the greater the charge Q irregardless of its sign. But the strong dependence of this effect on the frequency of the sinusoidal voltage (the higher frequency, the stronger effect) was really unexpected. One of the possible reasons for this effect can be attributed to the formation of corona around the HV pin at the pre-breakdown stage. The current of this pre-breakdown corona can deposit the charge of opposite sign than that of the pre-posedit charge. The discharging the pre-posedit charge will increase with duration of the pre-breakdown corona (i.e. with diminishing the frequency of the applied voltage) that leads to an increase in the breakdown voltage.

![Figure 2](image_url)

**Figure 2.** The relation between the voltage amplitude $U_b$ of the first breakdown in sinusoidal barrier corona and the magnitude of the pre-deposited charge $+Q$ or $-Q$ for two different frequencies of sinusoidal voltage. Ar, $P=770$ Torr. 1) 3 kHz, $-Q$, $+U_b$; 2) 3 kHz, $+Q$, $-U_b$; 3) 400 Hz, $-Q$, $+U_b$.

At the beginning, we present in Figure 3 the results on the barrier corona breakdown in absence of the pre-posedit charge $Q$. The experiment has revealed the following feature of such breakdown: under
sinusoidal voltage with the same amplitude, the first breakdown can occur in any half-cycle and not always immediately after switching on the sinusoidal voltage. As a rule, the breakdown occurs after several half-cycles of the sinusoidal voltage. Besides, in absence of the pre-posited charge $Q$, the first breakdown always occurs near the maximum of the sinusoidal voltage, therefore the current pulse and the transversal size of the plasma sheet on the barrier exceed those formed during the breakdown with the presence of pre-posited charge $Q$ (see the proper images in Figures 3 and 4).

![Figure 3](image1.png)

**Figure 3.** The voltage waveforms for the sinusoidal barrier corona breakdown at $f=3$ kHz with no pre-posited charge: a) the breakdown happened in the first negative half-cycle; b) the breakdown happened in the second positive half-cycle; c) the image of the plasma sheet formed on the barrier by breakdown current pulse; this photo corresponds to the waveform presented in Figure 4a. Exposure time is 5 μs. The HV electrode is shown with a dashed line. The above-given scale is equal to 60 mm.

Before the examination of data presented in Figure 4 note the following. The executed by us comparison of the images of plasma sheets $S1$ and $S2$ formed respectively by the auxiliar discharge providing the pre-posited charge and by the first breakdown current pulse revealed that the visual diameter of $S1$ is always less than that of $S2$. It means the pre-posited charge $Q$ can be fully or partially eliminated by a current pulse of the first breakdown which deposits the opposite sign’s own charge on the barrier. In other words, the pre-posited charge $Q$ influences mainly the first breakdown but all breakdowns happening after the first one are being influenced also by the charge and plasma created by a current pulse of the previous breakdown.

One may see in Figures 3 and 4 that the typical visual diameter of the plasma sheet on the barrier ranges within 20-70 mm that is much larger compared to the interelectrode gas gap of 1 mm. It means the corona breakdown is being determined predominantly by the processes controlling the surface breakdown rather than processes controlling the volume breakdown in the short pin-to-plane gap. The difference between these breakdowns is that the volume breakdown is accompanied by the formation of plasma in the pin-to-plane gap but the surface breakdown includes the deposition of the electric charge on the barrier and formation of plasma covering the surface charge. The plasma propagation along the barrier and the surface charge deposition interplay with each other and form in total the self-consistent breakdown process.

The results presented in Figure 4 show that both the maximum current pulse (correlated with the maximum sharp diminishing the applied voltage) and the maximum transversal size of the plasma sheet on the barrier happen at the first breakdown in each half-cycle. Figure 4 shows also the increase in the value of the pre-posited charge $Q$ leads to an increase in the number of repeated breakdowns in the half-cycle. Besides, both the breakdown voltage $U_b$ and the transversal size of the plasma sheet formed by every secondary breakdown are smaller than those corresponding to the first breakdown.

Note the plasma sheet formed in half-cycle by the first breakdown is always located symmetrically around the axis of pin-to-plane barrier corona, while the plasma sheets formed by secondary breakdowns are not axisymmetrical. One may see in Figure 4 that every secondary plasma sheet is being formed only within a certain sector around the axis. As a rule, every subsequent plasma sheet is not being overlapped appreciably with the plasma sheet formed by the previous breakdown.
The shaded vertical strips on all waveforms indicate the moments where the images were taken. The numerals above the strips correspond to those pointed beneath the discharge images shown in the right. The dashed line in each figure shows the sinusoidal voltage formed by the generator in the absence of the barrier corona.

**Figure 4.** To the left – the set of the voltage waveforms of the sinusoidal barrier corona in Ar with multiple breakdowns during the half-cycle at frequency $f=3$ kHz happening under different magnitudes and sign of the pre-posed charges: $Q= -2.4 \cdot 10^{-8}$ C (a); $Q= -1.4 \cdot 10^{-7}$C (b); $Q= +6 \cdot 10^{-8}$ C (c).

To the right – the set of the plasma sheet images formed on the barrier due to the barrier corona breakdown (shots are taken at angle of $45^\circ$ to the barrier surface). These images are synchronized with the marked moments on the proper voltage waveforms: the numerals at the photo correspond to the numerals on the waveform. The scale line is given at the top of each picture and equal to 60 mm. Exposure time is 5 µs. The HV pin electrode is shown with a dashed line.

Close examination of the results presented in Figure 4 has revealed the following features in the sinusoidal barrier corona breakdown. With a positive pre-posed charge $Q$, the first breakdown occurs in the first negative half-cycle without delay after switching on the sinusoidal voltage; in the
case of negative $Q$, the first breakdown happens in the first positive half-cycle after switching on the sinusoidal voltage.

4. Conclusion

The breakdown formation of the sinusoidal barrier discharge in every half-cycle is accompanied by the formation of microdischarges developing in the gap and on the surface of a barrier. This process leads to the deposition of the electric charge on the dielectric. It is clear the surface charge deposited in the previous half-cycle influences the first breakdown in each subsequent half-cycle of the sinusoidal voltage. The situation is more complicated when many breakdowns happen one after another during alone half-cycle. This issue is one of the important questions in physics of the microdischarges and was investigated in this work experimentally by the example of a barrier corona in pin-to-plane configuration. In order to clarify the surface charge influence in more detail, the experiments with the pre-posed charge on the barrier were performed.

It was found out the area on the dielectric barrier occupied by a pre-posed charge was always smaller than the area of the plasma sheet formed by the first breakdown in a half-cycle. It means that the first breakdown covers the whole area occupied by a pre-posed charge and deposits the own charge of the opposite sign. In other words, the first breakdown can diminish the resultant pre-posed charge (or completely neutralize it and even change the sign of the resultant surface charge). In any case, the experiment showed that the resultant charge does not eliminate (or impede) the occurrence of the next repeated breakdowns, which still occur even at a lower magnitude of the applied voltage compared to the first breakdown. We associate the possibility for repeated breakdowns in a half-cycle either with the incomplete neutralization of the pre-posed charge by the first and next breakdowns or (if complete neutralization of pre-posed charge and change the sign of the resultant surface charge is happened) with the plasma sheet formed on the barrier by each previous breakdown. This plasma can survive up to the next breakdown and shield the negative influence of the surface charge and therefore promote the next breakdown.

So, one may conclude that the surface breakdown in SDBD is controlled not only by the surface charge but the plasma sheet formed by the previous breakdown as well.

Acknowledgement

The work is supported by the RFBR (grant No 19-52-53003-a).

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