Development Process of Impulse Surface Flashover on Alumina Dielectrics in Vacuum

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ABSTRACT

For higher electrical insulation performance of vacuum circuit breakers (VCB), the surface insulation characteristics in vacuum should be improved. In this paper, we investigated the development mechanism of impulse surface flashover on alumina ceramic insulator in vacuum. We measured the still images and ultra fast framing images of fast developing surface flashover in synchronous with applied impulse voltage and current waveforms. The light emission transition in initiation of surface flashover was also clarified. We found the dark area was formed around the cathode and conducting channel was formed from the anode in developing process of surface flashover in vacuum.

Index Terms — **Vacuum, surface flashover, surface discharge, alumina insulator, secondary electron emission.**

1 INTRODUCTION

FOR environment-friendly performance, vacuum circuit breaker (VCB) and vacuum interrupter (VI) are required to be developed for higher voltage application [1]. In order to enhance the operational voltage of VCB and VI, it is necessary to improve high voltage electrical insulation performance in vacuum. In particular the surface flashover on solid insulator is one of the fundamental factors for the electrical insulation of VCB/VI.

The secondary electron emission avalanche (SEEA) can trigger the surface flashover [2]. It is influenced by many factors on insulators, such as; the material properties, surface conditions and surface charge distribution [3-9]. We have investigated charging characteristics on alumina surface and influences of surface charging on flashover characteristics [10,11]. The fundamental properties of surface flashover initiation have been clarified. However, the fundamental mechanism of the developing process of surface flashover in vacuum itself has not yet been clarified in detail.

In this paper, we measured the still image and ultra fast-framing image of impulse surface flashover on alumina dielectrics in synchronous with the applied impulse voltage and current waveforms. We investigated the surface discharge development mechanism of impulse surface flashover focusing on the current and light emission in flashover process.

2 EXPERIMENT

2.1 EXPERIMENTAL SETUP

Figure 1 shows the experimental setup with measurement systems. The vacuum pressure in the chamber is set at 10^{-5} Pa order. The impulse generator generates a negative impulse voltage (–1.2/50 μs). We measure a voltage waveform by universal voltage divider and a discharge current waveform by high frequency current transformer. Ultra fast-framing image of discharge is measured using a digital camera with image intensifier (I.I.) to amplify the light emission, whose exposure time is controlled in nanoseconds using gate signal by pulse generator. We can take two images successively per voltage application with two separate camera systems.

Figure 2 shows the electrode configuration. Alumina dielectrics (HA-92) size is 150 mm × 150 mm × 5 mm^t and average surface roughness (Ra) is submicron order. The diameter of high voltage electrode is 2 mm. The opposite grounded electrode is 20 mm in diameter. These electrodes are

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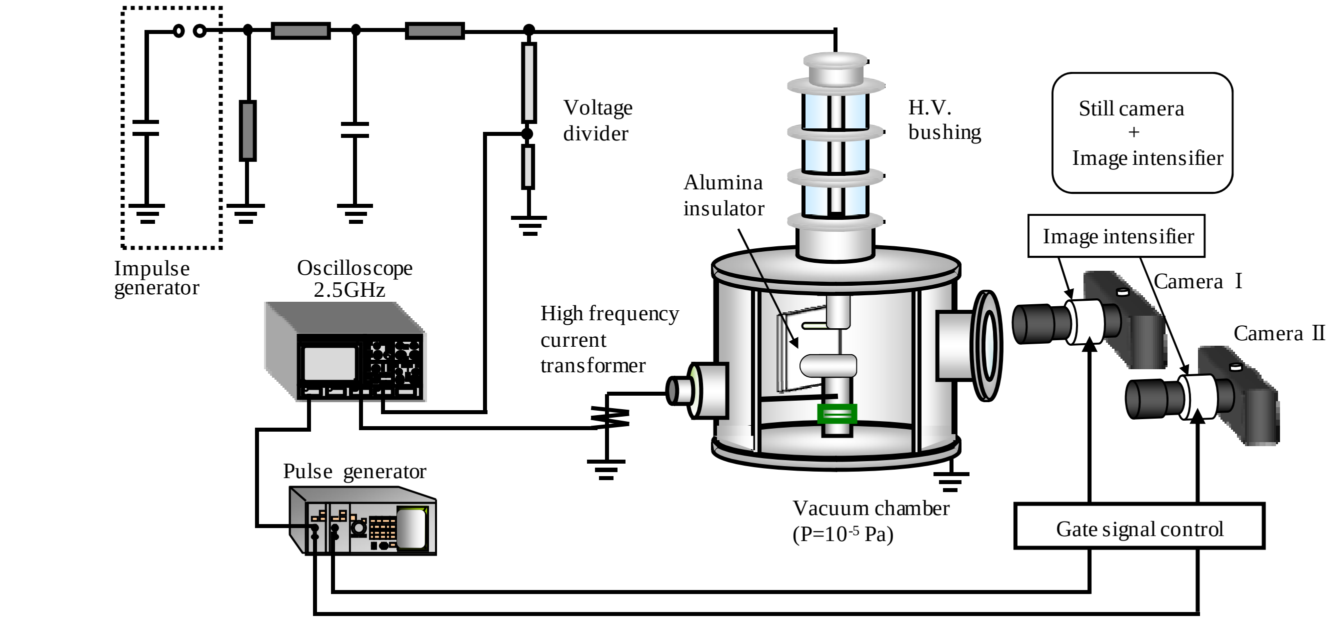
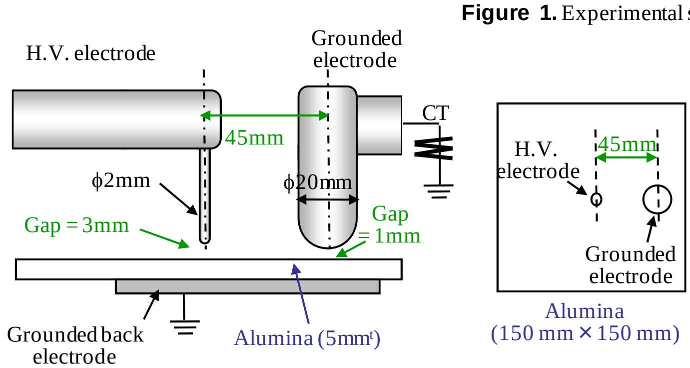


Figure 1. Experimental setup and measuring systems.



(a) Side view (b) Top view

Figure 2. Electrode configuration.

made from SUS304 stainless steel. A discharge current is measured at the opposite grounded electrode.

Figure 3 shows the equi-potential distribution in this electrode system. The lines of electric force have almost perpendicular incident angles to the alumina surface.

We applied a negative impulse voltage to the high voltage electrode and generated surface flashover. We measured the voltage and current waveforms of surface flashover and ultra fast two light emission images at each voltage application.

2.2 EXPERIMENTAL RESULT

Figure 4 shows a still image of surface flashover without image intensifier under –28 kV impulse application. There are a surface flashover path between the high voltage electrode and opposite grounded electrode and intense light emission around the electrodes.

Figure 5 shows an example of the voltage and current waveforms in surface flashover under impulse voltage application. The current is raised up in the vicinity of the

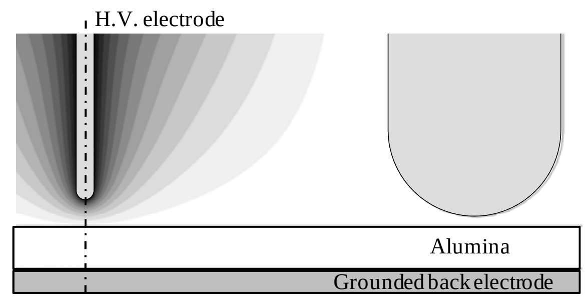


Figure 3. Equi-potential distribution.

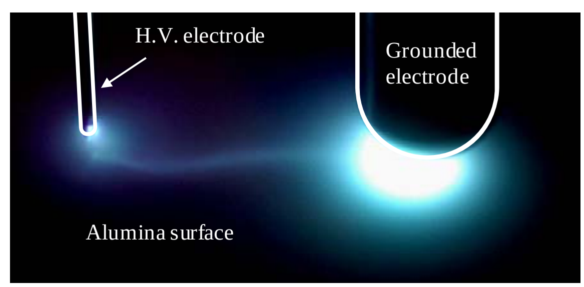


Figure 4. Still image of surface flashover. (-28 kV impulse)

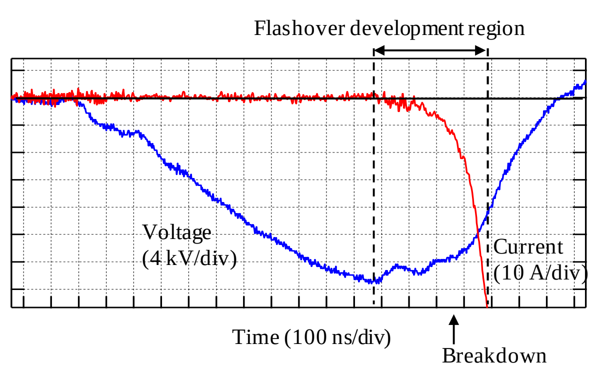


Figure 5. Surface flashover waveforms.

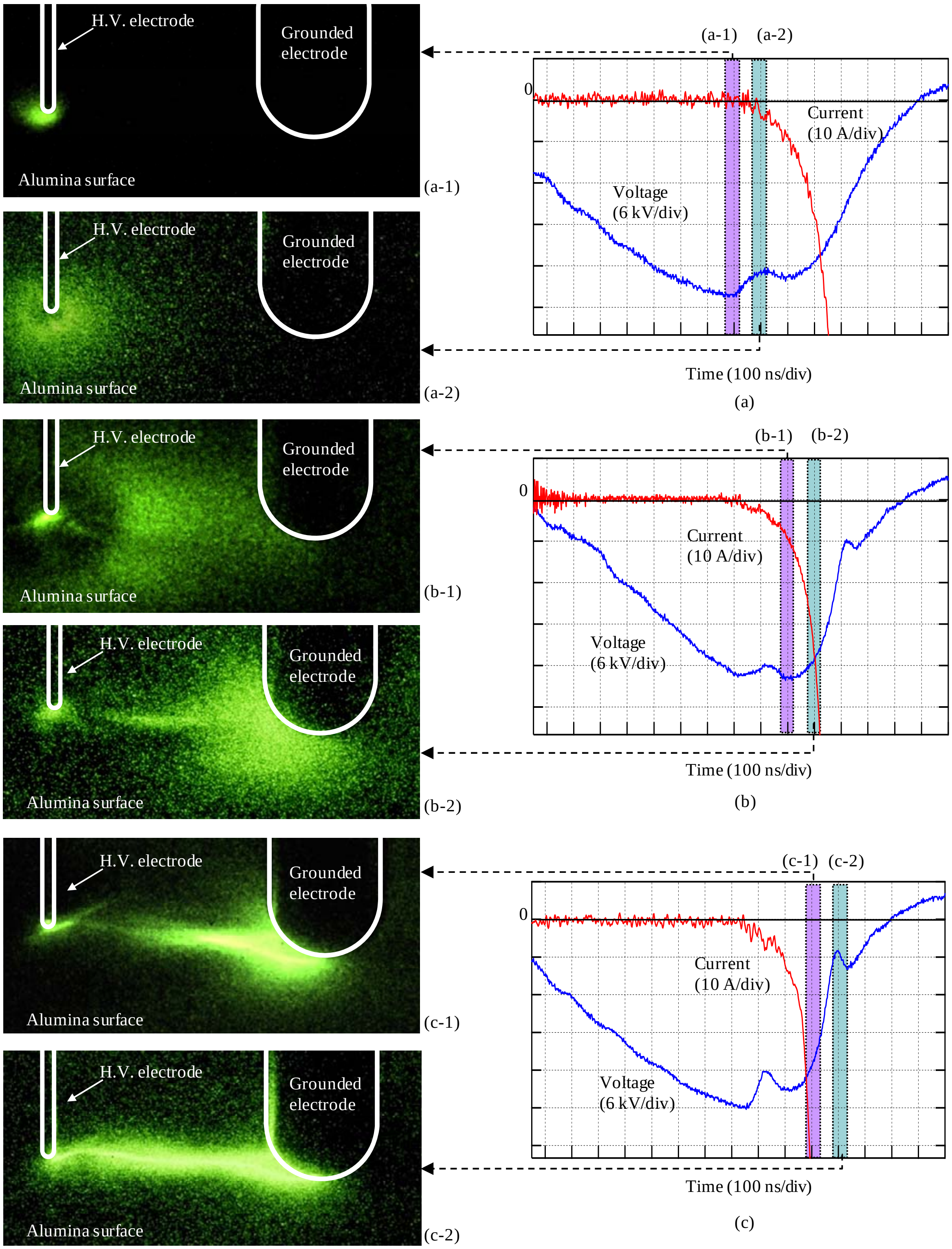


Figure 6. Fast-framing image and surface flashover waveforms

voltage peak. Note that the flashover development process exists for 200-400 ns before breakdown, where the current and light intensity increase with voltage decrease.

Figure 6 shows the ultra fast-framing images of surface flashover and applied voltage and discharge current, that corresponding to each two images; i.e. Figure 6a corresponds to Figures 6a-1 and 6a-2, Figure 6b to Figures 6b-1 and 6b-2, Figure 6c to Figures 6c-1 and 6c-2 respectively.

Exposure time of framing images was 50 ns. In Figure 6, the period (a-1) is the moment when the current starts and the period (a-2) is the point just after the current starts. The period (b-1) is during flashover development. The period (b-2), (c-1) and (c-2) are just before the breakdown, the moment of breakdown and just after the breakdown respectively. Figures 6a-1 and 6a-2 indicate that light emission extends from high voltage electrode on alumina surface at early stage of flashover development process. Figures 6b-1 and 6b-2 indicate that dark area is formed around the high voltage electrode and the light emission around the opposite grounded electrode becomes brighter. In Figures 6a-2 to 6b-2, the dark area extends on alumina surface progressively. Figures 6c-1 and 6c-2 indicate that intense light emission extends from opposite grounded electrode and leads to the high voltage electrode at breakdown. Figure 6b-2 indicates that light emission shown in Figure 6c-1 is beginning to be formed. Transition of these light emissions in flashover developing process requires several tens nanoseconds and a generation of surface flashover requires several hundred nanoseconds.

3 DISCUSSIONS

3.1 DEVELOPMENT MECHANISM OF SURFACE FLASHOVER

From Figure 6, there are three steps of surface flashover development process. At first, the electron emitted from the cathode and SEEA extends on alumina surface and reaches the anode, this duration corresponds to Figures 6a-1 to 6b-2. Next, the conducting channel is formed around anode on alumina surface as shown in Figures 6b-2 to 6c-1. Finally, the conducting channel induces the breakdown at Figures 6c-1 to 6c-2. Some of anode interaction may cause gas desorption and form conducting channel.

The dark area was found transiently in surface flashover developing process. The prospective model of initiation of surface flashover and forming dark area based on measurement results can be shown in Figure 7. In Figure 7, these mechanisms are as follows:

(a) Field emission electrons from the cathode impact on the alumina surface under the cathode. Secondary electrons hardly fly due to the fact that lines of electric force have perpendicular incident angles to the alumina.

(b) The electric field distribution in the vicinity of the cathode is relaxed and distorted due to the transiently-formed negative charging below the cathode. The field emission electrons and SEEA extends on alumina surface and the electron impact on alumina around cathode decreases due to the electric field distribution.

(c) The cathode luminescence of alumina disappears and the dark space is found. The electron multiplication is caused due to some of anode interaction and development of SEEA and the conducting channel starts to be formed from the anode.

3.2 INFLUENCE OF TRANSIENTLY FORMED NEGATIVE CHARGING

In Figure 6a and Figure 6a-1, electron impact concentrated on alumina surface under high voltage electrode and negative charging was transiently formed at the period (a-1). We

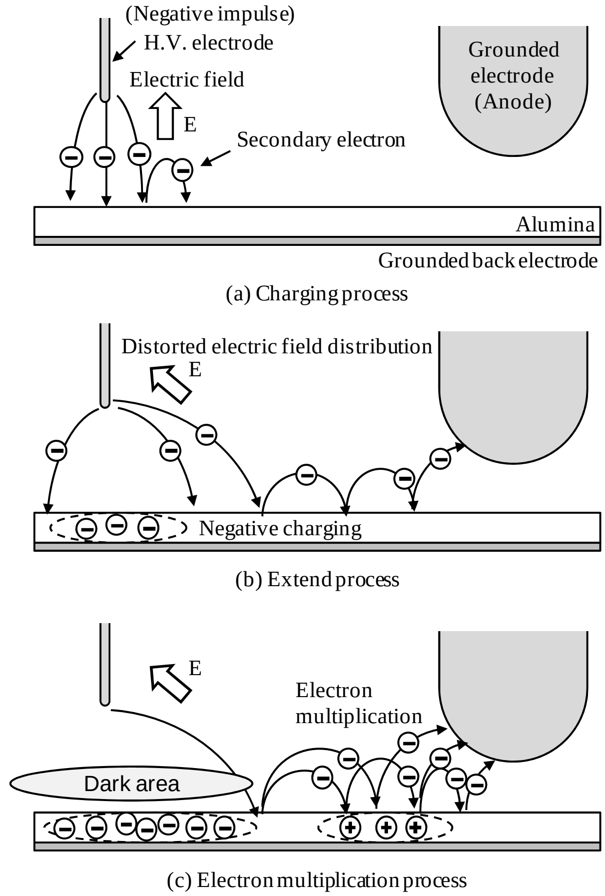
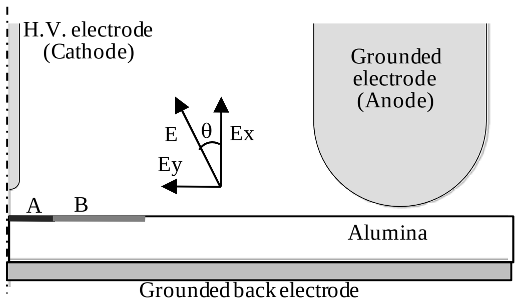


Figure 7. Estimation of surface flashover initiation and forming dark area mechanism.

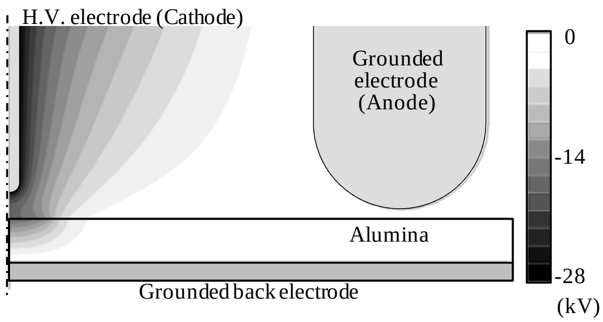
estimated that the amount of transiently-formed charging was -10^{-8} C order by integrating the current waveform. In order to discuss the influence of transiently-formed negative charging, we calculated electric field distribution assuming negative charging around high voltage electrode.

Figure 8 shows the calculation result of equi-potential distribution assuming negative charging on alumina surface. Applied voltage is –28 kV as surface flashover voltage. Figure 8a shows the calculation model. Area A and B are the range from 0 mm to 5 mm and from 5 mm to 15 mm, respectively, on alumina surface under the high voltage electrode. We assumed that the negative charge existed on area A or both areas A and B. We calculated equi-potential distribution and angle θ of incident lines of electric force to alumina surface.

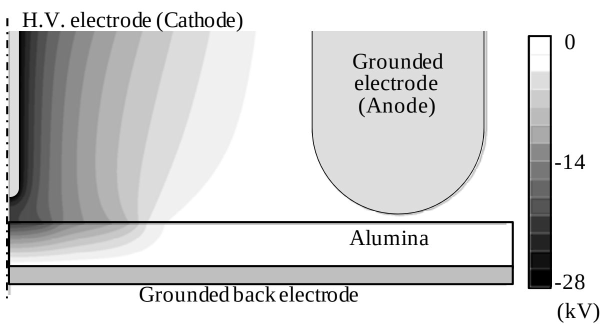
Figure 8b shows equi-potential distribution when area A is -2×10^{-4} C/m^2 and area B is 0 C/m^2. Electric field distribution is distorted by negative charge at area A and incident angle of lines of electric force changes from perpendicular to parallel. Figure 8c shows equi-potential distribution when area A is -2×10^{-4} C/m^2 and area B is -1×10^{-4} C/m^2, which represents the extension of negative charging area. In Figure 8c, the area where incident angle of lines of electric force approaches parallel extends due to extension of negative charging.



(a)Calculation model



(b) Area A: -2 × 10^{-4} C/m^2, area B: 0 C/m^2



(c) Area A: -2 × 10^{-4} C/m^2, area B: -1 × 10^{-4} C/m^2

Figure 8. Calculation result of equi-potential distribution when negative charging exists (applied voltage: -28kV).

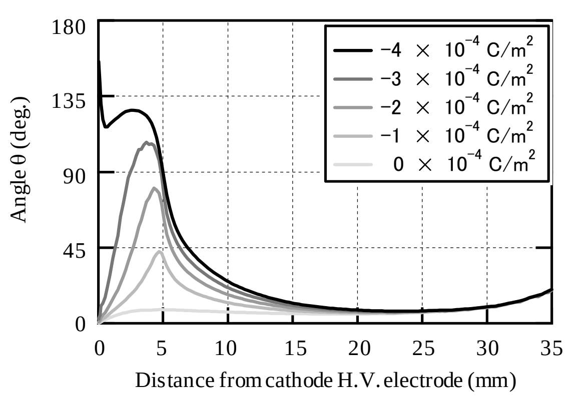


Figure 9. Incident angle of lines of electric force to alumina surface (applied voltage: -28 kV, area A: 0 C/m^2 to -4 × 10^{-4} C/m^2).

Figure 9 shows the angle θ of incident lines of electric force to alumina surface when the charge of area A changes from 0 to -4×10^{-4} C/m^2. The angle θ approaches parallel as the amount of negative charge increases.

-10^{-4} C/m^2 order charge, which corresponds to -10^{-8} C order charge at the area (10 mm × 10 mm), changes the incident angle of lines of electric force to parallel. It is possible enough that -10^{-8} C exists around the high voltage electrode due to observed current. Therefore transiently-formed negative charging can distort electric field distribution and stimulate surface flashover development at early stage of surface flashover developing process.

4 CONCLUSION

We measured surface flashover waveforms and very fast-framing images and investigated developing process of negative impulse surface flashover on alumina. The experimental results indicated that there were some different processes of propagation in the impulse surface flashover in vacuum. The processes are as follows;

(1) Electron emits from cathode and SEEA extends on alumina surface and reaches the anode.

(2) Conducting channel is formed around anode on alumina surface.

(3) The conducting channel induces the breakdown.

We also found that the dark area is formed around the cathode in developing process of surface flashover. Including the dark area, the developing mechanism of surface flashover could be influenced by transiently-formed charging on alumina. Transiently-formed charge around cathode can change the incident angle of lines of electric force from perpendicular to parallel. The amount of charge for changing the incident angle of lines of electric force agrees well with the observed current.

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