Development Mechanism of Impulse Surface Flashover on Alumina Dielectrics in Vacuum

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***Abstract*- We investigated the development mechanism of impulse surface flashover on alumina ceramic insulator in vacuum. We measured the still image and framing image of fast developing surface flashover in synchronous with applied impulse voltage and current waveforms. The light emission transition in initiation of surface flashover was clarified. We found the dark area is formed around the cathode and conducting channel is formed from the anode in developing process of surface flashover in vacuum.**

I. INTRODUCTION

From the view points of environment-friendly characteristics, higher voltage application of vacuum circuit breaker (VCB) and vacuum interrupter (VI) are required to be developed. 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 [1]. It is influenced by many factors on insulators, such as; the material properties, surface conditions and surface charge distribution [2-8]. We have investigated charging characteristics on alumina surface and influences of surface charging on flashover characteristics [9,10]. The fundamental properties of surface flashover initiation have been clarified. However, the fundamental mechanism of the developing process of surface flashover itself has not yet been clarified in detail.

In this paper, we measured the still image and very 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.

II. 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, a discharge current waveform by high frequency current transformer, and light intensity by photo multiplier tube. Very 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 made from SUS304 stainless steel. A discharge current is measured at the opposite grounded electrode.

Figure 3 shows the 2D calculation result of 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 two light emission images at each voltage application.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. *Experimental results*

Figure 4 shows a still image of surface flashover without image intensifier under -28kV 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 voltage peak. Note that the flashover development

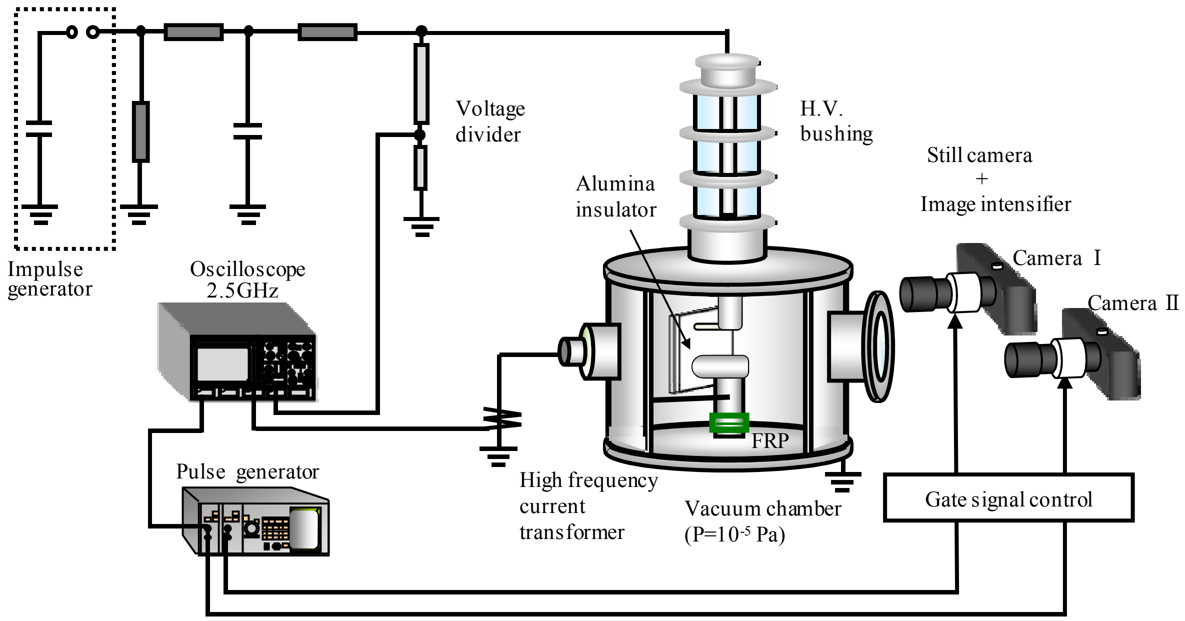

Fig. 1. Experimental setup and measuring systems.

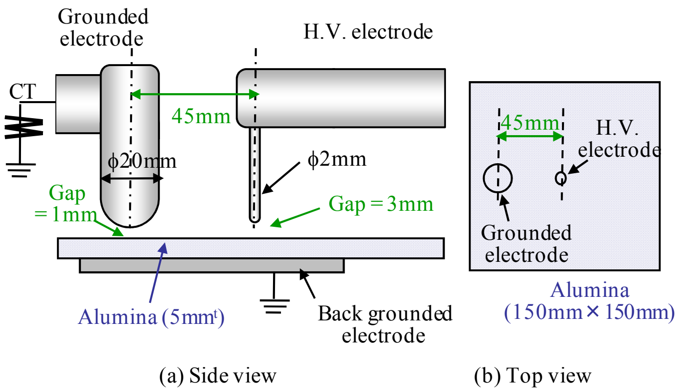

Fig. 2. Electrode configuration.

process exists for about 300 ns before breakdown, where the current and light intensity increase with voltage decrease.

Figure 6 shows the very fast-framing images of surface flashover. Figure 7 shows the applied voltage and discharge current, corresponding to each two images of Figure 6; i.e. Figure 7 (a) corresponds to Figure 6 (a-1) and (a-2), Figure 7 (b) to Figure 6 (b-1) and (b-2), Figure 7 (c) to Figure 6 (c-1) and (c-2) respectively.

Exposure time of framing images was 50ns. In Figure 7, 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 6 (a-1) and 6 (a-2) indicate that light emission extends from high voltage electrode on alumina surface at early stage of flashover development process. Figures 6 (b-1) and 6 (b-2) indicate that dark area is formed around the high voltage

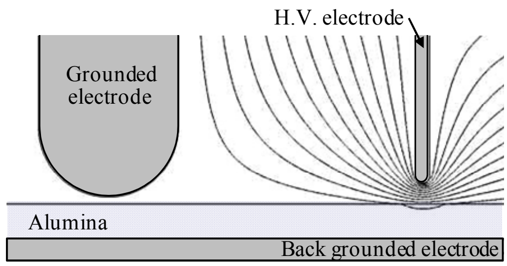

Fig. 3. Equi-potential distribution.

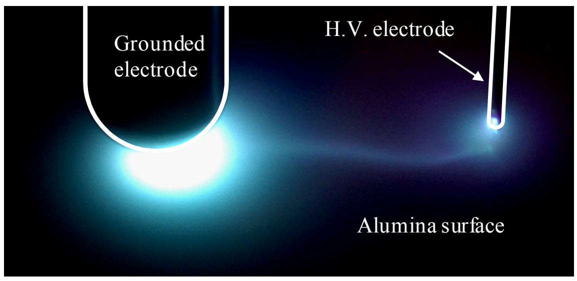

Fig. 4. Still image of surface flashover. (-28kV impulse)

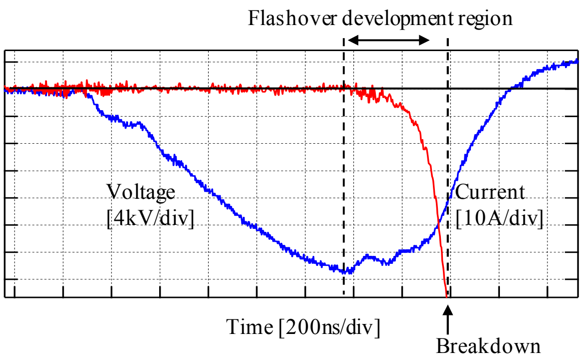

Fig. 5. Surface flashover waveforms.

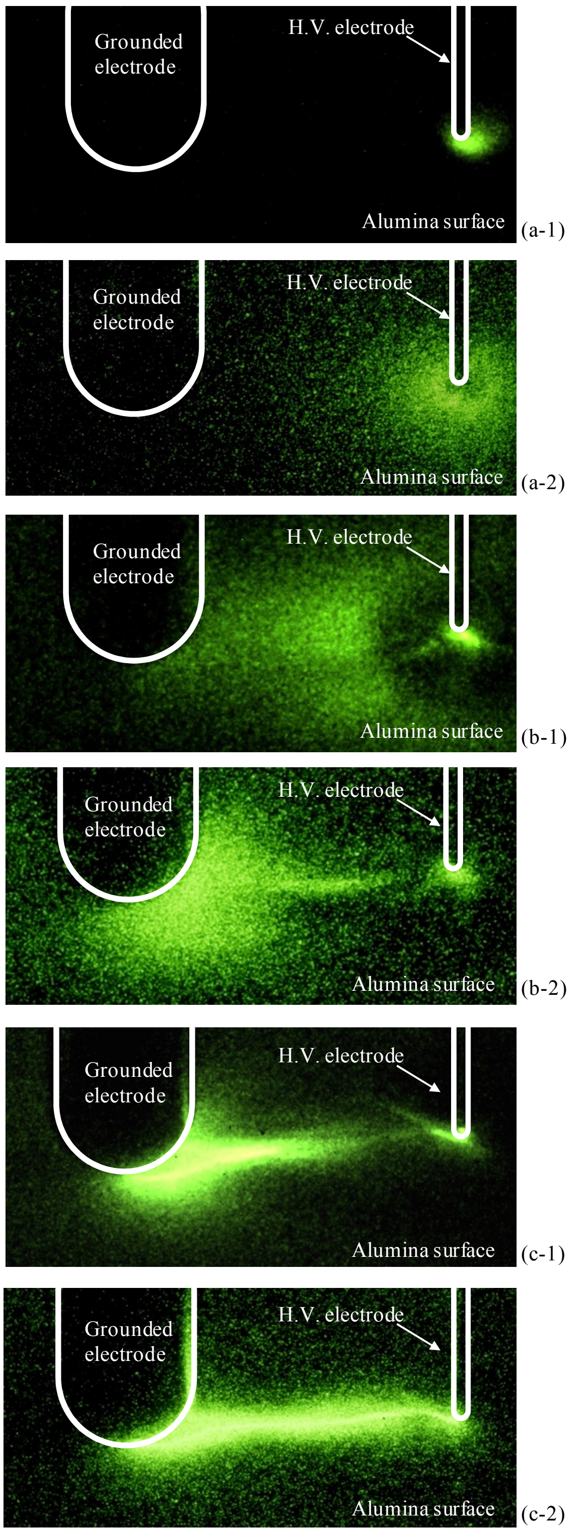

Fig. 6. Fast-framing image of surface flashover.

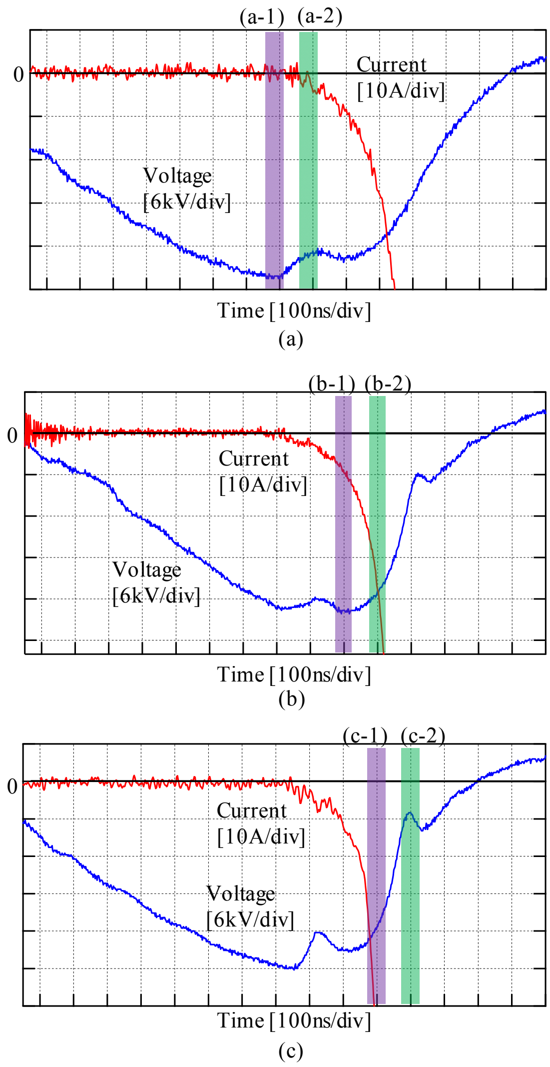

Fig. 7. Surface flashover waveform corresponding to fast-framing image.

electrode and the light emission around the opposite grounded electrode becomes brighter. In Figures 6 (a-2)-(b-2), the dark area extends on alumina surface progressively. Figures 6 (c-1) and 6 (c-2) indicate that intense light emission extends from opposite grounded electrode and leads to the high voltage electrode at breakdown. Figure 6 (b-2) indicates that light emission in Figure 6 (c-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.

B. *Development Mechanism of Surface Flashover*

From Figure 6 and Figure 7, there are three steps of surface flashover development process. At first, the electron emitted from the cathode and SEEA extend on alumina surface and reaches the anode, this duration corresponds to Figures 6 (a-1)-(b-2). Next, the conducting channel is formed around anode on alumina surface as shown in Figures 6 (b-2)-(c-1). Finally, the conducting channel induces the breakdown at Figures 6 (c-1)-(c-2). Some of anode interaction may cause desorption gas 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 8. In Figure 8, these mechanisms are as follows:

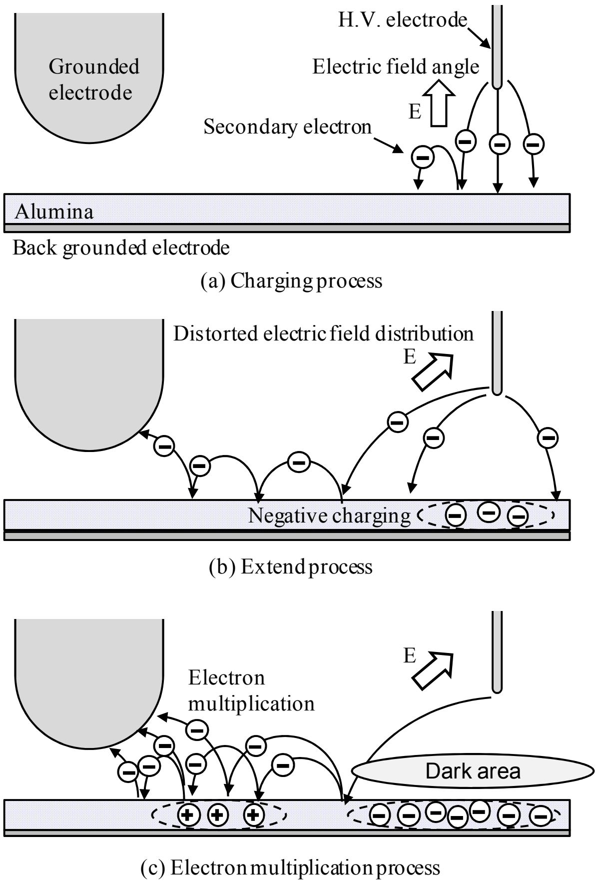

Fig. 8. Estimation of surface flashover initiation and forming dark area mechanism.

(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 extend 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.

IV. 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.

(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.
(4) 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 and some of anode interaction.

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