Influence of Surface Charges on Alumina Dielectrics on Impulse Flashover Characteristics in Vacuum

Hidenori Kato[1], Katsumi Kato[1], Ayumu Morita[2], Hitoshi Okubo[1]
[1] Nagoya University, Nagoya, JAPAN
[2] Hitachi, Ltd., Ibaraki, JAPAN

Abstract- **In this paper, we investigated the surface flashover characteristics under the existence of surface charge on alumina ceramic insulator in vacuum. We investigated the surface flashover voltage with varying the location and magnitude of surface charge. We discussed the surface flashover mechanisms under the existence of the surface charges of alumina dielectrics in vacuum.**

I. INTRODUCTION

For environment-friendly characteristics, vacuum circuit breakers and vacuum interrupters (VCB/VI) are required to be developed for higher voltage application. In order to enhance the operational voltage of VCB/VI, high voltage electrical insulation techniques in vacuum is necessary to be improved. In particular, the surface flashover characteristics on solid insulator could be crucial in relation to the electric field concentration and surface charge [1,2].

It is said that the secondary electron emission avalanche (SEEA) [3] can trigger off the surface flashover. However, the fundamental properties of surface flashover have not been clarified yet because they are influenced by many factors on insulators, such as the material properties, surface conditions, and surface charge distribution [3,4]. Therefore, it is important to clarify how strongly surface charge influences the surface flashover characteristics in vacuum.

We have been investigating the charging characteristics on alumina surface in vacuum [5,6]. The result revealed that surface charge was influenced by surface roughness and electric field distribution.

In this paper, we measured the surface flashover under the existence of surface charge on insulator in vacuum. We investigated the dependence of the location and magnitude of surface charge on surface flashover characteristics. The measurement results were analyzed by the secondary electron emission mechanism.

II. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup. Experiments were carried out at 2.0 x 10^{-4} Pa. There are four motion feed throughs for experiments. In vacuum, we can generate the surface charge on dielectrics and measure 2-dimensional distribution with a surface potential meter.

A. Surface Charge Generation

Figure 2 shows the electrode configuration. We set up the high voltage rod electrode and alumina dielectrics (HA-92). The diameter of rod electrode is 1mm. Alumina dielectrics size is 150mm x 150mm x $5mm^t$ and average surface roughness (Ra) is 0.69μm. We made a vacuum gap 70mm between alumina dielectrics and ground electrode and arranged back ground electrode 10mm in width behind alumina dielectrics.

In order to generate the surface charge on alumina dielectrics, we applied positive or negative dc ramped voltage on the high voltage electrode. After that, alumina dielectrics was placed on the grounded electrode, and we measured 2-dimensional distribution of surface charging potential on alumina dielectrics with a surface potential meter.

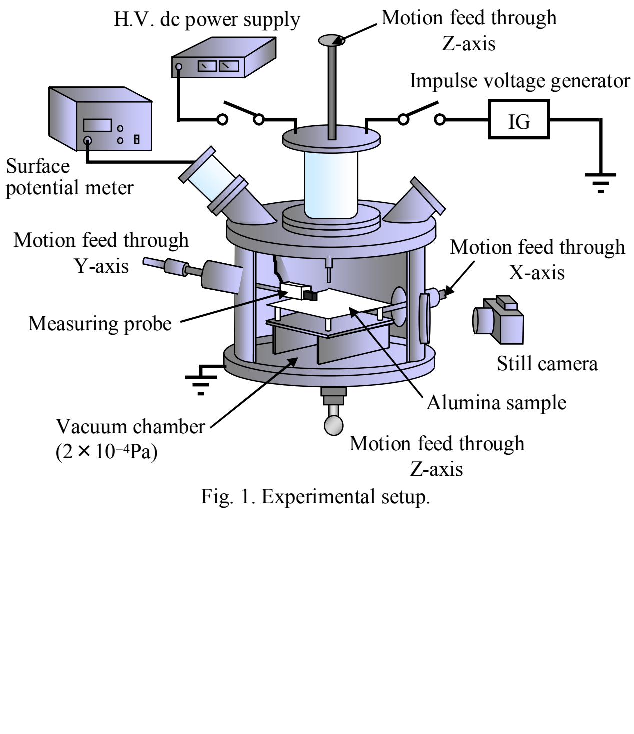

Fig. 1. Experimental setup.

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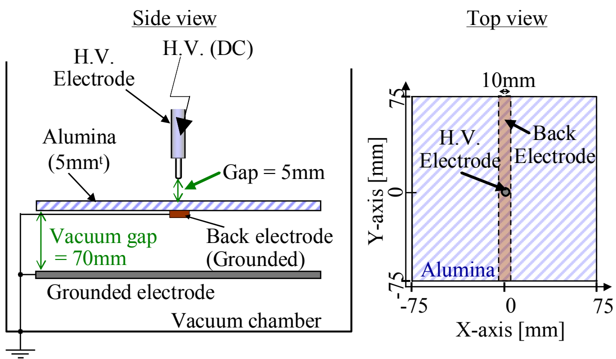


Fig. 2. Electrode configuration (for surface charge generation).

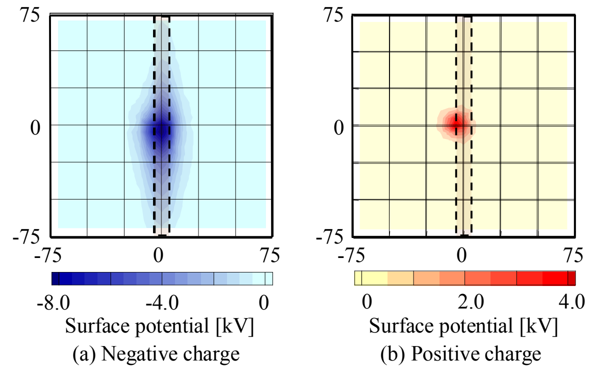


Fig. 3. Positive and negative 2-D surface potential distribution.

The surface potential distribution is shown in Figure 3. Figures 3(a) and (b) show the negative and positive charge distributions, respectively. The areas of surface charge were restricted to the same width as the back electrode.

B. Surface Flashover Generation

Figure 4 shows the electrode configuration for surface flashover generation. We arranged grounded electrode at 50mm far from the high voltage electrode and back electrode under the alumina. In order to generate surface flashover, we applied a negative impulse voltage (1.2/50μs) to the high voltage electrode.

We measured the surface flashover characteristics on alumina dielectrics. We changed charge magnitude and the location on the insulator below the high voltage electrode (Case A) and at the point that was 25mm distance from the high voltage electrode (Case B).

Figure 5 shows calculation results of equi-potential distribution without surface charge. The electric lines of force have perpendicular incident angles to the alumina surface in this electrode configuration.

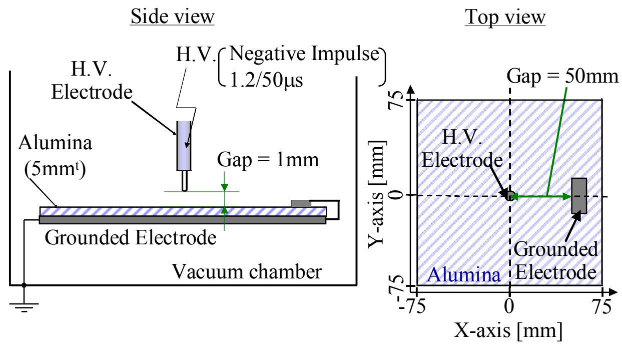


Fig. 4. Electrode configuration (for surface discharge generation).

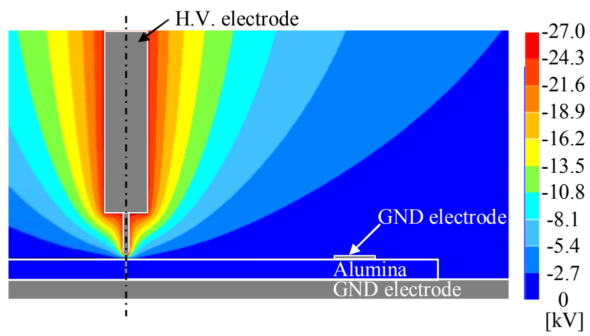


Fig. 5. Equi-potential distribution without surface charge.

III. Experimental Results And Discussions

A. Experimental Results

Figure 6 shows an example of the surface flashover path. Surface flashover started at high voltage electrode and developed toward opposite ground electrode.

Figure 7 shows influence of surface charging potential on surface flashover voltage. When surface charge located at the starting point of surface discharge (Case A), positive charge reduced surface flashover voltage and negative charge raised surface flashover voltage. On the other hand, when surface charge located at the center of between high voltage electrode and grounded electrode (Case B), both positive charge and negative charge reduced surface flashover voltage.

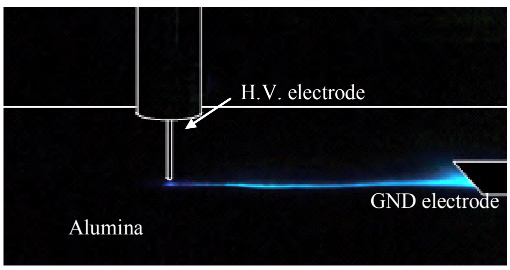


Fig. 6. Surface flashover path.

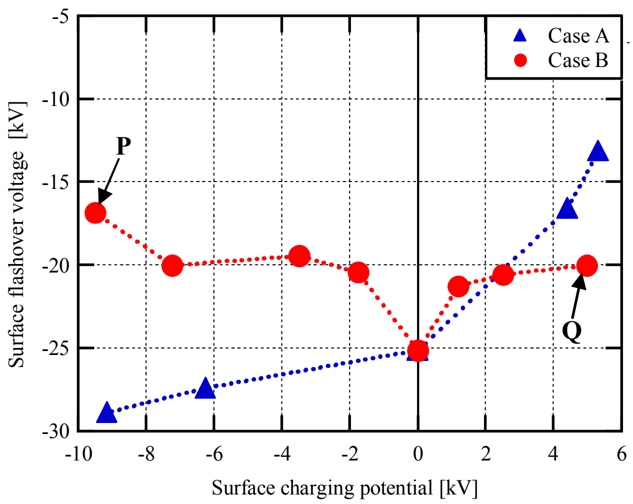


Fig. 7. Influence of surface charging potential on surface flashover voltage.

B. Influence of Charge on Surface Discharge Inception

Surface charge of Case A may influence surface discharge inception. As surface charge located near the cathode electrode, electric field at the electron emission may be relaxed or emphasized by surface charge.

Figure 8 shows relationship between surface charging potential of Case A and flashover electric field strength (Ep). Ep was defined as the electric field strength at 0.15mm distance from the high voltage electrode. From Figure 8, Ep was 20~30[kV/mm], and independent on surface charging potential. As a result, when the surface charge exists only near the cathode electrode, the surface discharge inception voltage is determined by the electric field strength at the point of electron emission.

C. Influence of Charge on Surface Discharge Development

Surface charge of Case B may influence development of surface discharge. As surface charge located on the way of discharge path, the surface charge may influence conductive property of alumina dielectrics, secondary electron emission characteristics, and flight of secondary electron. In order to discuss the influence of surface charge on the flight of secondary electron, we calculated electric field along alumina surface. From the result, we calculated flight distance of a secondary electron and secondary electron energy at the collision against alumina surface.

Figure 9 shows a schematic model of secondary electron orbit. It is supposed that a secondary electron starts at an angle of ϕ, initial energy E_{n0}. The surrounding electric field vector at the start point of electron has the angle θ.

In calculation, we assumed that electric field is constant during the flight of electron. The flight distance of secondary electron S and secondary electron energy E_n at the collision against alumina surface is calculated as

$$S = 2\frac{E_{n0}}{E_z}\sin 2\phi\left(1+\frac{\tan\theta}{\tan\phi}\right) \cdots\cdots\cdots\cdots (3.1)$$

$$E_n = E_{n0}\left(1+4\sin\phi\cos\phi\tan\theta+4\cos^2\phi\tan^2\theta\right) \cdots (3.2)$$

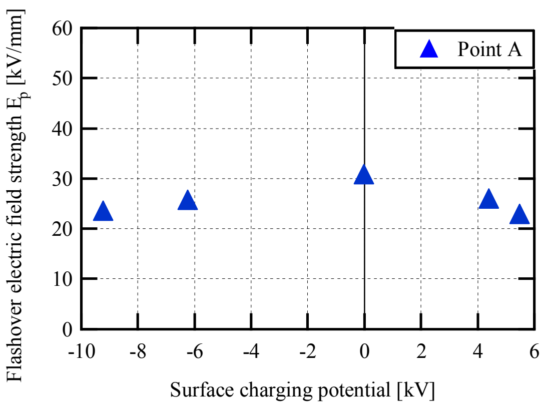


Fig. 8. Relationship between surface charging potential and electric field strength.

Figure 10 shows calculation results of equi-potential distribution when surface charge exists on Case B. Figure 10(a) shows the potential distribution for negative charge (applied voltage Va = −16.9kV, surface potential Vs = −9.5kV which shows the case of point P in Figure 7), and Figure 10(b) shows the potential distribution for positive charge (applied voltage Va = −20.0kV, surface potential Vs = 5.0kV which shows the case of point Q in Figure7). Figure 11 shows the potential distribution around the alumina surface.

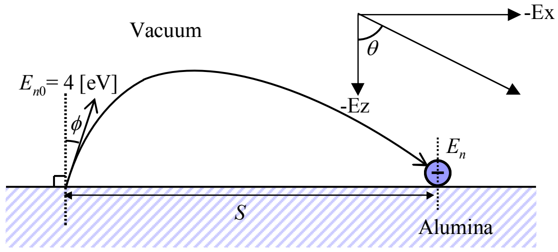


Fig. 9. Schematic model of secondary electron orbit.

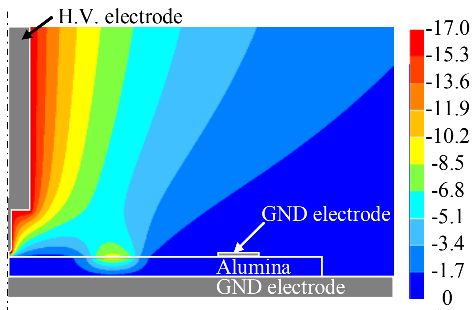


Fig. 10. Equi-potential distribution with surface charge (Case B).

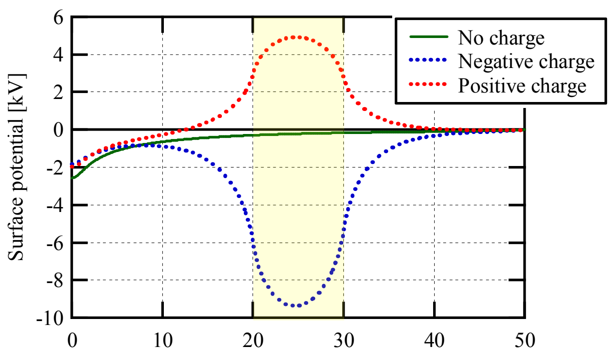
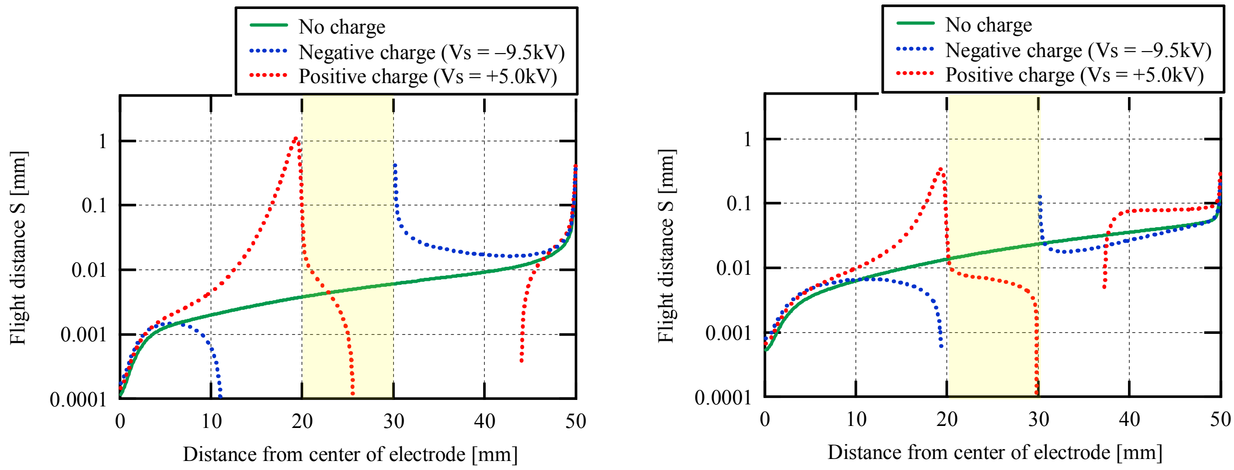


Fig. 11. Surface potential.



(a) $\phi = 5^{\circ}$ (b) $\phi = 80^{\circ}$

Fig. 12. Flight distance of secondary electron.

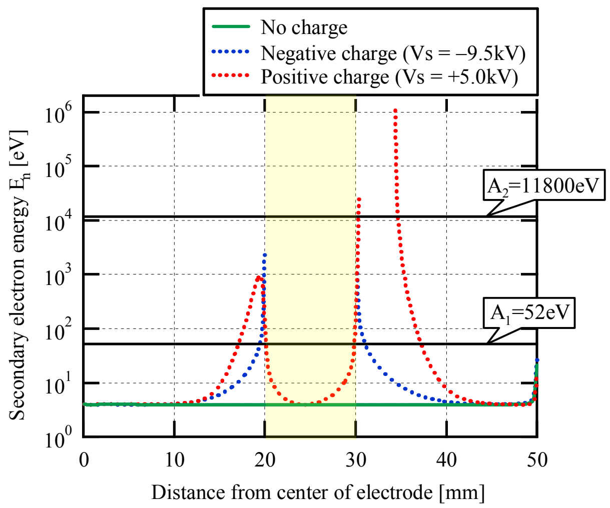


Fig. 13. Secondary electron energy at collision against alumina surface.

Figure 12 shows flight distance of secondary electron calculated by (3.1). When negative charge exists, secondary electron becomes difficult to fly far in front of charge and easy to fly far in back of charge. When positive charge exists, secondary electron becomes easy to fly far in front of charge and difficult to fly far in back of charge. In addition, when secondary electron fly at an angle of $\phi = 5°$ is strongly influenced by surface charge than when a secondary electron flies at an angle of $\phi = 80°$.

Figure 13 shows secondary electron energy at the collision against alumina surface when a secondary electron flies at an angle of $\phi = 5°$. When no surface charge exist, E_n is 4eV. In other words, E_n is the same as initial energy E_{n0}. Secondary electron emission coefficient of alumina is higher than 1 when secondary electron energy is from 52eV to 11800eV [7]. So, no surface charge exist, secondary electron emission avalanche is difficult to occur. On the other hand, when surface charge exists, secondary electron energy is high enough to make secondary electron emission avalanche occur. As a result, the surface charge on the way of discharge path plays a role for making secondary electron energy high enough required for the secondary electron emission avalanche.

IV. Conclusions

We investigated the influence of surface charge on surface flashover characteristics in vacuum. The experimental results revealed the surface charge is critical factors to the surface flashover phenomena. It was also clarified that the surface charge influences on inception and development of surface flashover.

When surface charge located near the cathode electrode, positive charge made surface flashover voltage lower and negative charge made surface flashover voltage higher. We could explain the results by the change of electric field at flashover by surface charge.

When surface charge located at the way of discharge path, either positive or negative charge made surface flashover voltage lower. We could explain the results by the role of surface charge for making the secondary electron energy higher for satisfying the condition of secondary electron emission avalanche.

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E-mail of authors: hidenori@okubo.nuee.nagoya-u.ac.jp