高沿面耐電圧セラミックスの開発研究

RESEARCH AND DEVELOPMENT ON SURFACE FLASHOVER VOLTAGE OF CERAMICS

三原修司[#,A)], 前田岳志 [A)], 吉岡正和 [B)], 松本浩 [B)], 栗原俊一 [B)], 大場俊幸 [C)]
Shuji Mihara [#,A)], Takeshi Maeda[A)] , Masakazu Yoshioka [B)], Hiroshi Matsumoto [B)] , Toshikazu Kurihara [B)] , Toshiyuki Ohba[C)]
[A)] Kyocera Corporation
[B)] KEK, High Energy Accelerator Research Organization
[C)] Nippon Advanced Technology Co, Ltd

Abstract

Alumina ceramics is one of the most important and widely used materials for hermetically sealed high voltage insulators. However, their ability to withstand high voltage is limited by the surface flashover resistance of the ceramic material. Despite extensive research to improve surface flashover voltage in a vacuum, the surface flashover resistance mechanism is not well understood. It is hypothesized that surface flashover depends on the material properties of the ceramics. In this paper, we will report our studies regarding surface flashover of various types of alumina ceramics in which resistivity and secondary electron emission coefficient differs in an ultra-high vacuum atmosphere. We found that it is possible to control surface flashover by lowering resistivity and the secondary electron emission coefficient of the ceramic material.

1. Introduction

Alumina ceramics is widely used for high voltage insulators and RF windows. The insulation capability in a vacuum is limited by the surface flashover of the ceramic. It is believed the characteristics of ceramics are directly related to surface flashover resistance. The mechanism of surface flashover is not well understood, however, there is a theory that when high voltage is applied to the anode and cathode, field emission electrons are emitted from the triple junction thus starting secondary electron multiplication which eventually progresses over the surface of the ceramic. Authors built high voltage gradient equipment to measure field electron emission under ultra-high vacuum. Using this equipment, we have been researching and observing the fundamental mechanism of surface flashover to better understand the physical phenomenon, and study the effect of material properties on surface flashover, thus allowing a method to develop improved materials.

Under this study, focusing on charge up and secondary electron multiplication as cause for surface flashover on the ceramics, listing resistivity and secondary electron emission coefficient as properties that influence on those phenomena, we have developed alumina materials of different properties in these parameters and conduct high voltage gradient tests. As a result, we concluded that material with low resistivity and low secondary electron coefficient can control and possibly eliminate surface flashover. We have developed a new material with improved properties, without the use of surface coatings. With this material, we can manufacture complicated designs with superior reliability.

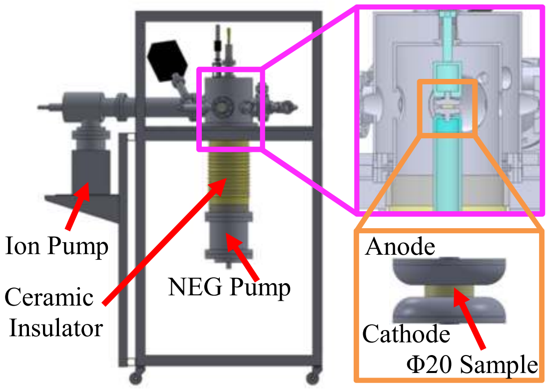

Fig1: Experimental apparatus.

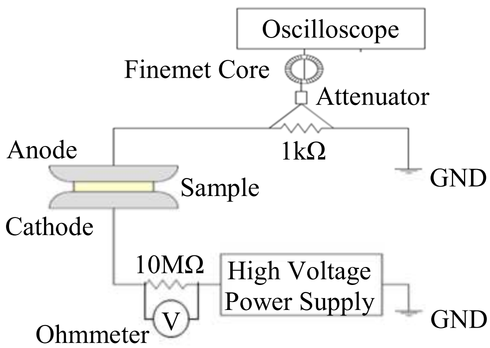

Fig2: Measurement circuit of surface flashover.

Maximum degree of vacuum	5×10^{-9}Pa
Lower limit of measurement of dark current	0.01nA
Gap of electrode distance	0～20mm
Voltage between electrode	-70kV max

Table1: Performance of experimental apparatus.

2. Experimental apparatus and procedure

2.1 Experimental apparatus

Fig. 1 shows the apparatus used for this experiment, Fig. 2 shows the measurement circuit of surface flashover and Table 1 indicates the performance of the experimental apparatus. This apparatus and circuit was built for measuring the dark current and the flashover current that flows when a DC electric field is applied on the both ends of ceramics. The ceramic sample (20mm diameter) is placed between the cathode and anode electrodes. Negative high voltage is applied to the cathode and the anode is grounded. The anode is isolated from the vacuum chamber and then surface flashover current is applied from the cathode to the anode over the sample surface. After the high field gradient is applied, the dark current was measured using an Ohmmeter set 10MΩ resistance connected between the cathode and the high voltage power supply. To achieve an ultra-high vacuum environment, we used an Ion pump for coarse evacuation during baking and used a NEG pump for main evacuation.

2.2 Samples

We used 4 samples with different volume resistivity, surface resistivity and secondary electron emission coefficients. Table 2 shows the properties of each sample.

Material		High purity alumina	A	B	C
Purity	%	99.99	-	-	-
Volume resistivity	Ω・cm	10^{14}	10^{14}	10^{13}	10^{13}
Surface resistivity	Ω/sq	10^{13}	10^{13}	10^{13}	10^{5}
Secondary electron emission coefficient	-	9.2	5.7	6.1	3.4

Table2: Properties of alumina samples.

Sample C was produced using a special surface process of Sample B material. Because this treatment decreases resistivity only on the surface of the sample, the volume resistivity of the entire sample remains at 10^{13} Ω・cm even though surface resistivity goes down to 10^{5} Ω/sq. (Fig. 3 shows the relationship between machined depth and the surface resistivity on sample C).

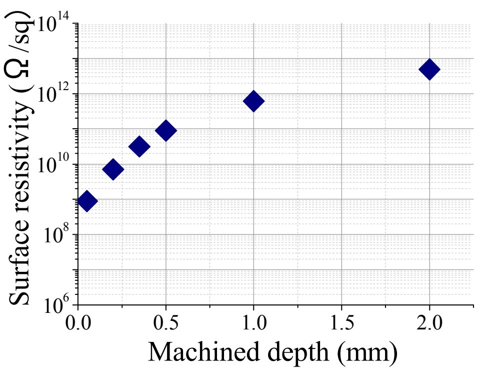

Fig3: Machined depth and the surface resistivity on sample C.

2.3 Procedure

The samples and electrodes were cleaned using ultrasonic cleaning equipment, acetone was used as cleaning solution. Fig. 4 shows the results of the experiment after introducing the samples to an ultra-high vacuum atmosphere.

A) The first surface flashover voltage test is Run number 1, starting from field gradient 0MV/m.

B) Samples are exposed to field gradient for 5 minutes and then the voltage is increased by increments of 0.2MV/m for each test.

C) If surface flashover occurred; we either continue the test by increasing the voltage or reducing the field gradient to 0MV/m to start the next Run number.

D) Run number 2 starts from field gradient 0MV/m and when flashover occurred; we either continue the test by increasing the voltage or reducing the field gradient to 0MV/m to start the next Run number.

E) This procedure is repeated, recording the flashover field gradient values.

F) Dark current is measured using and Ohmmeter at each field gradient.

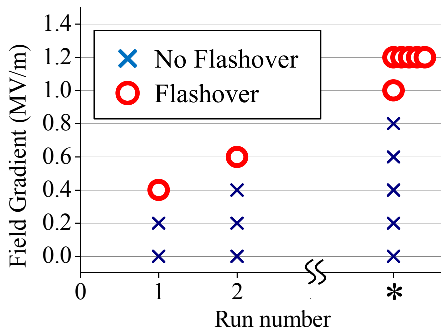

Fig4: Detail of experimental method.

After taking measurements per the procedure above, a 3 axis graph was created (Fig. 5), showing the relationship between run numbers, the field gradient and the number of flashovers so we can easily recognize the trend between the flashover field gradient and the number of flashovers per run number.

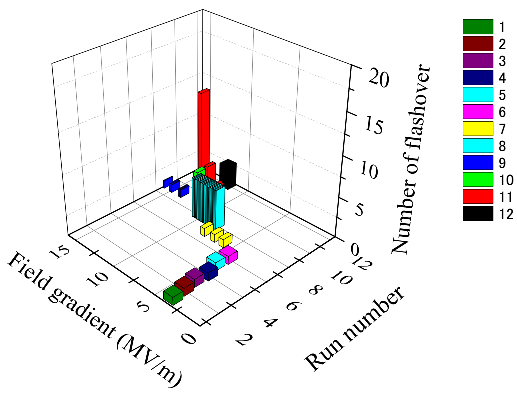

Fig5: Example of result.

3. Result and discussion

3.1 Dark current measurement

Fig. 6 shows the dark current measurement results. For high purity alumina, the dark current rapidly increased when the field gradient increased above 6.8MV/m. However, sample A showed very little dark current. Sample B had less dark current than the high purity alumina; however a slight increase can be seen versus Sample A.

In order to test sample A at higher field gradients, we decreased the sample thickness from 5mm to 2.5mm and tested up to 28MV/m. Results from the 2.5mm test piece confirmed that dielectric breakdown occurred at 26.4MV/m. The increase in dark current seen just before 26.4MV/m was due to progression of dielectric breakdown.

Sample C was tested by applying much larger currents compared the other samples as shown in Fig. 7, field gradient and current followed Ohm's law. Sample C exhibited no flashover during the test.

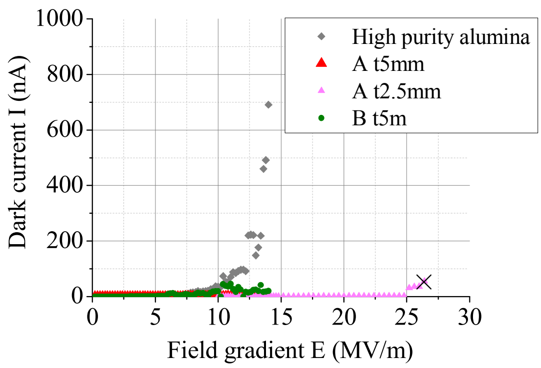

Fig6: Result of the dark current.

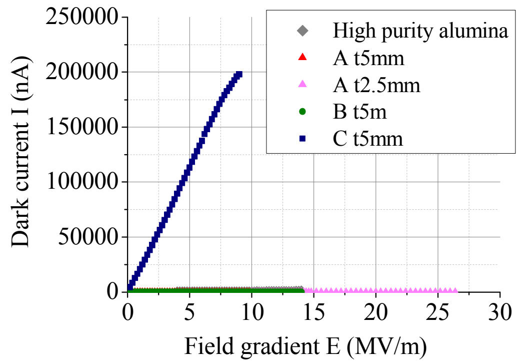

Fig7: Result of the dark current (Sample C).

Fig. 8 shows a Fowler-Nordheim plot based on the foregoing field gradient and the dark current measurement results. High purity alumina showed obvious linear graph falling to the right and confirmed that there are field emission and current enhancement as its result.

On the other hand, sample A does not have such decline and no clear linearity, thus, almost no or very little field emission and current enhancement were confirmed. Sample B also has very little field emission and current enhancement. Sample A showed dependence on their sample thickness but this is considered that the thin sample has less dark current because of smaller kinetic energy of electron.

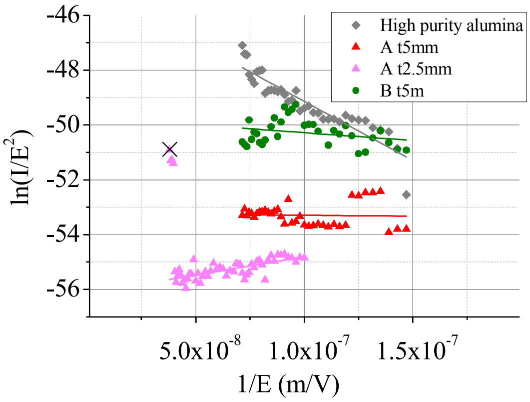

Fig8: Fowler-Nordheim plot.

3.2 Number of flashover

The number of flashover for each material is shown in Fig. 9 to Fig. 12. The flashover field gradient for high purity alumina was increased by conditioning. The number of flashover did not decrease even after conditioning and more than 20 times flashover occurred at field gradient of 14 MV/m.

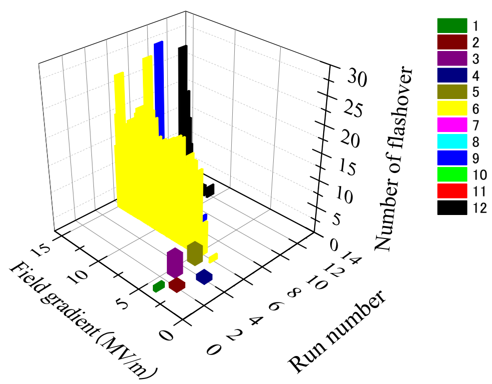

Fig9: Result of high purity alumina.

As Fig. 10 shows, sample A has less 20 times of flashover at field gradient 14MV/m – this result is less than that of high purity alumina. Conditioning has not done yet – so, measurement will be done afterwards.

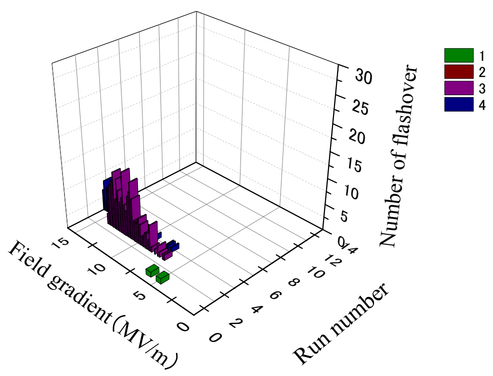

Fig10: Result of sample A.

Fig. 11 shows that sample B increased flashover field gradient by conditioning like the case of high purity alumina. The difference with the result of high purity alumina is that the number of flashover has drastically decreased. This is assumed that contaminants or projections on material surface before measurement disappeared and real material characteristics appeared.

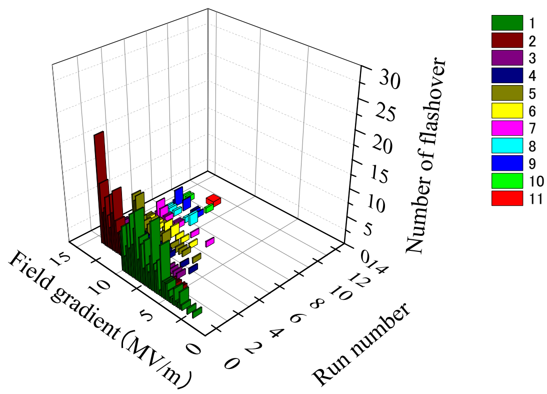

Fig11: Result of sample B.

Fig. 12 shows that surface flashover did not occur once on sample C.

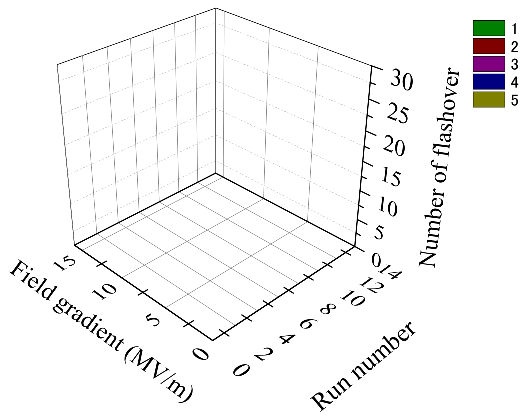

Fig12: Result of sample C.

4. Future experiment

These experiments proved that if we decrease a ceramic materials electrical resistivity or secondary electron emission coefficient, we can minimize field electron emission and can avoid flashover. However, among samples we tested at this time, we could not detect which parameter, either electrical resistance or secondary electron emission coefficient, influenced on sample B because we applied the decrease of both factors for this. On the other hand, as for the dark current measurement in Fig. 6, we showed its magnified data of the dark current in the vertical axis of Fig. 13. As Fig. 13 shows, sample A and sample B have different dark current. Sample B shows small dark current and the surface cleaning effect is expected as Fig. 14 indicates. Therefore, we are going to verify influence of low electrical resistance against the other material that we could not test at this time in following way. We will keep sample B under the field gradient that will not cause flashover for a long time and introduce cleaning effect by the dark current. We then measure the number of flashover and compare between before and after the test as well as with sample A in order to confirm surface cleaning effect that is uniquely expected for sample B.

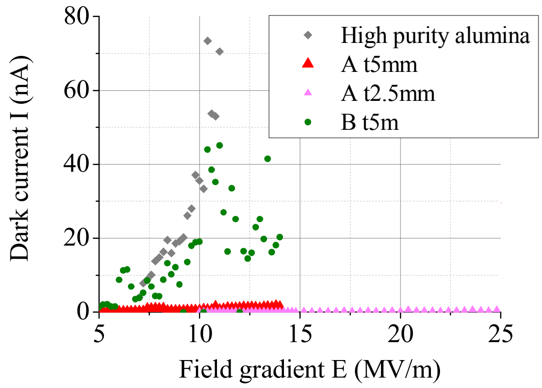

Fig13: Dark current result (Y-axis expansion).

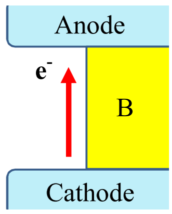

Fig14: Expected effect by the dark current on sample B.

5. Conclusions

We have developed high field gradient test equipment that can measure the field electron emission in an ultra-high vacuum environment. Based on our studies, we have verified ceramic material properties influence surface flashover control.

- We could minimize the field emission and current enhancement that will cause the surface flashover due to the decrease of material resistivity and secondary electron emission coefficient. We verified that the decrease of those material properties will be effective for controlling the surface flashover.
- Surface flashover could be eliminated by decreasing surface resistivity and the secondary electron emission coefficient.
- We have developed a new ceramic material with improved material properties– which can reduce flashover without surface coatings. This material can be used for complicated designs and offers high reliability versus standard ceramic materials.

References

[1] R.V. Latham, "High Voltage Vacuum Insulation", Academic Press.