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THE STRENGTH OF SiO_2 ADDED MgO CERAMICS TO WITHSTAND FLASHOVER-TREEING APPEARANCE UNDER ELECTRON BOMBARDMENT IN VACUUM

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ABSTRACT

To improve insulating capability of magnesia (MgO) ceramics under electron beam bombardment in vacuum, the addition of SiO_2 was studied. A scanning electron microscope (SEM) was used as a source of electron beam and vacuum condition. The capability which was represented by a waiting time to appear the first flashover treeing (hereinafter time to flashover treeing / TTF) changed with adding SiO_2 to MgO. It was found that increasing SiO_2 additions increased the TTF and got its maximum value for 6 wt% additions. From this study when 6 wt% SiO_2 added MgO was used, the insulation property of MgO was significantly increased 5.5 times of withstanding the appearance of first flashover. From three terminals method, it was found that the 6 wt% SiO_2 added MgO had the lowest surface conductivity.

1. INTRODUCTION

Material behavior under stress up to failure conditions is an important issue due to the development of new and high performance materials to meet a wide variety of industrial needs. In harsh environment such as high lightning strike density [1], the reliable insulator for overhead high voltage transmission line is needed. In space technology, materials under space radiation for large power applications need to be developed for spacecraft and space station [2]. In the electrostatic separator [3] materials under electron beam bombardment to prevent breakdown are needed. These conditions are considered to be very severe to the insulation; because they may cause a material failure when the field stress exceeds a critical value.

Studies and models for electron-irradiated insulators have been reported intensively in [4,5] and references therein. In the present paper flashover strength represented by video recording of the first appearance of a treeing (tree-like structure such as shown in Fig. 1 [6]) was used for characterizing SiO_2 added MgO materials. It was reported [6-7] that under the electron beam bombardment the TTF of a high purity sintered magnesia (MgO) ceramic was reduced by prolonging the expose time of the material to the air.

MgO is a wide band gap insulator with its high melting point (2800^{o}C), relatively low thermal expansion coefficient (13.5x10^{-6} K^{-1}) and high alternating current dielectric strength (>2,000 kV/cm). It was found [6] that under the primary beam energy of 25 keV the TTF of a new sample was 7.5 min and it became 3 min after exposing the sample to the air as long as three days. Since the flashover process involves secondary

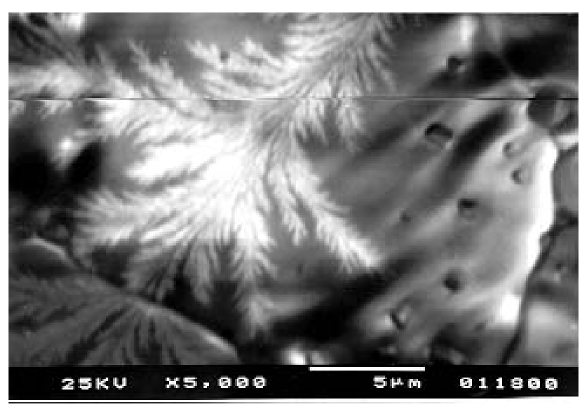

Fig. 1 Flashover treeing of pure MgO surface under electron beam bombardment [6]. Primary beam energy was 25 keV.

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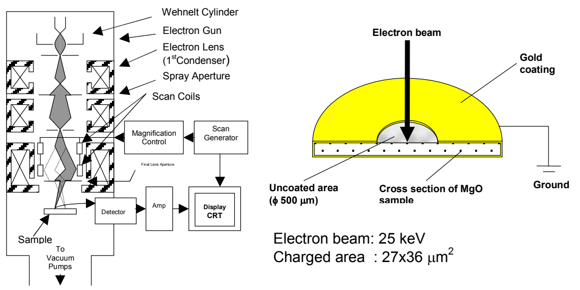

Schematic diagram of a SEM

Sample cross section

Fig. 2 Experimental arrangement.

electron emission yield from the material surface [8], materials with low secondary electron emission yields were considered to improve insulation property of MgO. In this work, high purity SiO_2 that have low emission yield [9] was used as material addition. Because the increase of electric field was proportional to the irradiation time [6,10], in this work a TTF was used as a parameter to evaluate the strength of MgO based insulators to withstand a first flashover treeing appearance. As comparisons, the surface conductivity of SiO_2 added MgO and the TTF of an electrical insulator porcelain were evaluated. The average waiting time (Tw) between discharge for Teflon, kapton and milar as the effects of low energy incident electrons (20 keV, 10 nA/m^2) done by K.G. Balman, et.al. [11] is also presented.

2. EXPERIMENTAL

The MgO and SiO_2 powders with 99.95 and 99.9% purity respectively were used for powder mixtures of various desired compositions. The powder mixtures (MgO and SiO_2 mixtures) were ground in ethanol and then dried. Every sample of 0.15 g was pressed into a disk of 10 mm diameter at the pressure of 200 MPa. The green samples of MgO and SiO_2 mixtures were sintered in air at 1650°C for 7.5 h for obtaining high density (above 90%). An X-ray diffractometer (XRD) and an energy-dispersive X-ray spectrometer (EDS) were used to obtain the compositional maps and the phase changes of the obtained samples, respectively. Prior to the examination under a scanning electron microscope (SEM JEOL T220A), the surface of the sintered sample was metal coated for observing the microstructure and remained an uncoated area of 500 μm in diameter at the center as an investigated area. Silver paste was used to mount the sample on the SEM sample holder. The sample was placed inside the SEM vacuum chamber ($4x10^{-7}$ Pa). The operating voltage of

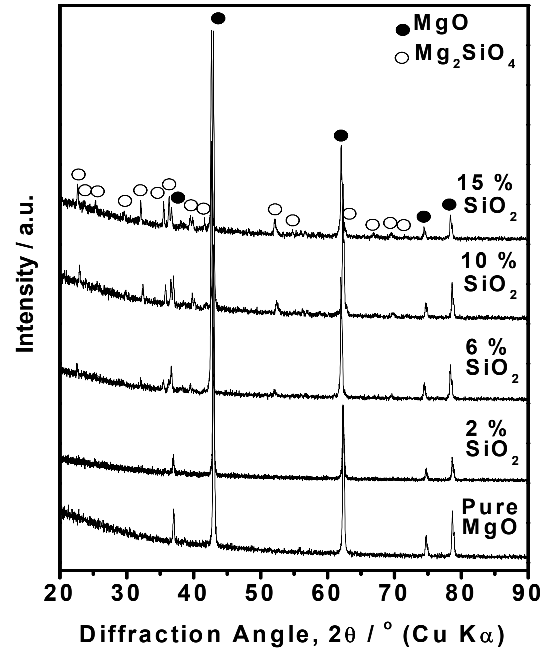

Fig. 3 X-ray diffraction pattern of several sintered SiO_2 added MgO powders.

the SEM was set on 25 kV, and the produced electron probe was directed to scan the area of 27x36 $μm^2$ (by setting magnification 5,000x) at the center of the uncoated area (see Fig. 2). The scanned area was maintained at a fixed position during an electron beam bombardment until appearing a flashover treeing. The experiment was repeated several times for other same samples. The samples were not touched, cleaned, rubbed or otherwise altered. Sample of insulator porcelain found by cleaving the outer part of the insulator in a suitable size was ultrasonic cleaned and dried at 400°C for 2 hours. As an addition, the surface conductivity of samples was measured by three terminals method follows the ASTM standard D 257.

3. RESULT AND DISCUSSION

Figure 3 shows the XRD patterns of SiO_2 additions into MgO. The new phase was attributed to the olivine structure of forsterite (Mg_2SiO_4). The peaks of Mg_2SiO_4 were remarkable obtained when the SiO_2 addition was increased (see for 10 and 15 wt% additions).

Fig. 4 shows the microstructure and compositional maps of SiO_2 added MgO materials with their various compositions. By adding SiO_2 to MgO resulted in decreasing the grain size. It was observed from the compositional maps that the distribution of Si is

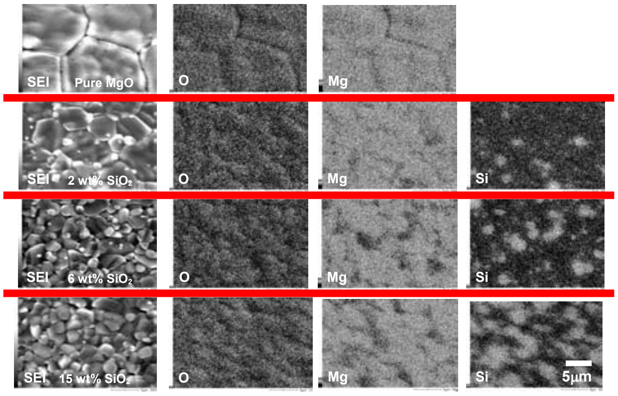

Fig. 4 The microstructure and compositional maps of SiO_2 added MgO with various compositions

thoroughly spread at the surface. From 2 wt% SiO_2 additions, Si was spread evenly at the surface. Increasing the SiO_2 addition was found to show the same condition. Therefore, SiO_2 addition was considered to improve effectively the insulation property of MgO.

Figure 5 shows the typical treeing appeared on the surface of 15 wt% SiO_2 added MgO which was composed by small grains with in size of 2 µm diameter. The treeing was propagated through the grain boundaries since the grain boundaries worked as a critical place of treeing initiation [7]. When the sample surface was composed by larger grains, then the typical treeing occurred such as shown in Fig. 1. The treeing was initiated from somewhere at the edge of the charged area and then propagated over the grain. When an electron beam bombardment was applied for a porcelain insulator, the typical shape of a treeing is shown in Fig. 6. There was no any grain on the glassy phase surface. The treeing was widely spread into the investigated (charged) area.

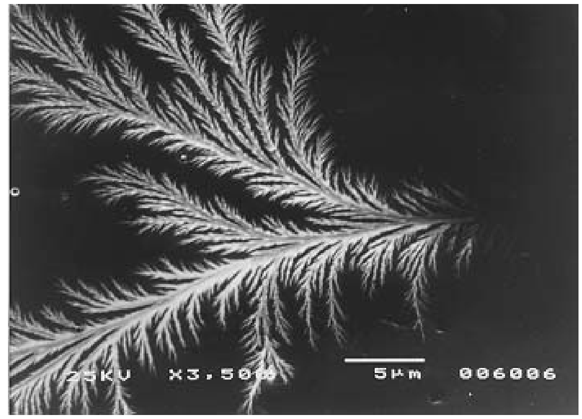

Fig. 6. Typical of a flashover treeing appeared on the surface of a porcelain insulator.

Figure 7 shows the results of any TTF obtained by adding SiO_2 to MgO. It was found that the noticeable change was found for SiO_2 addition. The TTF was found to increase lightly for 2 wt% additions, increase sharply for 6 wt% additions that reached the maximum value of 41 min and then decreased for further addition. These phenomena might be explained by the atomic distribution on the sample surface, since morphology and molecular composition influence to the electrical strength [12]. From the compositional maps of SiO_2 added MgO as shown in Fig. 4, the distribution of Si was spread evenly on the surface. This condition was found for all investigated SiO_2 additions. The existence of Si in all surface space might be considered to be better to improve the insulation property of MgO. However, further addition of SiO_2 over 6 wt% addition was found to reduce the TTF. The reduced TTF might be attributable to the influence of further formation of Mg_2SiO_4.

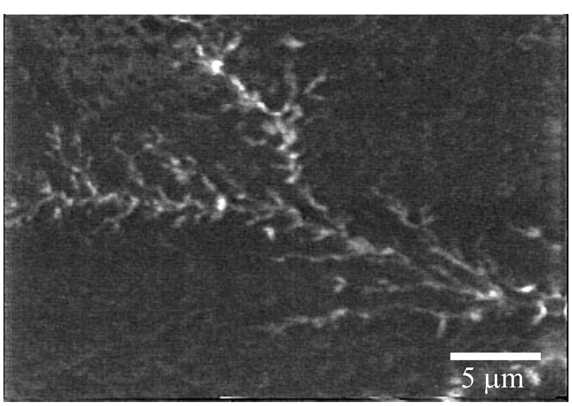

Fig. 5 Typical of a flashover treeing appeared on a surface of 15 wt% SiO_2 added MgO.

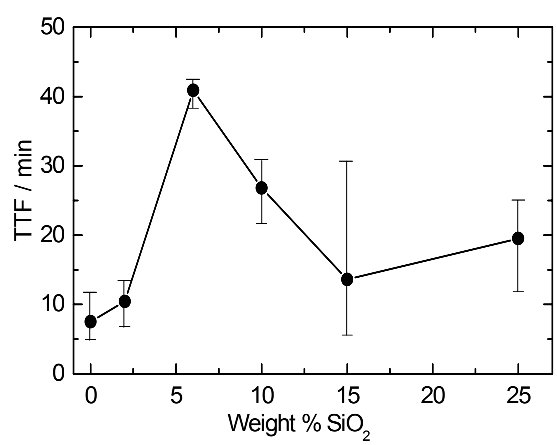

Fig. 7 Time to flashover treeing of SiO_2 added MgO.

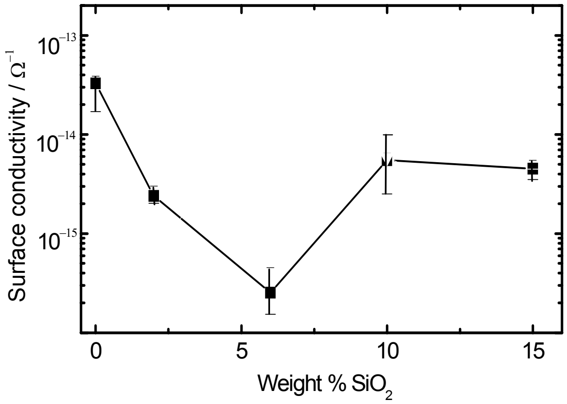

Fig. 8 Surface conductivity of SiO_2 added MgO.

From the surface conductivity measurement as shown in Fig. 8 the results exhibited the noticeable change. The surface conductivity decreased by one and two magnitude orders for 2 and 6 wt% SiO_2 additions, respectively, and then increased for 10 wt% additions. Therefore, from this study, the 6 wt% SiO_2 additions resulted in withstanding flashover treeing appearance 5.5 times from that of pure MgO.

Figure 9 shows the comparison of waiting time between discharge (Tw) done by Balmain et.al. [11] and TTF as results of the present study. Balmain used monoenergetic electrons produced by the β-decay of ^{90}Sr to ^{90}Y to charge/discharge the spacecraft dielectrics surfaces. From Fig. 9 it can be considered that 6wt% SiO_2 added MgO ceramic is a promising material that can be placed under electron irradiation in vacuum environment.

4. SUMMARY

A treeing might occur on the surface of an insulator when it was bombarded by electron beam until exceeding a critical value. It was found that the difference of grain size within a certain charged area might effect to an appeared treeing shape/size. The strength of SiO_2 added MgO to withstand flashover treeing appearance was evaluated by bombarding the samples by 25 keV electron beam at a charged area 27x36 μm^2. There was a significant increase of TTF when SiO_2 addition was 6 wt%. The surface conductivity agreed with this result, it was found that the conductivity of 6 wt% additions of SiO_2 was decreased by two magnitude orders from that of the pure MgO and as a lowest value among the investigated samples. It could be considered that 6 wt% SiO_2 added MgO became a promising material that is placed under electron bombardment and in vacuum environment.

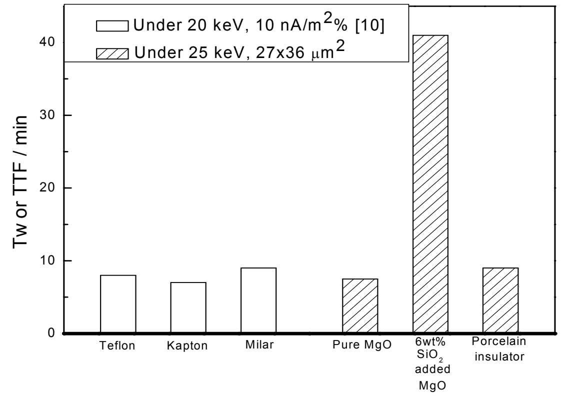

Fig. 9 Comparisons between waiting time between discharges (Tw) [10] and time to flashover treeing (TTF) for the selected insulators.

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