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SURFACE BREAKDOWN PROPERTY OF SIO_2 ADDED MGO UNDER ELECTRON BOMBARDMENT IN VACUUM: A PROMISING MATERIAL FOR SPACECRAFT AND SPACE STATION

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ABSTRACT

A surface breakdown (flashover) might occur on the surface of an insulator when it was bombarded by electron beam until exceeding a critical value. The strength of SiO_2 added MgO to withstand flashover treeing appearance was evaluated by bombarding the samples by 25 keV electron beam generated by a scanning electron microscope. There was a significant increase of bombardment-time to initiate surface breakdown when SiO_2 addition was 6 wt%. This compound was about 5 times better in withstanding breakdown compared with materials commonly used in spacecraft such as teflon, kapton and milar materials. It could be considered that 6 wt% SiO_2 added MgO became a promising material for spacecraft and space station where space radiation may damage spacecraft body or influence the communication system.

Keywords: MgO, surface breakdown, SEM, treeing, electron bombardment.

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 (Sirait, 1985) the reliable insulator for overhead high voltage transmission line is needed. In space technology, Yamano *et al.* (1999) reported that materials under space radiation for large power applications need to be developed for spacecraft and space station. In an electrostatic separator, Kalbreier and Goddard (1993) shows that materials under electron beam bombardment to prevent breakdown are needed. These entire situations are considered to be very severe to the insulation since 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 by Sessler, *et al.* (2004) and Liu *et al*. (2004) and references therein. The phenomenon that involves surface charging, discharging and surface breakdown (flashover) may damage the instrument and lead to material degradation. The flashover mechanism has been studied for many years, and it is believed that a flashover is initiated at a triple junction of metal, insulator and vacuum (Miller, (1989). On the other hand, a number of experiments (Neuber *et al*., 1999; Choi *et al*., 2004; Balmain and Hirt, 1980 and 1983 and Le Gressus and Blaise, 1992) have stressed the role of surface charging that lead to a flashover. In later theories, electron bombardment is often used to make charge accumulation on an insulator surface. Balmain and Hirt (1980 and 1983) observed subsequent breakdown on the electron flux irradiated specimen by measuring the specimen peak current. This method was used to evaluate the surface discharge property of kapton, milar and teflon materials. They proposed that the incubation of an accumulated charge at submerged layer may lead to the occurrence of a discharge (flashover). Later, Le Gressus and Blaise (1992) observed optically-visible flashover (tree-like structure) when a wide-band-gap polycrystalline Y_2O_3 sample was first charged with a 30 keV beam and then discharged with a low beam energy of 3 keV. The accepted idea of this observation is that the flashover is due to the space charge destabilization under low energy electron irradiation. Since a scanning electron microscope (SEM) can produce a controlled electron beam, research utilizing the beam to produce a measured optically-visible flashover treeing for material characterization has been left unexplored so far. Sutjipto *et al*. (2000a) investigated the effect of electron bombardment on a measured optically-visible flashover treeing (tree-like structure) for a high purity polycrystalline MgO ceramic. Fig. 1 shows a treeing appeared after about 7 min (hereinafter as a bombardment-time to flashover treeing or *TTF*) of 25 keV electrons bombardment. It was considered that a flashover treeing may happened when the electric field at the surface exceeding a critical value. The increase of electric field is proportional with bombardment-time Sutjipto *et al*. (2000a) and Cazaux (1999). It was also found that the *TTF* was reduced to 3 min after the material was exposed in air for three days. Therefore, it can be considered to evaluate surface breakdown property of an insulator by using energetic electrons produced in an SEM Sutjipto *et al*. (2006a,b).

MgO is a wide band gap insulator with its high melting point (2800^{o}C), relatively low thermal expansion coefficient (13.5×10^{-6} K^{-1}) and high alternating current dielectric strength (>2,000 kV/cm). Miller (1989) stated that a surface breakdown process involves a secondary electron emission yield from a material surface. Therefore, materials with low secondary electron emission yields were considered to improve insulation property of MgO. In this work, high purity SiO_2 that has a low emission yield Lide (1991-1992) was used as material addition into MgO. Several compositions were made to produce different *TTF*s. At the end of this report, the surface breakdown properties of MgO based materials and a porcelain insulator are compared with

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those of teflon, kapton and milar materials done by Balmain and Hirt (1980 and 1983).

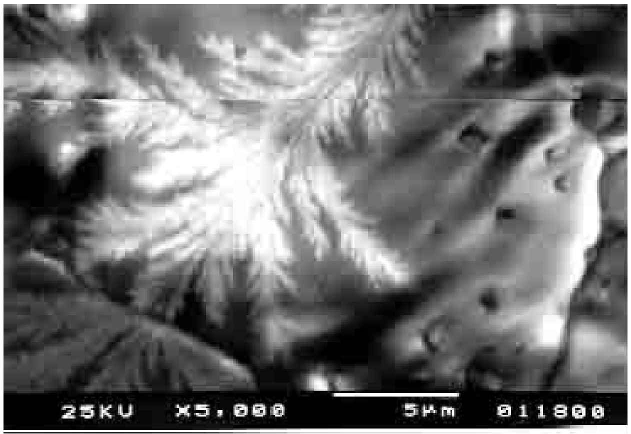

Fig. 1. Flashover treeing of pure MgO surface under electron beam bombardment (Sutjipto *et al*. (2000). Primary beam energy was 25 keV.

MATERIALS AND METHODS

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 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 (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.

RESULTS AND DISCUSSION

Fig. 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.

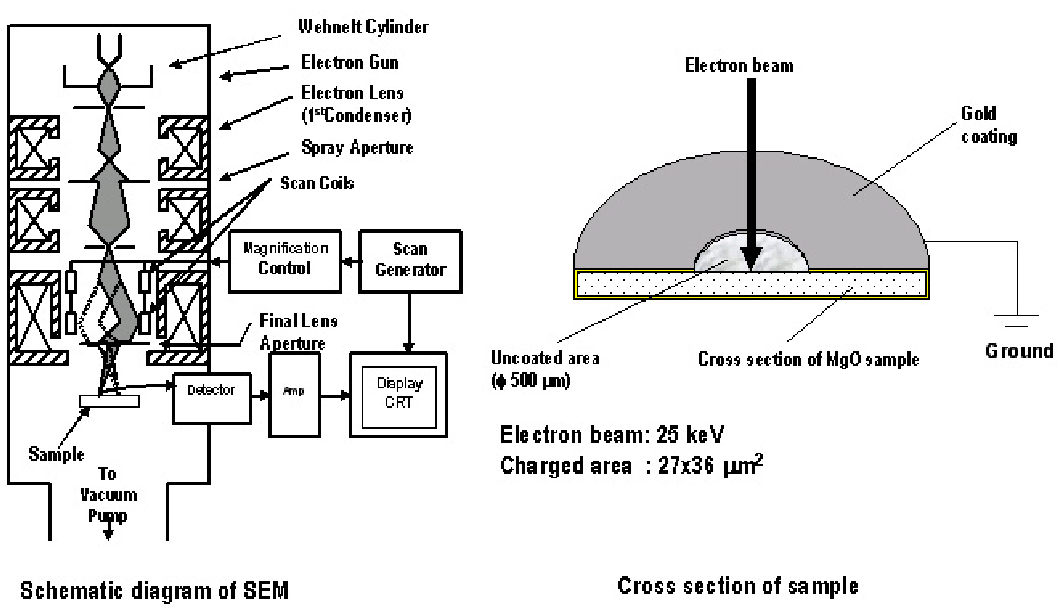

Fig. 2. Experimental arrangement.

It was observed from the compositional maps that the distribution of Si is 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.

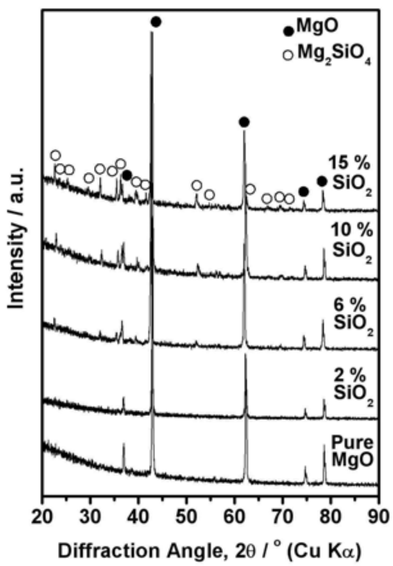

Fig. 3. X-ray diffraction pattern of several sintered SiO_2 added MgO powders.

Fig. 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 Sutjipto *et al.* (2000b). 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. 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 Hosier *et al.* (2000). 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.

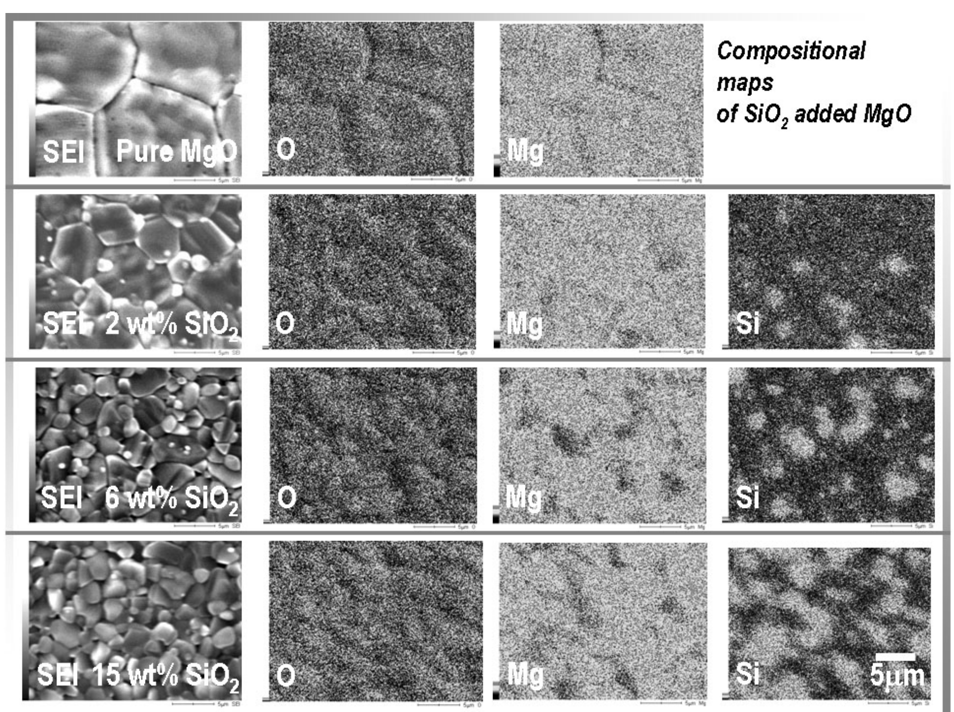

Fig. 4. The microstructure and compositional maps of SiO_2 added MgO.

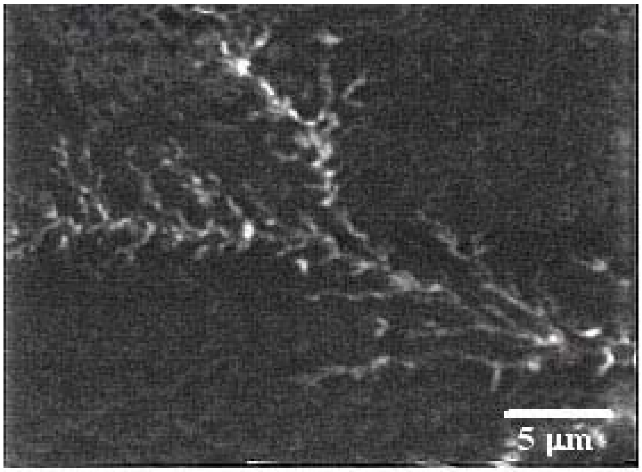

Fig. 5. Typical of a flashover treeing appeared on a surface of 15 wt% SiO_2 added MgO.

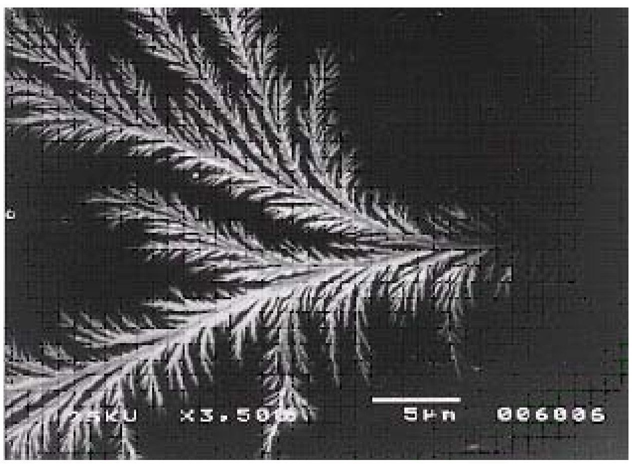

Fig. 6. Typical of a flashover treeing appeared on the surface of a porcelain insulator.

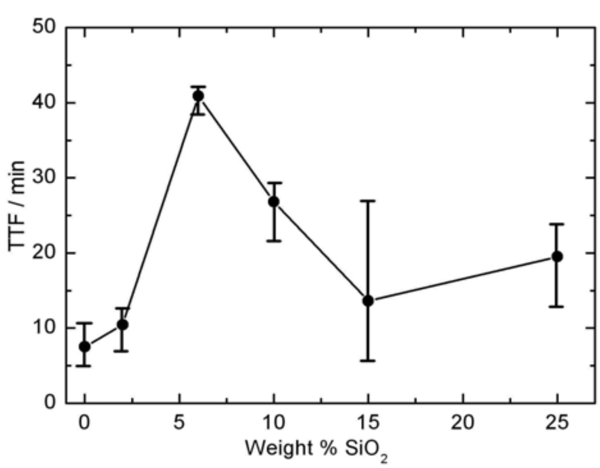

Fig. 7. Time to flashover treeing of SiO_2 added MgO.

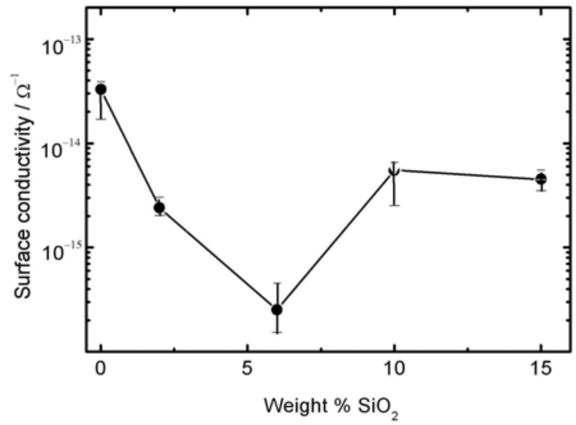

Fig. 8. Surface electrical conductivity of SiO_2 added MgO.

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. Fig. 9 shows the comparison of waiting time between discharge (Tw) done by Balmain *et al.* (1980 and 1983) and *TTF*s of the present work. Balmain *et al.* (1980 and 1983) 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 in a vacuum environment under electron bombardment.

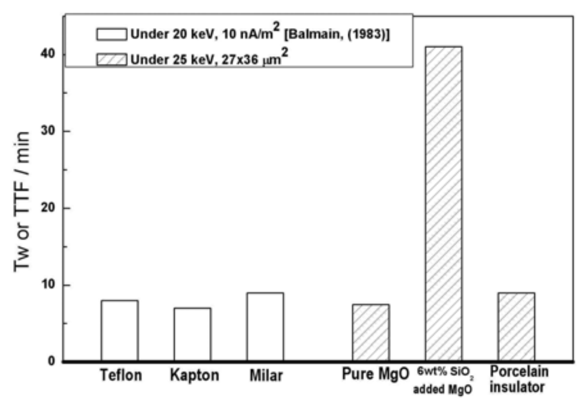

Fig. 9. Comparisons between waiting time between discharges (Tw) [Balmain and Hirt (1983)] and bombardment-time to flashover treeing (*TTF*) for the selected insulators.

CONCLUSIONS

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 of 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 a 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 for spacecraft and space station.

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