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Behavior of MgO Based Ceramics under Electron Irradiation

A.G.E. Sutjipto[a]*, Y.P. Asmara[b], M.A. Jusoh[a]

[a]Faculty of Industrial Sciences & Technology, Universiti Malaysia Pahang
[b]Faculty of Mechanical Engineering, Universiti Malaysia Pahang

Abstract

MgO is one of environment friendly ceramic material under harsh environment such as electron irradiation. Different response of MgO ceramics under the irradiation was reviewed. The response was in the appearance of surface breakdown/flashover on the surface of MgO after a certain time under irradiation exposure. The different response was shown for small addition of CaO, ZrO_2 and SiO_2 into high purity of MgO. Addition of CaO resulted in the appearance of flashover could be 30% earlier of that of pure MgO. Moreover, addition of ZrO_2 resulted in 70% earlier. On the other hand, small addition of SiO_2 revealed that the MgO based ceramics could withstand the appearance of flashover under the same energetic electron irradiation.

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Keywords: MgO; surface breakdown; flashover; scanning electron microscope; electron irradiation

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, it was reported [2] that spacecraft charging under space irradiation generates problem on electronic devices and may cause accident. In an electrostatic separator, it was [3] shown 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.

Magnesia (MgO) is one of environment friendly ceramic materials. It was for long time that MgO is the best ceramic for producing more secondary electrons under electron avalanche in protecting layer of plasma display panel [4]. It is also considered that MgO has many applications in other harsh environment. The MgO is a very good contender as a neutron reflector in fast neutron reactors [5], it is envisaged as a matrix of the ceramic-ceramic composite nuclear fuel for minor actinide transmutation [6], and it could be also used as an electrical insulator for diagnostic components in the ITER fusion reactor [7], making it a potential candidate for applications in the nuclear energy field. Under such operating conditions, the MgO will definitely be subjected to various types of irradiation.

In particular electron irradiation, it was introduced [8] the use of a scanning electron microscope (SEM) as a source of energetic electrons to irradiate uncoated dielectric ceramic to study the capability of the material to withstand the appearance of surface breakdown (flashover). A flashover is a process of charging and discharging on the surface. The charging process will then create an increasing of surface electric which may cause breakdown when the limit of electric field is achieved. MgO was chosen since the materials was very stable under electron irradiation. On the other hand, MgO is very sensitive ceramic to produce secondary electrons when it is exposed under electron irradiation. There are two possibility behaviors of MgO when energetic electrons are directed into it whether suppresses or doubles the production of secondary electrons. The earlier will

* Corresponding author. Tel.: +609 549 2303; fax: +609 549 2766.
E-mail address: agusgeter@ump.edu.my

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cause the material to withstand surface breakdown and the later one is to allow flashover to occur easily. This paper is to evaluate both behaviors of MgO based ceramics under electron irradiation. First it will be introduced the use of SEM with a certain operating voltage to drive energetic electrons to direct into uncoated dielectric ceramic that may create a surface electric field. Then under the same energy of irradiation, MgO with different addition will be evaluated.

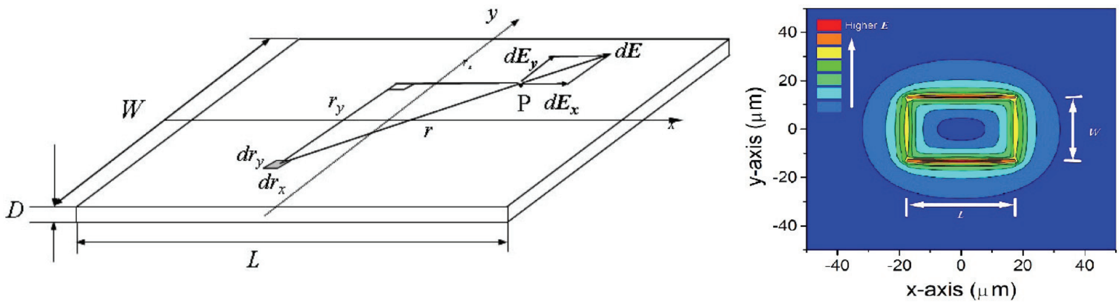
2. Methods

When energetic electrons of a SEM irradiates an insulating material, it causes the emission of secondary electrons. Secondary electrons are electrons which are ejected from a sample during electron beam irradiation. The total secondary electron emission yield δ is given by n_{SE}/n_I where n_{SE} is the number of secondary electrons emitted from a sample irradiated by the number of incident electrons, n_I. When δ is greater than one, the sample surface becomes positively charged. Secondary electrons are generated from a shallow escape depth of D. The electrons are produced along the entirely of the beam electron trajectories within the specimen. The thickness, D, of this region is not well known, but is less than about 50 nm for insulator [9].

Figure 1 (a) shows a model of rectangular charged area. The electric field at any point due to a group of point charges is found by an integral of the equation (1) as

$$E(x,y,z) = \int dE = \frac{1}{4\pi\varepsilon}\int \frac{dq}{r^2} \tag{1}$$

where dq is a differential element of the charge distribution, r is its distance from the point P, and dE is the electric field it establishes at that point.



(a) (b)

Fig. 1. Distribution of electric field: rectangular model (a) and plot of the field (b) where the highest field (red) is at the edge of scanned area.

The mechanism of a surface flashover (optically-visible flashover treeing) is as follows. Under the period of charging, by using equation 1 above, the highest electric field is created at the edge of the scanned area (shown in figure 1(b)). Consequently, the highest field may cause more electrons which are emitted from the subsurface region around the edge. The increase of period of charging may increase the number of electrons above the surface (containing secondary electrons and field-emitted electrons) and cause a potential difference between the edge (more negative charges) and the center (less negative charges or zero) of the scanned area. When the potential difference reaches a critical value, some of the electrons from the edge region may be accelerated and attracted towards the center. The electrons impact upon the surface producing additional electrons by tertiary emission. Some of these tertiary electrons will again strike the surface producing second-tertiary electrons. Continuation of this process results in a cascade along the surface that develops into a tertiary electron emission avalanche. This avalanche, in turn, can lead to a complete breakdown. Some of these electrons will be detected by the Everhart-Thornley (E-T) detector as an optically-visible flashover treeing. Once a flashover treeing is completed, the potential difference between the scanned area edge and the center becomes zero. In this stage, the surface becomes positively charged. Figure 2 shows the process of a flashover appearance on MgO under electrons irradiation.