Electron Energy Dependent Charging Effects of Multilayered Dielectric Materials

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Electron Energy Dependent Charging Effects of Multilayered Dielectric Materials

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Abstract

Measurements of the charge distribution in electron-bombarded, thin-film, multilayered dielectric samples show that charging of multilayered materials evolves with time and is highly dependent on incident energy; this is driven by electron penetration depth, electron emission, and material conductivity. Based on the net surface potential, displacement current and beam energy allow the charge distribution to be inferred. To take these measurements, a thin-film, insulating Sb₂Te₃, structure with a conductive middle layer was charged using 200 eV and 5 keV electron beams with regular 15 ± 5 pulses at 1 nC/m² to 300 nC/m². Results show that there are two basic charging scenarios which are consistent with simple charging models; these are analyzed using independent determinations of the material's electron range, yields, and conductivity. Large negative net surface potentials led to electronic breakdown and large visible arcs, which have been observed to lead to detrimental spacecharge effects.

Theory

In order to investigate the charging of multilayered dielectric materials, pulsed charging experiments were conducted using multilayered dielectric mats of SiO₂-based materials. A single-beam, a conductive middle layer and an SiO₂ substrate were made with the conductive layer both grounded and ungrounded. Experiments were conducted in the main USU electron emission microscopy facility using standard vacuum test chambers modified for observation of low intensity UV/Vis/NIR glow over a broad range of sample temperatures. Figure 1 provides a general schematic of the experimental system used.

The samples were subjected to short pulses (1-5 s) of electron bombardment using a monochromatic electron beam with beam energies of 200 eV and 5 keV. A low energy electron gun (Stelar, EK-581) was used, producing a non-thermalized, low-flux pulsed beam (5-500 µA/cm²) over an energy range of 20 eV to 5 keV. The delivered electron beam current and beam profile were determined through measurement of the sample with about 10% uniformity over an ~2 cm diameter beam spot. Beam fluxes were measured with a secondary electron multiplier or nitrogen ionization current monitors and UV/Vis and NIR spectrometers, an SRL CCD still camera, and a NQR video camera for optical measurements.

Figure 2 (a) Electron Range R(El) as a function of incident energy for Ag, Cu, and SiO₂. (b) Total Electron Yield as a function of incident energy for SiO₂. (c) Scattering as a function of temperature for SiO₂.

Results

Backscattered electrons undergo a quasi-elastic collision near the surface and backscatter, imparting no net charge to the material. Secondary electrons are generated by incident electrons that scatter collide near the surface, which impart energy to several other electrons in the material, before being ejected from the surface leading to net charge loss. The total yield is the sum of the backscattered yield and the secondary yield. When the total yield is less than unity, charging is negative. When the total yield exceeds unity, the material's surface becomes positively charged. As the net surface potential reaches a certain potential of a few volts positive, some secondary electrons are also produced to the surface which then cats backscattered electrons with ions holes creating an upper limit on the net surface potential.

Conductors: The conductivity of a material determines how easily deposited charge layer can move through the material in response to a charged field. The charge density produced by the charged layers, the depolarization layer, and the conductive layers in the material is modeled in Figs. 8 and 9. The measured currents will have two terms: a particle current conductivity proportional to the conductivity and a displacement current due to the change in the electric field due to charge accumulation.

Surface Dielectric Deposition – Ungrounded

For a 200 eV monoenergetic electron beam the electron range in disordered SiO₂ is approximately 3 nm, as shown in Fig. 2a. At this depth, the electrons just penetrate into the first layer, but do not reach the conductive layer. From the total yield for disordered SiO₂ at 200 eV, we see that the depolarization layer is the dominant layer in this case. Thus, we should see a small-limiting positive net surface potential due to a net deficit of electrons. This agrees with the sign of the measured net surface potential as measured in Fig. 7a).

Surface Dielectric Deposition – Grounded

For a 200 eV monoenergetic electron beam with a conductive substrate, we see similar behavior for the surface voltage as seen for the ungrounded sample. Positive surface potentials are observed in Fig. 7c, as expected.

Conductive Layer Deposition – Ungrounded

For a 5 keV monoenergetic electron beam the electron range in disordered SiO₂ is ~560 nm, as shown in Fig. 2b. At this depth, the electrons penetrate through the surface dielectric and into the conductive layer. The total yield for disordered SiO₂ at this energy is ~1, which should lead to a non-zero net surface potential in Fig. 7g).

Conductive Layer Deposition – Grounded

For a 5 keV monoenergetic electron beam with an ungrounded conductive layer, we again deposit charge in the conductive layer. We also have a total electron yield less than unity as before. Because the conductive layer is ungrounded there will be no net charge dissipation mechanism. Thus, there is no limiting behavior from extractions of secondary electrons, so we should see a high net negative potential in this Fig. 7h). For this scenario, after higher negative net surface potentials were reached, breakdown and arcing was observed.

Experimental

Four experiments are conducted as depicted in Fig. 6. The experiments differ in terms of the incident energy and flux, and as we will see below, produce dramatically different results. To interpret the experiments described, introduce the following three physical phenomena—the electron range, electron yield and the electron transport (conductivity) of the material—and how they are affected by the experimental conditions.

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The electron range is the maximum distance an electron of a given incident energy and flux can travel in a material. This is a key parameter that depends on the material and the incident energy, and is obtained from the need to find the surface potential, displacement current and beam energy allow the charge distribution to be inferred. To take these measurements, a thin-film, insulating Sb₂Te₃, structure with a conductive middle layer was charged using 200 eV and 5 keV electron beams with regular 15 ± 5 pulses at 1 nC/m² to 300 nC/m². Results show that there are two basic charging scenarios which are consistent with simple charging models; these are analyzed using independent determinations of the material's electron range, yields, and conductivity. Large negative net surface potentials led to electronic breakdown and large visible arcs, which have been observed to lead to detrimental spacecharge effects.