Charging Effects of Multilayered Dielectric Spacecraft Materials: Surface Voltage, Discharge and Arcing

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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 electrons penetrating depth, electron emission and material conductivity. Based on the net surface potential’s dependence on beam current, electron range, electron emission and conductivity, measurements of the surface potential, displacement current and beam energy allow the charge distribution to be inferred. To take these measurements, an in-house developed SISR, structure with a conductive middle layer was charged using 200 keV and 5 keV electron beams with regular 15 ps pulses at 1 nA/cm² to 50 nA/cm². 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 electronic 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 spacecraft charging effects.

Experiments

In order to investigate the charging of multilayered dielectric materials, pulsed charging experiments were conducted using multilayered dielectric materials of SiO₂ on Si substrates, a conductive middle layer and an SiO₂ substrate. Experiments were made with the conductive layers both grounded and ungrounded. Experiments were conducted in the main USU electron emission system which has various test stages modified for observation of low intensity UV/VIS/IR glow over a broad range of electron energies. Figure 1 provides a general schematic of the experimental system used.

The samples were subjected to short pulses (≤5 s) of electron bombardment using a monochromatic microbeam electron beam of energies between 500 keV and 5 keV. A low energy electron gun (Stahl, KE-551S) was used, that can deliver a well-characterized, low-flux pulsed beam (between 50-pA/cm² to 1 μA/cm²) over an energy range of 20 keV to 5 keV. The defocused electron beam current was adjusted to a level that resulted in a homogenous current density profile at the sample with about ±10% uniformity over an ∅-3 cm diameter beam spot. Beam fluxes were measured using a Faraday cup. Beam current densities of 200 nA/cm² at 200 keV and 2.7 mA/cm² at 5 keV were used for the experiments reported here, with an exposed sample area of 4.96±0.2 cm².

Theory

Four experiments are considered 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, we use 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.

Theory | Surface / Volume | vacuum | Simulations
--- | --- | --- | ---
(a) | Grounded | Simulated a grounded backing to respond to an electron flux. In Fig. 7a, we simulate the surface and volume potential’s response to the charging of a multilayer specimen. In Fig. 7b, we simulate the surface potential evolution of the multilayer specimen. The density of the material is shown in Fig. 7c. With grounded backing, we observe similar behavior even for the surface voltage as seen for the ungrounded scenario. Positive surface potentials are observed in Fig. 7c, as expected.

Conclusions

For a 5 keV monoenergetic electron beam on a grounded specimen, we observe similar behavior for the surface voltage compared to the ungrounded scenario. For the surface energy, this is due to the lower net surface potential compared to the ungrounded scenario. For the surface energy, this is due to the lower net surface potential compared to the ungrounded scenario.

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Fig. 4. Diagram of incident electron flux impinging on a pristine sample, electron charging the insulator and grounded substrate when only beam is present. The yield flux is shown for the displacement current. The yield flux is shown for the displacement current.

Fig. 5. Electrons are due to beam-driven charge layer(s) and grounded planes. The resulting electric field can lead to net current transport of the uncharged layer(s) and displacement currents resulting from charge migration into the grounded planes. Conductivity determines how fast uncharged charges can move.

Fig. 6. Schematic diagram for the measurement of the charge density distribution and net surface potential. The electron beam is incident on the sample, which is grounded to the backplane. The charge density distribution is measured using the in-house developed SISR, and is used to determine the net surface potential at the sample's surface. The net surface potential is measured using a high-precision Picoammeter.

Fig. 7. Measurements of surface potential vs time (a), (c), (e) and real and complex conductance curves vs time (b), (d), (f) for: (a), (c) surface dielectric deposition with low energy electron beam and ungrounded conductive layer; (c), (d) surface dielectric deposition with low energy electron beam and grounded conductive layer; (f) dielectric layer deposition with high energy electron beam and grounded conductive layer. The data are shown as the circles . The positive charge centers (holes) are shown as s. Positive (a, c, d, and negative) (e and (g) surface voltages are indicated.

Fig. 8. Charging models for a multilayered dielectric with a conductive substrate: (a) surface dielectric deposition with low energy electron beam and ungrounded conductive layer; (b) surface dielectric deposition with low energy electron beam and grounded conductive layer; (c) dielectric layer deposition with high energy electron beam and grounded conductive layer; (d) dielectric layer deposition with high energy electron beam and ungrounded conductive layer; (e) dielectric layer deposition with high energy electron beam and grounded conductive layer; (f) dielectric layer deposition with high energy electron beam and ungrounded conductive layer; and (g) dielectric substrate deposition with high energy electron beam and grounded conductive layer. The data are shown as the circles . The positive charge centers (holes) are shown as s. Positive (a, c, d, and negative) (e and (g) surface voltages are indicated.

Results

For a 5 keV monoenergetic electron beam on a grounded specimen, we observe similar behavior for the surface voltage compared to the ungrounded scenario. For the surface energy, this is due to the lower net surface potential compared to the ungrounded scenario.

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