EXPERIMENTAL VALIDATION OF A NUMERICAL MODEL PREDICTING THE CHARGING CHARACTERISTICS OF TEFLON AND KAPTON UNDER ELECTRON BEAM IRRADIATION*

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SUMMARY

In order to assess the effect of differential charging of spacecraft thermal control surfaces the dynamics of the charging process must be understood. To that end a program to experimentally validate a computer model of the charging process has been established.

Time resolved measurements of the surface potential have been obtained for samples of Kapton and Teflon irradiated with a mono-energetic electron beam. Results indicate that the computer model and experimental measurements agree well and that for Teflon secondary emission is the governing factor. Experimental data indicate that bulk conductivities play a significant role in the charging of Kapton.

INTRODUCTION

The effects of dielectric breakdown observed on board spacecraft and in the laboratory have demonstrated the need for a charging model capable of predicting surface voltages and internal electric fields for dielectric surfaces subject to the spacecraft environment. A joint theoretical and experimental program has been initiated to both improve and validate such a model using an iterative procedure. Concurrent development of the computer code and experimental measurements will allow modifications of both programs to produce an optimum correlation.

The model is a modification of one developed for Communications Research Centre (ref. 1) which takes into account subsurface charge dynamics, energy deposition ranges, secondary electron emission, radiation induced conductivities and bulk resistivity. The program predicts the temporal evolution of the

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surface voltage, charging currents, charge deposition profiles and internal electric fields for a given incident particle spectra and material parameters.

The model is being evaluated using data from an experimental program developed to measure the material parameters pertinent to the problem as well as the charging characteristics of the dielectric sample.

The work described here deals with the charging characteristics of Teflon and Kapton samples irradiated with a monoenergetic beam of electrons having an energy of up to 16 keV. The surface voltage is determined from the energy spectrum of secondary electrons measured with a curved plate electrostatic surface emission analyzer (ESEA). Particular attention has been directed toward avoiding fringing fields and surface leakage effects near the sample edges, obtaining a uniform irradiating beam density with minimum beam divergence effects, and adequately resolving the surface voltage during the charging processes.

Measurements on Teflon are in good agreement with the numerical model predictions. The results indicate that the equilibrium surface voltage is determined by secondary emission and that bulk resistivity and radiation induced conductivity are unimportant. The data points can be adequately predicted by an ideal one dimensional capacitor model. Measurements on Kapton have not been compared with numerical calculations. The results indicate that the bulk resistivity is important and that a leaky capacitor (i.e. a capacitor in parallel with a resistor) is required to approximate the charging characteristics. The results establish the practicality of using the ESEA for measuring the surface voltage during charging.

In the remainder of the paper, the experimental system is discussed briefly. This is followed by a presentation of the experimental techniques and the measurements obtained. A discussion of results and a conclusion section complete the paper.

EXPERIMENTAL SYSTEM

In order to carry out the required measurements the system shown in figure 1 has been assembled. The electron flood gun provides a source of energetic electrons (0-30 kV, 0-10 nA/cm^2) to irradiate the dielectric samples. The flux density of the beam is uniform to $\pm$ 15% over the surface of the dielectric. The total electron flux is continuously monitored.

The measurement system is enclosed in a multi-port glass vacuum chamber which is pumped by a turbomolecular pump. This pumping system was chosen to reduce surface contamination by pump oils which can affect secondary emission yields and surface conductivity.

The sample mount was designed principally to establish a one-dimensional geometry which conforms as closely as possible to the one-dimensional geometry assumed for the computer code. For this purpose the samples are mounted upon a split ring assembly so that fringing fields at the edge of the guard ring have no effect upon the dielectric in the region of the central disc. The dielectric is mounted to the split ring assembly by first removing an annular region of the metallic backing with sodium hydroxide. This region corresponds to the spacing between the guard ring and central disc. When the samples are affixed to sample mount using a conductive epoxy (Eccobond V-91), the guard ring and central disc are electrically isolated. With this configuration the equilibrium current measured with the central disc reflects only the bulk conduction currents through the dielectric. On the other hand, the current measured with the guard ring includes both bulk conduction current and surface leakage current. To provide further one-dimensionality a grounded grid has been placed 1 cm in front of the sample. This provides a uniform, parallel electric field normal to the sample surface. In this way electron beam divergence due to the fields produced as the dielectric charges is minimized.

The sample mount and grid are tilted at 14^{o} to relative to the beam in order to facilitate the measurement of secondary electrons which are ejected normally from the sample surface. After the secondary electrons pass the grid, they traverse a field free region and are detected by a curved-plate electrostatic surface emission analyzer (ESEA) which resolves the energy spectrum of the secondary and back-scattered electrons. The ESEA, developed by Panametrics, Inc. has an energy resolution of 5% of full scale and a time resolution of 4 sec. Picoammeters record the currents collected by the central disc, guard ring and beam current monitor.

MEASUREMENT TECHNIQUES AND RESULTS

In order to do the initial iteration of fitting experimental data with output of the computer model the time evolution of surface potential, charging current and secondary emission were measured.

The surface potential was determined from a set of time resolved secondary electron spectra obtained with the ESEA. This can be accomplished because the electron spectra secondary electrons are produced at the dielectric surface with a small kinetic energy (<100eV). The kinetic energy gained as these electrons fall from the dielectric surface potential to ground potential is a measure of the surface potential. By taking successive spectra of the secondary electrons and noting the maximum energy a set of time-resolved surface potentials can be obtained. This method was tested and calibrated by replacing the dielectric sample with a gold plate. The irradiated plate was biased at a number of potentials and the secondary electron energy measured with the ESEA. A linear relation was obtained between the applied bias and the energies of the emitted electrons establishing the calibration.

Figure 2 illustrates a set of four time-resolved spectra each of which has two distinct peaks. The first peak is the secondary electron peak which increases both in energy and magnitude with time. The magnitude provides a measure of secondary electron yield. The second peak corresponds to backscatter electrons whose energy remains essentially constant in time.

The split ring sample mount assembly is instrumented with picoammeters to measure individually the substrate currents flowing to the central disc and guard ring during charging. These currents along with the beam monitor current are recorded using a Bascom-Turner data acquisition system and are stored on magnetic disc. This data can then be recalled and analyzed.

In a typical charging run a new sample is installed and the surface potential and charging currents measured. Figures 3 and 4 exhibit the central disc currents measured and a normalized secondary yield for 125 μm thick samples of Teflon and Kapton under similar irradiation conditions (beam energy = 11.7 keV and electron flux $\simeq$ 1 nA/cm^2). It should be noted that due to geometrical factors that the secondary yield is not an absolute calibration and further experimental analysis is required.

In figures 5 and 6 the solid circles represent the temporally resolved surface potentials measured with the ESEA for the 125 μm Kapton and Teflon samples. At the end of a run the samples are discharged by back filling the vacuum chamber to 200 Torr with dry nitrogen. Subsequent charging runs indicate that the surface is almost completely discharged by this process.

A computer run was made for a Teflon sample for irradiation conditions that correspond to the experimental conditions (beam energy = 11.7 keV and electron flux = 0.96 nA/cm^2). A one-dimensional parallel plate geometry was used to calculate the surface to substrate capacitance (0.74 x 10^{-9}F). The backscatter yield was calculated to be a constant value equal to ten percent of the incident electron flux. The secondary yield was chosen to conform to data of Wall et al (ref. 3). The time-resolved surface potentials generated by the computer code are represented by the dashed curve in figure 5.

DISCUSSION OF RESULTS

The comparison of experimentally measured surface voltages with the theorectically predicted values in figure 5 reveals good agreement. The observation that the equilibrium voltage is approximately 1800 $\pm$ 125 V less than the beam voltage is consistent with the measurements of others and is also consistent with the explanation that the charging ceases when the secondary emission coefficient is unity (at the second cross-over point). Although the equilibrium current is buried in the noise and cannot be readily measured with the present technique the upper limit on the conductivity approaches the bulk conductivity value presented in the literature (ref. 4). The surface voltage measurements on Kapton (figure 6) reveals a larger equilibrium current and hence larger conductivity. In both the Teflon and Kapton measurements, the initial slope of the charging voltage curves (figure 5 and 6) are proportional to the ratio of the initial charging current to the calculated capacitance (i_c/C).

The experimental results were compared with simple one-dimensional capacitor models to evaluate the relative importance of various material characteristics on the charging results. For Teflon, the bulk conductivity was ignored and the surface voltage was calculated from the relation

$$v(t) = \frac{1}{C}\int_0^t i_c dt$$

where the charging current, i_c, was taken to be the central disc current. The results are shown as the curve in figure 5. The good agreement with the measured results demonstrates that bulk conductivity and radiation induced conductivity are relatively unimportant in the non-penatrating beam situation presented here. The measurements further establish the ESEA as a suitable non-perturbing method of measuring time dependent surface voltages for relatively slowly varying conditions. For Kapton, a leaky capacitor model was used to compute the surface voltage from the relation

$$v(t) = \frac{1}{C}\int_0^t \left[i_c(t') - \frac{1}{RC}\int_0^{t'} (i_c(t'') - \frac{v}{R}(t''))dt'' \right] dt'$$

where the sample resistance was experimentally determined from the equilibrium charging current and surface voltage. The results obtained by approximating v(t")/R by the equilibrium value are presented in figure 6 along with the experimental points. The relative good agreement shown there demonstrates the importance of dielectric conductivity on the charging characteristics of Kapton.

CONCLUSIONS

Measurements of charging voltage and charging currents have been made on dielectric samples irradiated by a monoenergetic electron beam. A guard ring sample mounted together with a transparent grid in front of the sample surface has been utilized to reduce the fringing fields, edge leakage currents and beam divergence effects to insure a one dimensional geometry. Comparison of experimental results with the prediction of a numerical model which takes secondary emission and subsurface charge dynamics into account reveals good agreement for 125 μm Teflon samples irradiated by ∿1 nA/cm^2 11.7 keV electron beam. Secondary electron emission is the important factor determining the surface voltage with bulk resistivity and radiation induced conductivity relatively unimportant. A one-dimensional capacitor model appears to represent the charging characteristics very well.

Measurements on Kapton samples are in relatively good agreement with a one-dimensional leaky capacitor model. The results reveal the more important effect that bulk conductivity has on the charging characteristics of Kapton. Calculations for Kapton using the numerical model are underway.

The good agreement between the theoretical calculation and experimental measurements establish the ESEA as a satisfactory instrument for measuring time dependent surface voltages at irradiation levels of ∿1 nA/cm^2. The agreement also indicates that leakage currents and fringing field effects at sample edges have been minimized.

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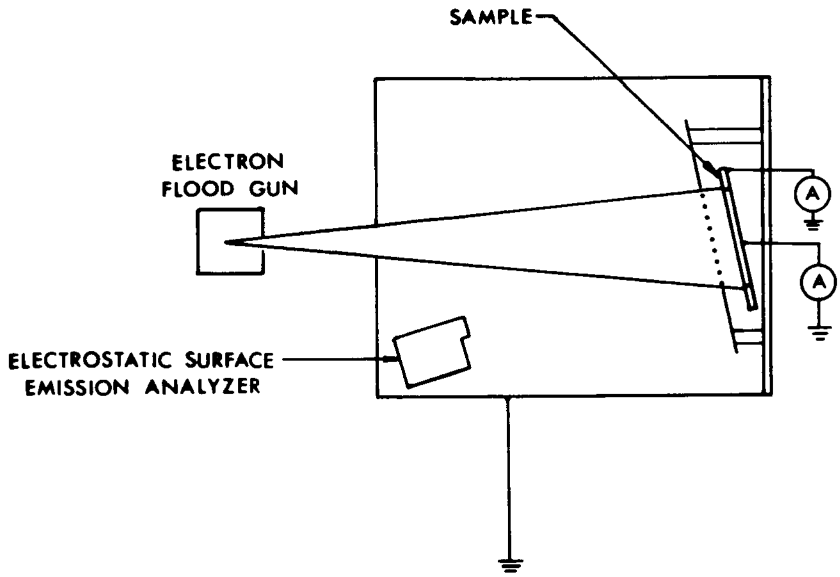

FIG. 1. EXPERIMENTAL SYSTEM

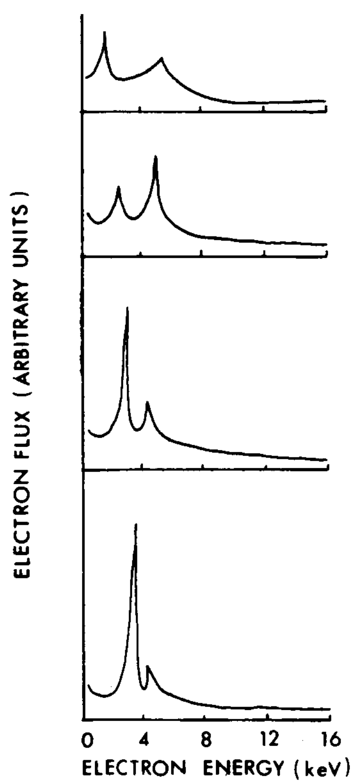

FIG. 2. ELECTRON ENERGY SPECTRA AT DIFFERENT TIMES DURING CHARGING.

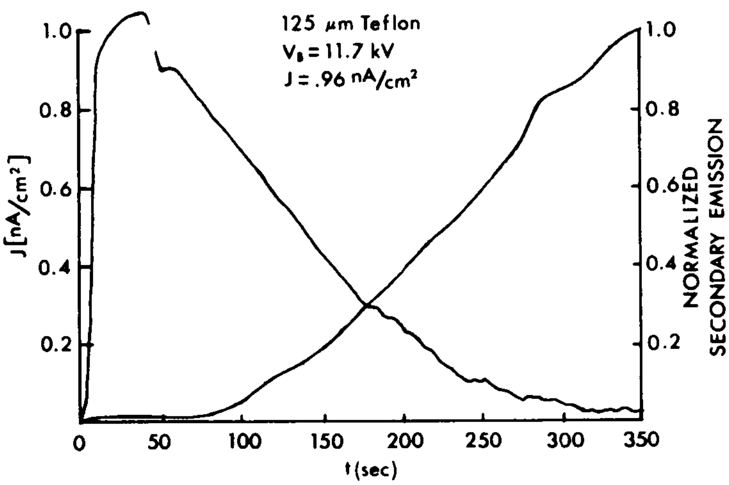

FIG. 3. CURRENT TO CENTRAL DISC AND SECONDARY ELECTRON EMISSION ON IRRADIATED TEFLON.

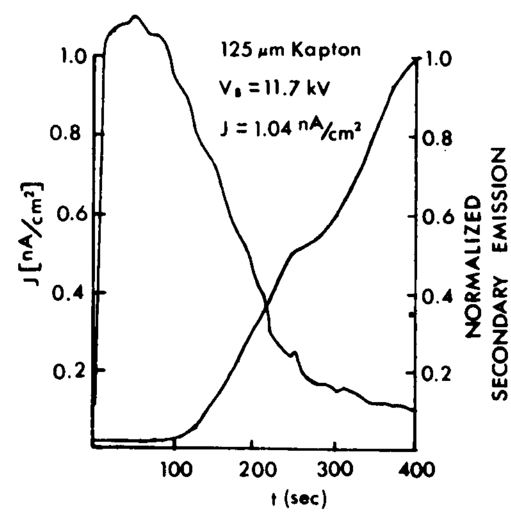

FIG. 4. CURRENT TO CENTRAL DISC AND SECONDARY ELECTRON EMISSION ON IRRADIATED KAPTON.

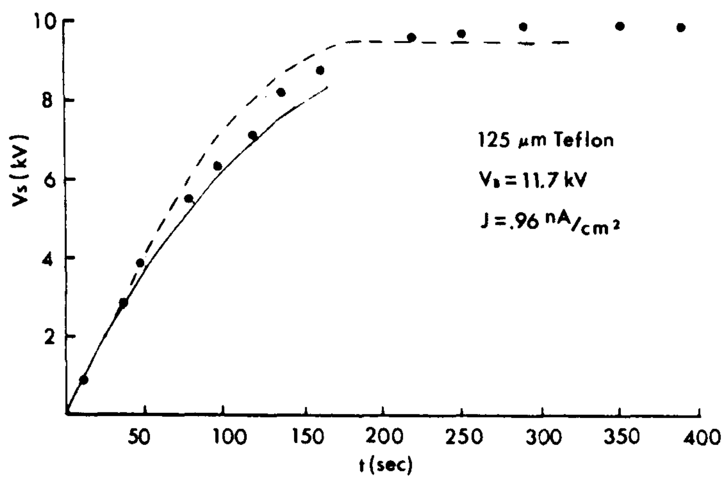

FIG. 5. SURFACE VOLTAGE ON IRRADIATED TEFLON WITH EXPERIMENTAL POINTS DENOTED BY DOTS, NUMERICAL MODEL CALCULATIONS BY DASHED CURVE, AND CAPACITOR MODEL CALCULATIONS BY SOLID CURVE.

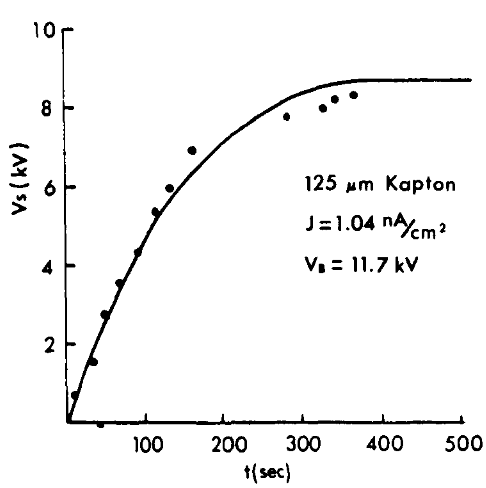

FIG. 6. SURFACE VOLTAGE ON IRRADIATED KAPTON WITH EXPERIMENTAL POINTS DENOTED BY DOTS AND CAPACITOR MODEL CALCULATIONS BY SOLID CURVE.