Contents

7. Conductivity Effects in High-Voltage Spacecraft Insulating Materials

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1. INTRODUCTION

A series of laboratory measurements has been performed to explore the effects of various external parameters on the conductivity properties of several typical and potential spacecraft insulating materials in a simulated space environment.

The materiale tested include Kapton, Tefloh. quarts. and polyvinylidene fluoride. The parameters varied in theee teste include sample thickness, temperature, applied vdltage. illumination intensity and wavelength. and electron beam energy and current dehsity. Tests were performed both with conventional optically transparent gold front-surface electrodes and with the front surfaces of the test samples exposed directly to an electron beam. All test) were conducted in a vacuum chamber at a pressure of approximately 10^{-6} torr.

During the course of this program,[1,2] a rather large number of tests were performed and many teste were repeated several times to verify unexpected results, It is not the Intent of this pager to present a detailed compilation Of the results of theee tests but to summarize some of the more interesting general properties of the materials tested.

Many of these propertiee should be of specific interest to thoee Involved in the modeling of spacecraft charging effects, in laboratory simulation testing of spacecraft materials, and in the design of future spacecraft.

2. SOME TEST RESULTS

The test setup shown schematically in Figure 1 was used to obtain the reeulte shown in Figures 2 through 11.

Test samples were prepared by sputtering 200Å thick gold center and guard electrades oh the front surfaces and somewhat thicker gold grbund electrodes on the back surfaces.

The area of the center electrode is approximately 7 cm^2. Although total Measured bulk currents are shown in the figures, the effective bulk resistivities (ρ_{bulk}) can be calculated, since

$$\rho_{bulk} = \frac{7(10^{-4})}{Id} \text{ (ohm-m)} \tag{1}$$

where V is the applied vbltage, I is the Measured current, and d is the sample thickness In meters.

Sample temperatures were cbntrolled by heating or cooling the large aluminum blbek on which the samples were mounted.

For some tests, a xenon light source was ueed to illuminate the samples through a quartz window in the vacuum chamber. Provisions were included far attenuating the light using neutral density filters and fbr selecting a particular portioh of the optical spectrum using a series of bandpasa filters.

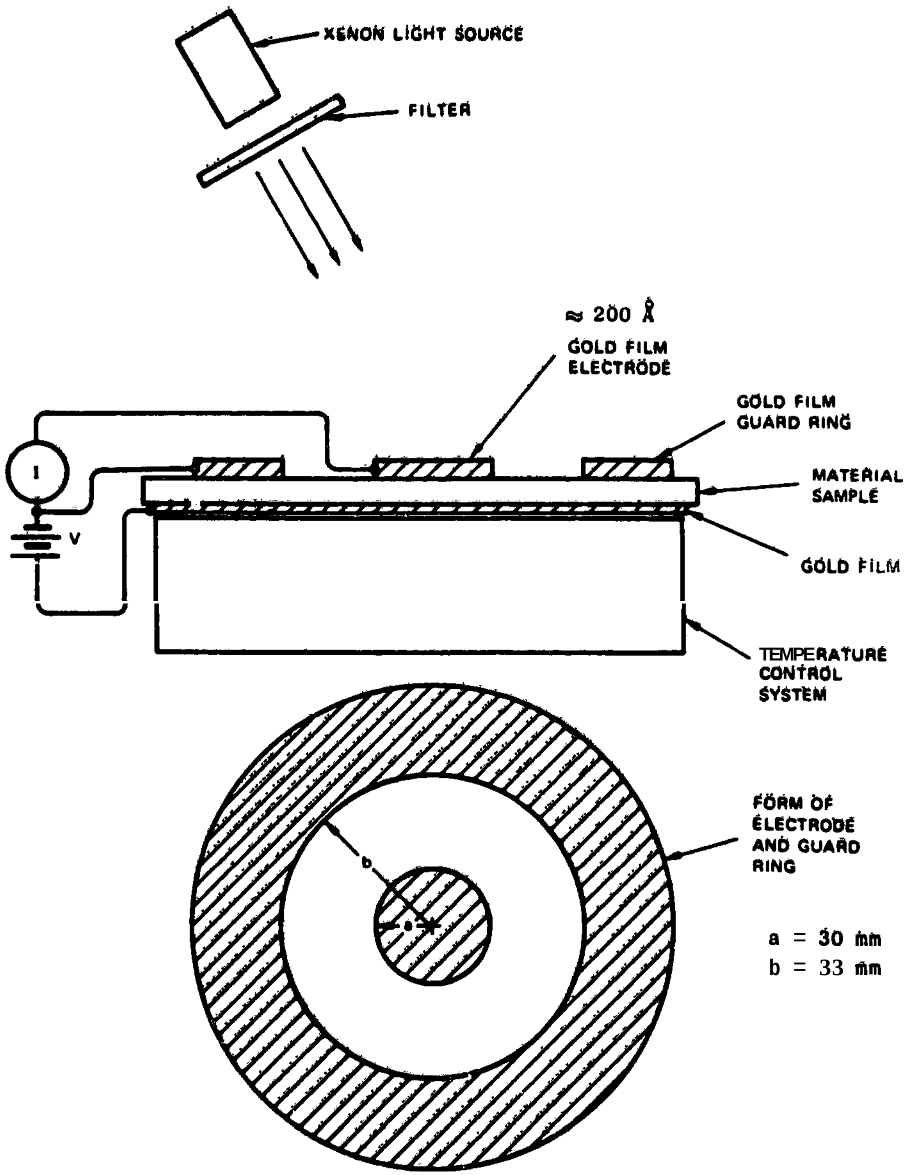

Figure 1. Setup for Front-Surface Electrode Tests

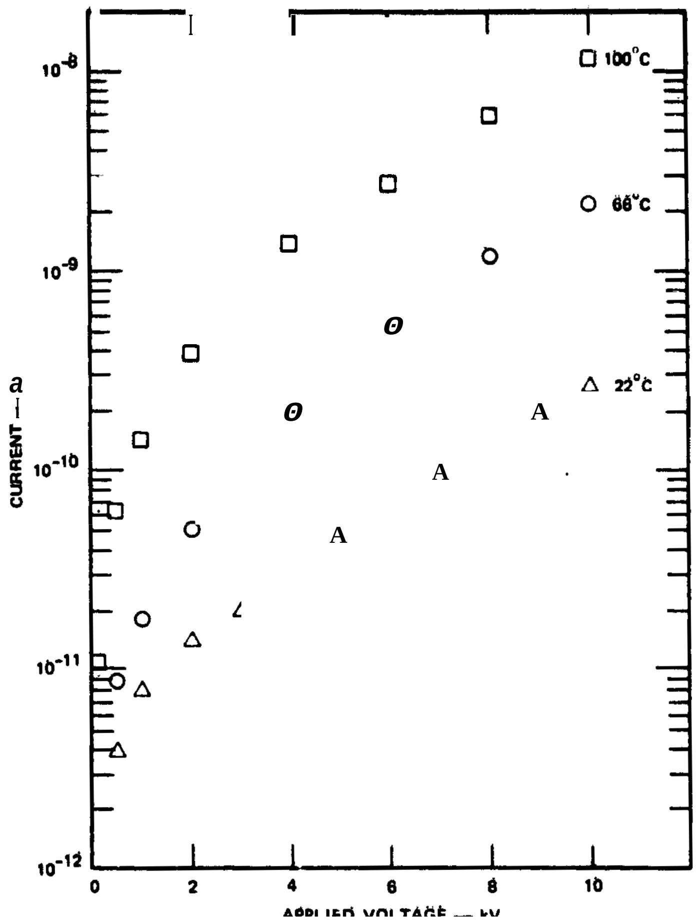

Figure 2. Dark-Bulk Current in Kapton V (5 mil) at Various Temperatures

Figure 2 shows an example of variations in conductivity with changes in sample temperature. The sample material in this case was Kapton V.

It should be noted that several types of Kapton are available. Kapton H (which was also tested) has been widely used in spacecraft thermal blankets. Kapton V is reported to have similar general properties but to allow less shrinkage at elevated temperatures.

It can be seen from Figure 2 that the dark bulk conductivity of Kapton V in- ------ --- iderably with increasing temperature.

The values of current shown in Figure 2 were each measured 1 min after the corresponding voltages were applied.

In these particular tests, the initial displacement currents appeared to have become negligible and the conduction currents were relatively stable after 60 sec-

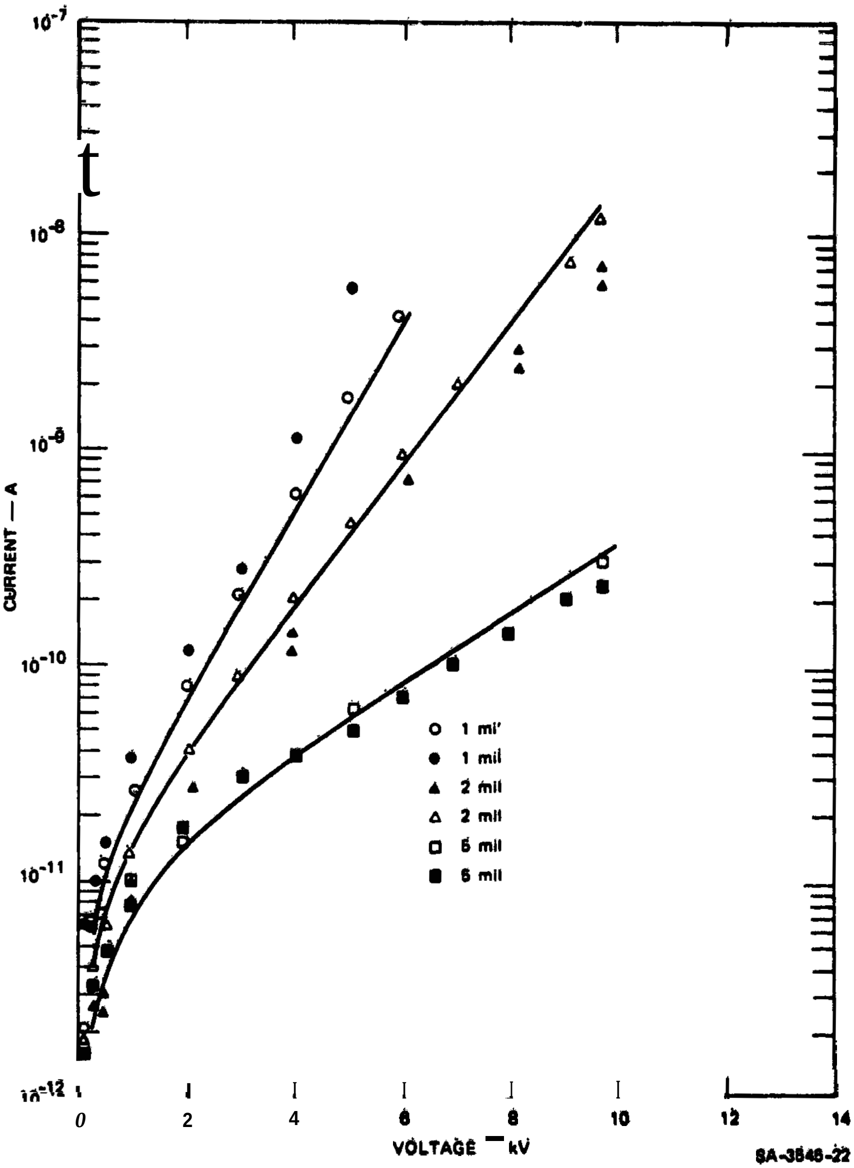

Figure 3. Bark-Bulk Current in Various **Thicknesses** of Kapton H at 22°C

onds. This wall Slat true in all tests, however, and in many cases, the measured currents in various materials under Certain conditions continued ti, change considerably for periods of several hours.

Figure 3 illuetratee the effect of material thickness an effective bulk conductivity of Kapton H. It can be seen, far example, that with ad applied voltage of 10 kV,. reducing the material thickness by a factor of 2, 5 produces an increase in current of two orders of magnitude. This corresponds to a 40X increase in effective bulk conductivity.

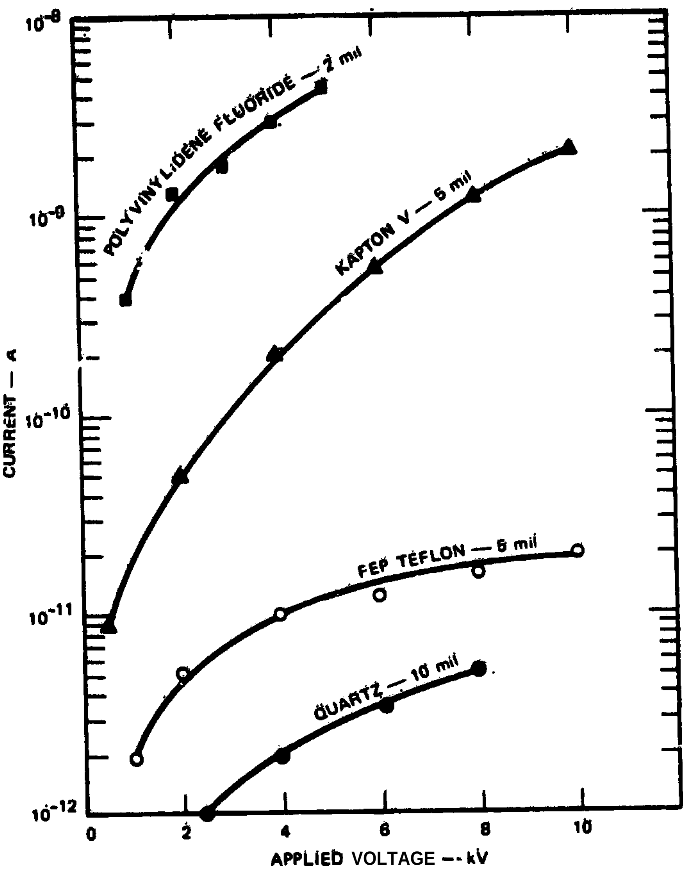

Figure 4. Dark-Bulk Currents in Various Materials at 66°C

Figure 4 show the dark bulk currents measured in various materials of different thicknesses. Due to the nonlinear effect illustrated in Figure 3, it is not possible to uee a simple linear correction to eliminate material thickness as a parameter in the Figure 4 data. In general, however, it har been obeerved that in the dark. FEP Teflon and quartz are better insulators than Kapton and polyvinylidene fluoride by appraximately two orders of magnitude.

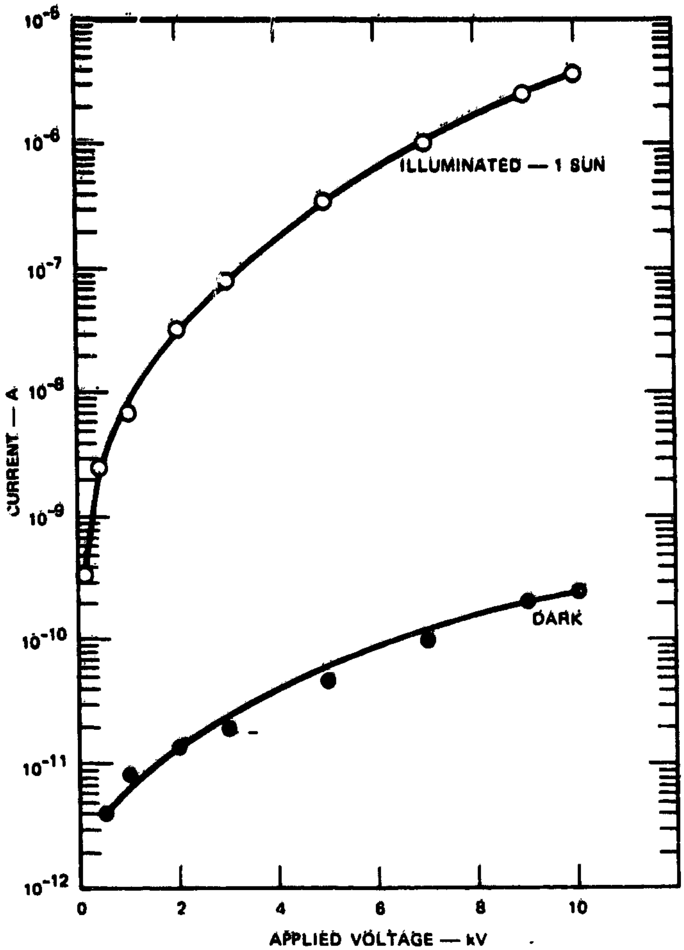

Figure 5. Bulk Current in Kapton V (5 mil) at 22°C

Figure 5 illustrates the ahart-term effect of illumination on the bulk conductivity of Kapton V. The xenon lamp, in this case, was used tb produce a power density of 1 solar constant. (≈ 1.4 kW/m^2) at the eample surface. With an applied voltage of 10 kV, the measured bulk Current with illumination is more than four orders of magnitude higher than the dark bulk current.

Similar but less pronounced effects were observed in FEP Teflbn and in quartz as shown in Figures 6 and 7.

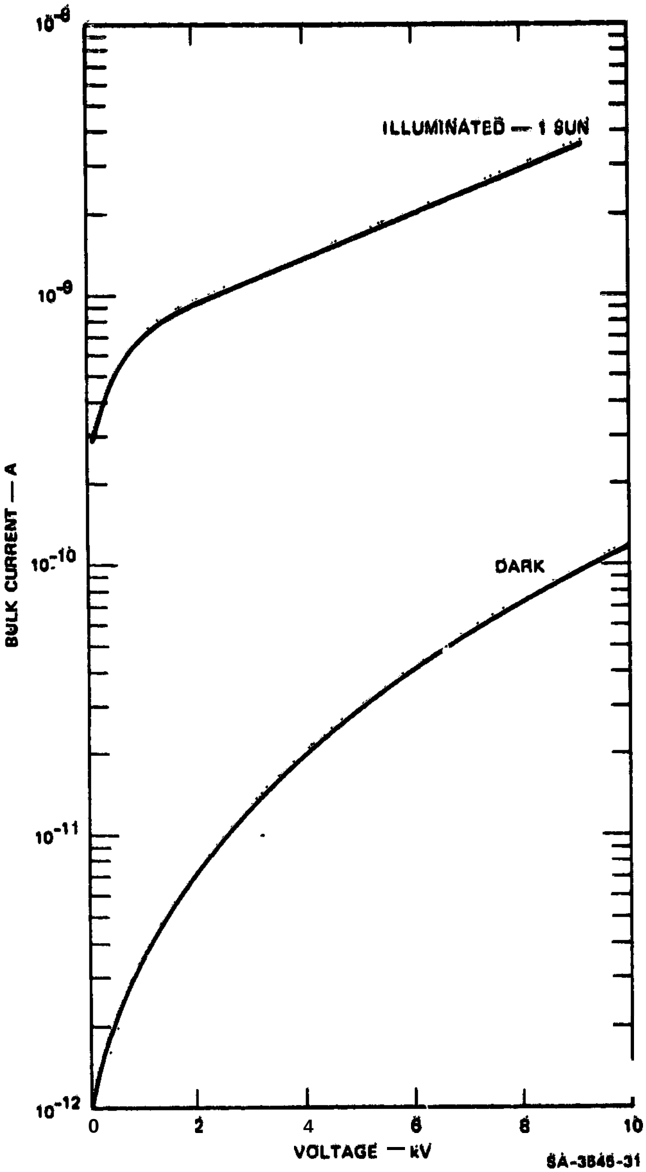

Figure 6. Bulk Current in FEP Teflon (5 mil) at 100°C

The data in Figure 6 were obtained at 100°C. The effect o 'umination was reduced at ldwer temperatures.. Even at 100°C, the relative increase in conductivity In FEP Teflon was twb or.'ers of magnitude less than that observed in Kapton V at 22°C.

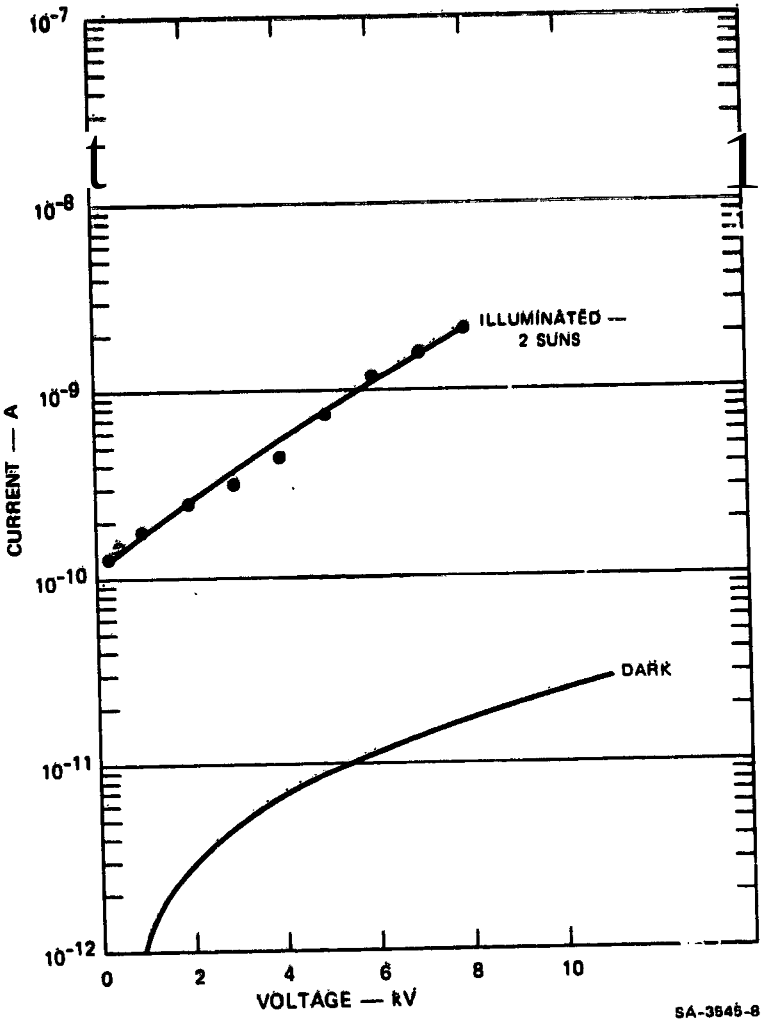

Figure 7. Bulk Current in Quartz (10 mil) at 100°C

The data in Figure 7 were obtained at 100°C with an incident energy density equivalent to two solar constants. It can be seen that the effect of illumination on the conductivity of quartz is also significantly lower than that observed in Kapton V.

The data in Figures 5, 6, and 7 were ail obtained within 5 niin of the time that the samples were initially exposed ta illumination.

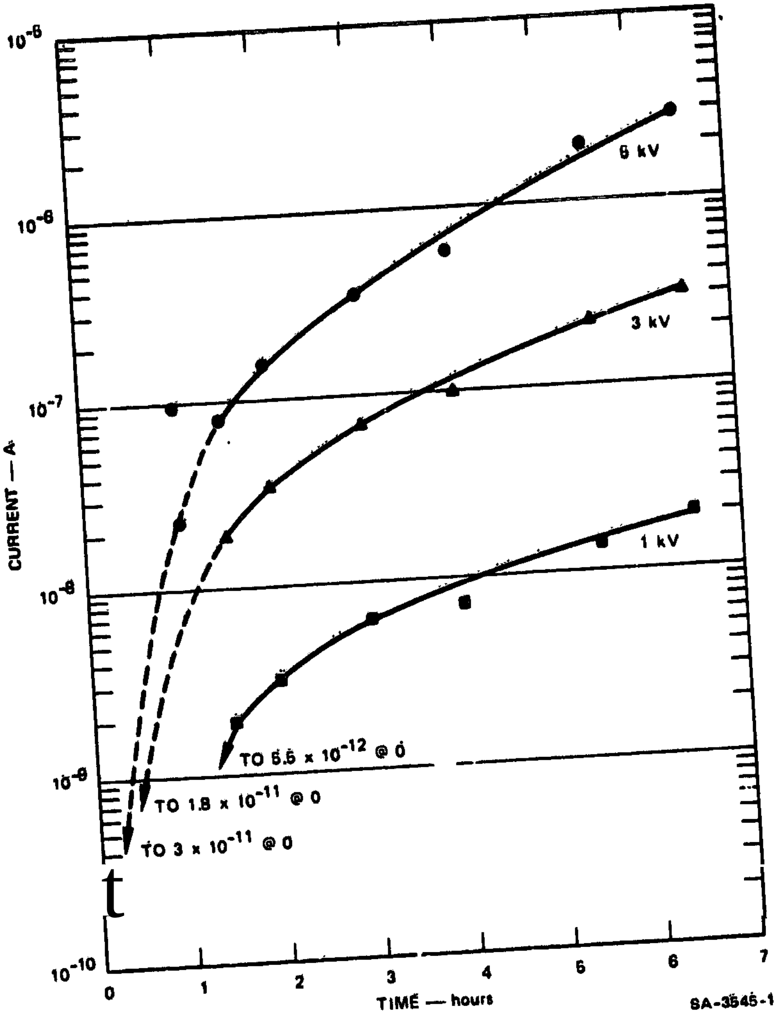

Figure 8. Dark-Bulk Current in Kapton H (5 mil) at 22°C Shortly After Various Periods of 1 Sun Illumination

An additional series of tests was performed in which Kapton H samples were illuminated for longer periods and the dark bulk currents were measured with various applied voltages within minutes after the lamp was turned off. The results of these tests are shown in Figure 8. It can be seen that the dark bulk current measured shortly after 6.5 hr of illumination is as much as five orders of magnitude higher than the dark bulk current before illumination.

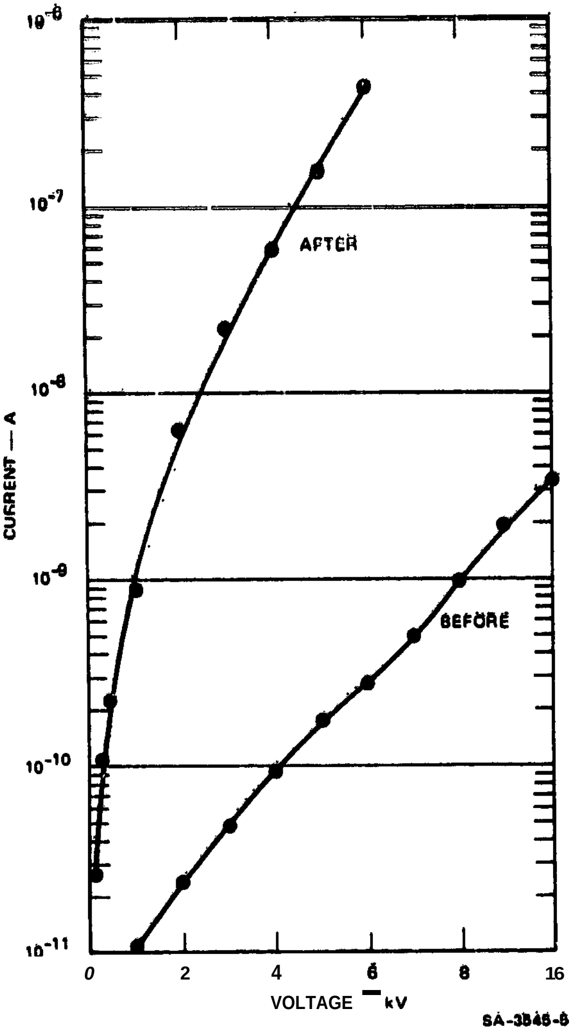

Figure 9. Dark-Bulk Current in Kapton H (5 mil) at 100°C Before add 85 Hours After 8.5 Hours of 1 Sun Illumination

Figure 9 illuetratee that the dark bulk conductivity after 8.6 hr of illuminatian remains three orders of magnitude higher even 85 hr after the lamp is turned off.

This long-term phenomenon may have an important effect on the charging properties of Kaptbn H materials on synchronous arbit satellites, particularly during eclipse periods.

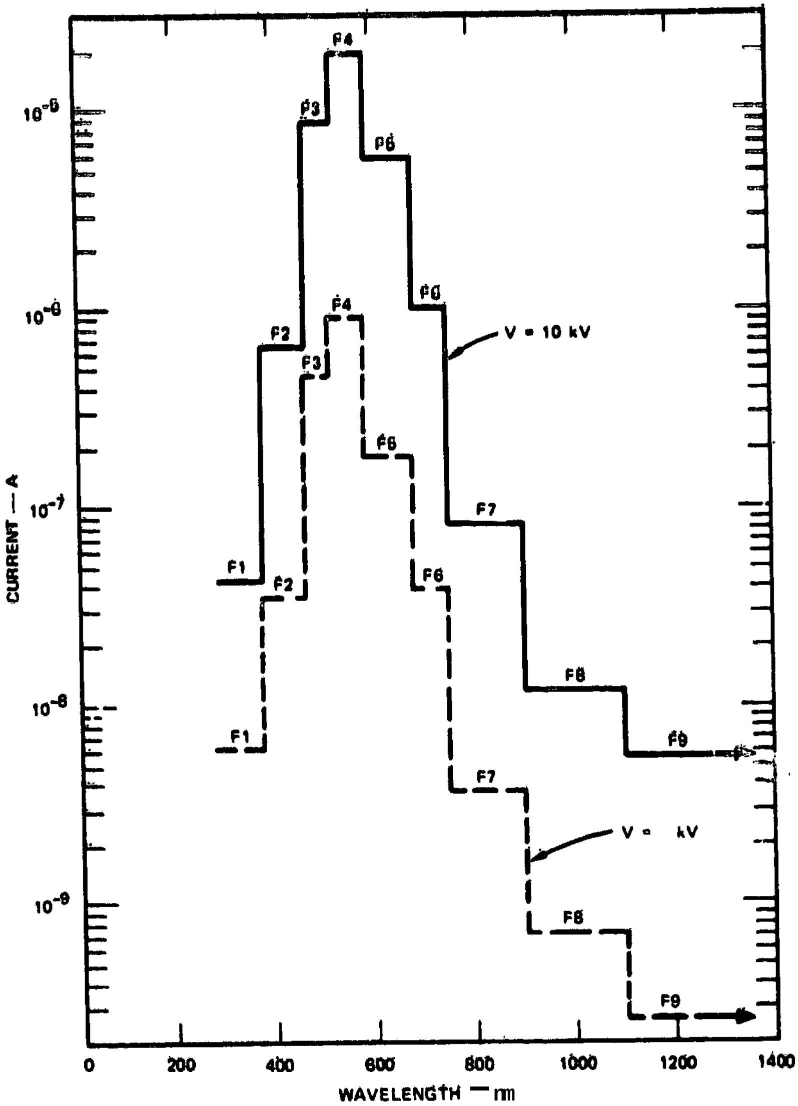

Figure 10. Normalized Bulk Photocurrents in kapton V (5 mil' at 22°C

In order to determine the optical wavelengths at which the conductivity of the sample materials id molt enhanced, tests Were performed with various bandpass filters inserted between the xenon lamp and the samples. Since the actual power density at the teet sample location varies with bandpass filter transmissioh properties and available lamp power within the passband, the raw results of theee teats have been normalized. The bulk currents shown in Figures 10 and 11 repreaent

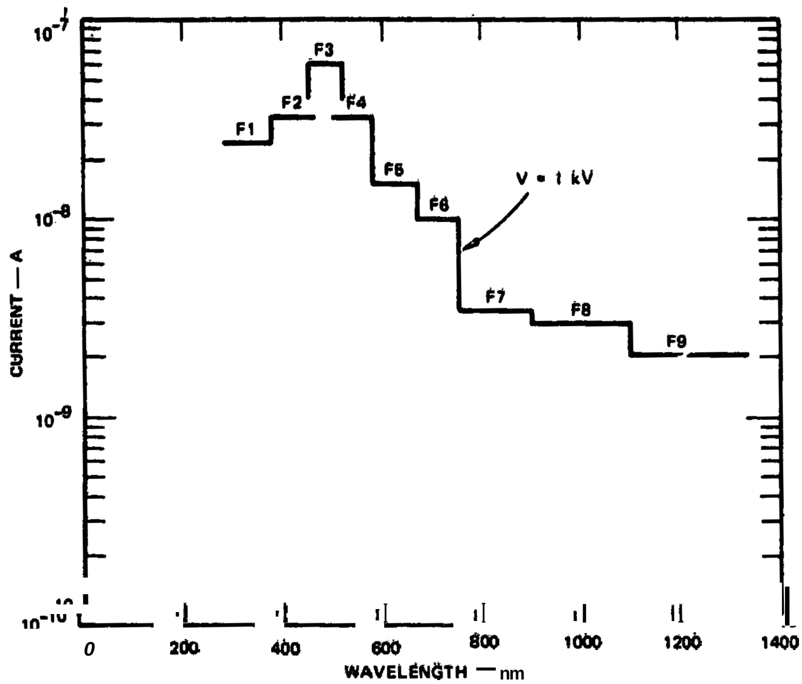

Figure 11. Normalized Bulk Photocurrent in Polyvinylidene Fluoride (2 mil) at 22°C

the measured currents normalized for an incident power density of 1.4 kW/m^2 concentrated within the filter passband.

It can be seen that the peak bulk normalized current occurs in the 500 to 580 nm passband for Kapton V and in the 450 to 524 nm passband for polyvinylidene fluoride. For both of these materials, these wavelengths correspond to regions of transition from high optical density to low optical density.

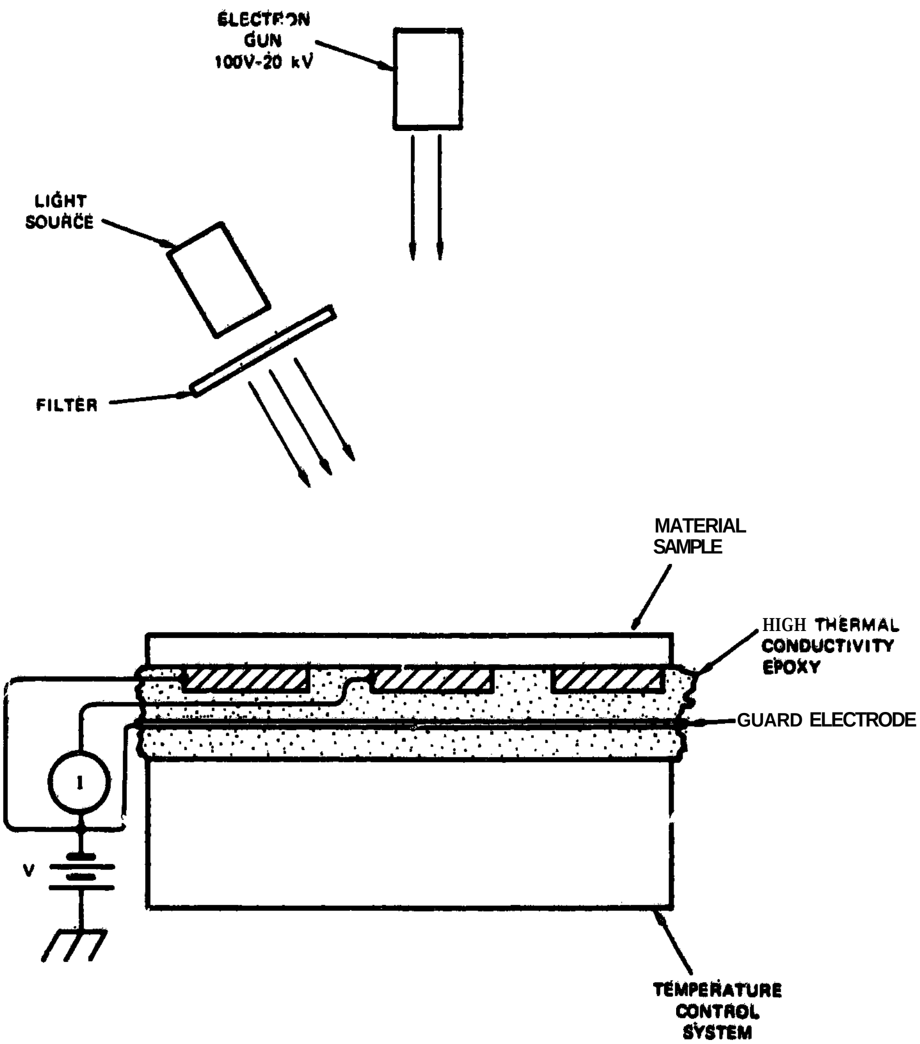

Figure 12. Setup for Electron-Beam Teste

The test configuration ueed for tests in which the front-surfaces of samples were exposed directly to an electron-beam is shown in Figure 12.

During the performance of electron-beam teste OR Kapton-V, it was found that with a constant incident electron-beam density, the magnitude of the bulk currant obtained at a specific electron-beam energy depends on the beani energies ueed for preceding test points.

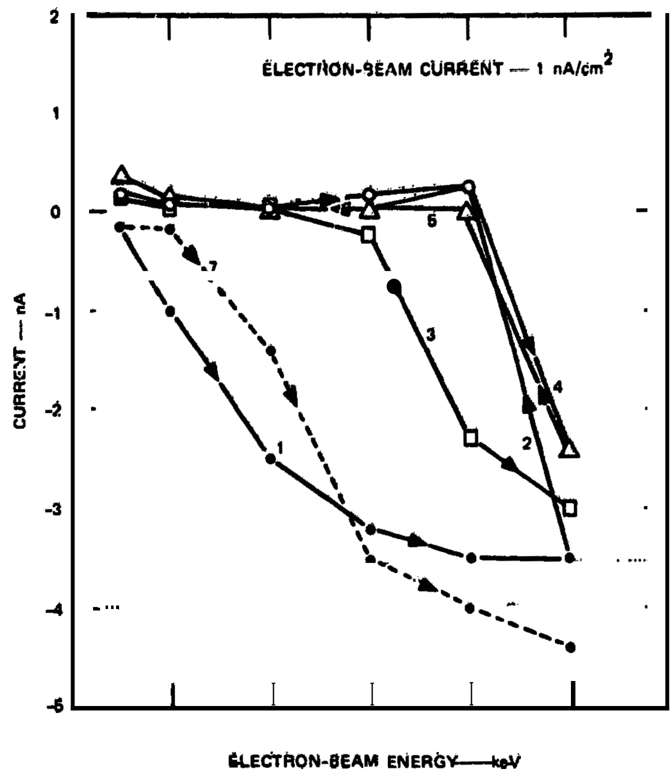

Figure 13. Dark-Bulk current vs Beam Energy in Kapton V (5 mil) at 22°C

An example of this "hysteresis" effect is shown in Figure 13. It should be noted that the left-hand current scale on this figure is not logarithmic but linear.

The initial measured currents obtained by stepping the incident electron-beam energy up from 1 keV to 10 keV, while maintaining the incident beam current constant at 1 nA/cm^2, are connected by the line labeled 1. Each of these currents was measured after the incident beam had remained at the indicated energy for 60 seconds.

The line labeled 2 shows the currents obtained as the beam energy was stepped down from 10 keV. It can be seen that curves 1 and 2 are quite different. Additional tests indicate that after stepping through the entire energy range several times in the dark, the results become similar in either direction (as shown in curves 4 and 5) and the "hysteresis" effect is no longer evident.

However, after the completion of Test 5, the electron-beam was turned off for 60 sec while the sample was exposed to 1 sun of illumination. The lamp was then turned off and the dark electron-beam test was repeated yielding the results shown by curve 7.

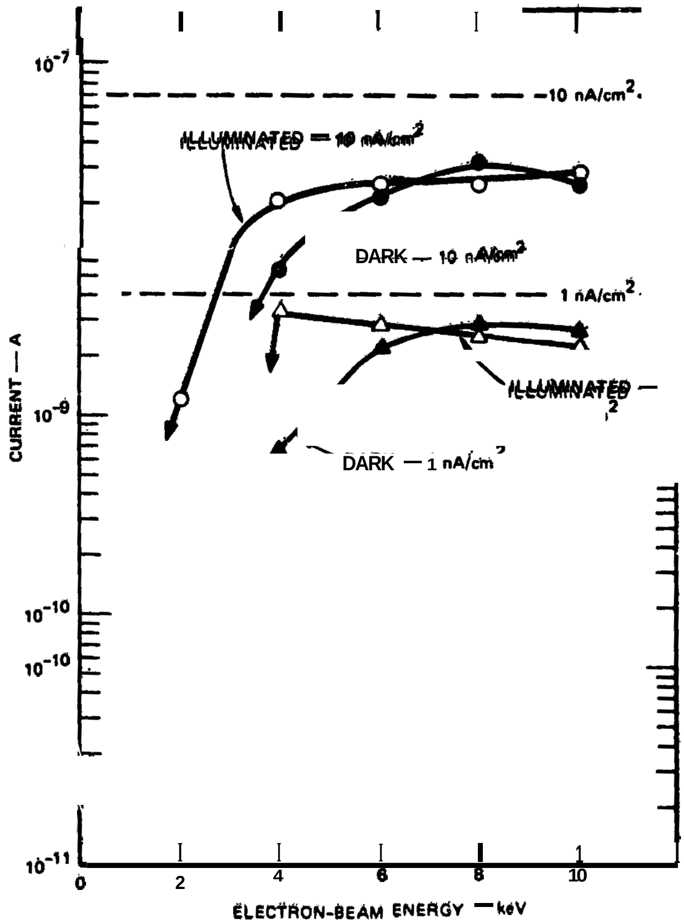

Figure 14. Bulk Currents in Polyvinylidene Fluoride (2 mil) et 22°C

The results of this and bther testa indicate that short periods of illumination tend to "erase" the sample and return it to near its original state.

The results shown in Figure 13 Were obtained with Kaptbn V. Similar effects were observed using polyvinylidene fluoride samplee.

In additional tests it was found that thie hysteresis effec: does not occur if the samples are illuminated throughout the test sequence.

Preliminary results of both dark and illuminated electron-beam tests on polyvinylidene fluoride and Kapton / are shown in Figures 14 and 15.

Figure 14 indicates that for polyvinylidene fluoride. et incident beani energies above approximately 6 keV, the bulk current is limited by the available incident beam current density. This is true both with and without illumination.

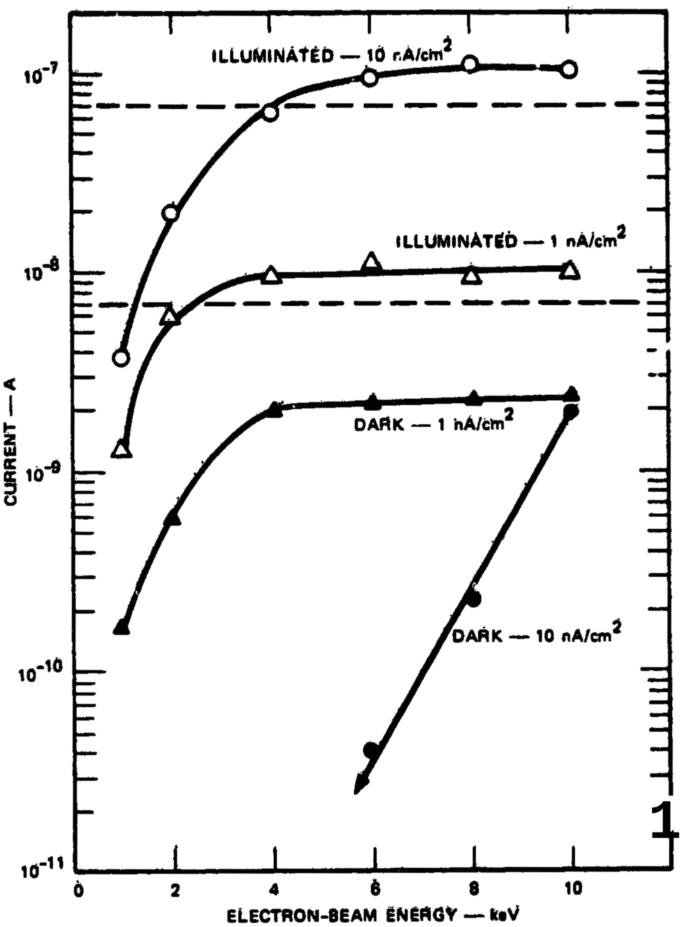

Figure 15. Bulk Currents in Kapton V (5 mil) at 22°C

With Kapton V, however, the bulk Current increases significantly under illumination as is Bhown in Figure 15.

The reasons for reduced dark bulk currents with increased incident current dehsity. particularly at lower beam energies obs...ed in Kaptan V, have not yet been explored.

3. CONCLUSIONS

The data preeented illustrate some of the complexities in electrical characteristics exhibited by typical spacecraft materiale as a result of interactions with various conditione of their environment.

Increased concern with spacecraft charging phenomena and their effects has recently resulted in increased efforts td provide more complete models of the spare environment and its interaction with spacecraft. There is, however, at present, a critical lack of theoretical and experimental information on material properties for use in these efforts as well as in the design of future spacecraft and in the development of new epacecraft materials.

In particular, efforts should be made to provide a better understanding of both the short-term and long-term effects of the space environment on material properties ahd of the effecte of material properties on spatecraft charging phenomena.

References

1. Coffey. H.T., Nanevicz, J.E. , and Adamo, R.C. (1975) Photoconductivity of High-Voltage Space Insulating Materials, Project 3545, Final Report, Contract NAS3-18912, Stanford Research Institute.
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