AEROSPACE REPORT NO.
TOR-0081(6506-01)-1

First Results of Material Charging in the Space Environment

Prepared by P. F. MIZERA, H. C. KOONS,
E. R. SCHNAUSS, and D. R. CROLEY, Jr.
Space Sciences Laboratory

H. K. KAN and M. S. LEUNG
Chemistry and Physics Laboratory
Laboratory Operations
The Aerospace Corporation

N. J. STEVENS, F. BERKOPEC, and J. STASKUS
NASA Lewis Research Center
Cleveland, Ohio 44135

W. L. LEHN
Air Force Materials Laboratory
Wright-Patterson Air Force Base, Ohio 45433
and
J. E. NANEWICZ
SRI International
Menlo Park, Calif. 94025

15 March 1981

Interim Report

Prepared for

SPACE DIVISION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
P.O. Box 92960, Worldway Postal Center
Los Angeles, Calif. 90009

Contract No. F04701-80-C-0081

Development Group
THE AEROSPACE CORPORATION

Aerospace Report No.
TOR-0081(6506-01)-1

FIRST RESULTS OF MATERIAL CHARGING IN THE SPACE ENVIRONMENT

Prepared by

P. F. Mizera, H. C. Koons,
E. R. Schnauss, and D. R. Croley, Jr.
Space Sciences Laboratory

H. K. Kan and M. S. Leung
Chemistry and Physics Laboratory
Laboratory Operations
The Aerospace Corporation

N. J. Stevens, F. Berkopec, and J. Staskus
NASA Lewis Research Center
Cleveland, Ohio 44135

W. L. Lehn
Air Force Materials Laboratory
Wright-Patterson Air Force Base, Ohio 45433

J. E. Nanewicz
SRI International
Menlo Park, Calif. 94025

15 March 1981

Development Group
THE AEROSPACE CORPORATION
El Segundo, Calif. 90245

Prepared for

SPACE DIVISION
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
P.O. Box 92960, World Way Postal Center
Los Angeles, Calif. 90009

Contract No. F04701-80-C-0081

ORIGINAL PAGE IS
OF POOR QUALITY

Report No.
TOR-0081(6506-01)-1

FIRST RESULTS OF MATERIAL CHARGING IN THE SPACE ENVIRONMENT

Prepared

P. F. Mizera
Space Sciences Laboratory

H. C. Koons
Space Sciences Laboratory

E. R. Schnauss
Space Sciences Laboratory

D. R. Croley, Jr.
Space Sciences Laboratory

H. K. Kan
Chemistry and Physics Laboratory

M. S. Leung
Chemistry and Physics Laboratory

N. J. Stevens
NASA Lewis Research Center

F. Berkopec
NASA Lewis Research Center

J. Staskus
NASA Lewis Research Center

W. L. Lehn
Air Force Materials

J. E. Nanevicz
SRI International

Approved

G. A. Paulikas, Director
Space Sciences Laboratory

J. R. Stevens, Principal Director
Space Test Directorate

The information in a Technical Operating Report is prepared for a particular program and is therefore not necessarily of broader technical applicability.

ABSTRACT

A satellite experiment, designed to measure potential charging of typical thermal-control materials at near geosynchronous altitude, was flown as part of the Spacecraft Charging at High Altitudes (SCATHA) program. Direct observations of charging of typical satellite materials in a natural charging event (> 5 keV) are presented. The results show some features which differ significantly from previous laboratory simulations of the environment.

ACKNOWLEDGMENTS

The early planning of this mission involved the efforts of many people too numerous to mention here. The launch support and subsequent data acquisitions were superbly handled by the Satellite Control Facility.

CONTENTS

ABSTRACT.. iii

ACKNOWLEDGMENTS... iv

I. INTRODUCTION... 1

II. INSTRUMENTATION... 3

III. RESULTS.. 5

IV. DISCUSSION 11

REFERENCES.. 13

PRECEDING PAGE BLANK NOT FILMED

FIGURES

1. Charging potentials of spacecraft materials during the natural charging event on April 24, 1979 at ≈ geosynchronous altitudes near local midnight................. 6

2. Measurements of Kapton, optical solar reflectors and gold plated magnesium taken during the same period as Figure 1 showing the rotation in and out of the satellite shadow.. 8

I. INTRODUCTION

Laboratory simulations of physical processes are an integral part of space experiments and research. However, the question arises as to how the simulation results compare to the results obtained outside of the controlled laboratory environment. Sometimes models can bridge the gap and provide some measure of the validity of the laboratory method. Electrical charging of typical spacecraft materials in the near geosynchronous environment is one such phenomenon for which considerable efforts of laboratory simulations and modeling techniques are becoming evident.

During geomagnetic substorms, a satellite at high altitudes can become immersed in a hot, tenuous plasma. Average energies of electrons can reach 5 to 10 keV and ions, factors of 2 to 3 higher. The magnitude of the charging (i.e., potential attained) that results is a function of the current balance from primary charged particle sources and secondary sources including solar induced photoelectrons. Usually, the photoelectrons are of sufficient intensity to offset significant charging due to the environmental electrons in the keV energy region and therefore most reported cases of spacecraft charging occur in the eclipse of the earth. However since most spacecraft are constructed from both conductors and a variety of insulators, differential charging can occur even in the presence of solar UV.

Most of the statistical results of spacecraft charging were derived from measurements observed on the Applications Technology Satellites (ATS 5 and 6).[1)2)] Their results indicate a rather significant probability of spacecraft charging events. It ranges between 15% to 20% for 1000 to 8000 V charging potentials as inferred from spectrum shifts in the charged particle environment.

Although laboratory simulations of material charging play an important role, extrapolation from the ground based programs to space applications involves many simplifying approximations. Consequently, in order to understand how to properly predict spacecraft charging in the high altitude regions of the earth's magnetosphere, a joint NASA-Air Force program termed SCATHA (Spacecraft Charging At The High Altitudes) was implemented in 1975 with the major source of space data to be furnished by the USAF Space Test Program (STP) 78-2 satellite.[3] Part of the experiment payload on P78-2 was the Satellite Surface Potential Monitor (SSPM) designed to measure currents and potentials of 'typical' spacecraft materials. A brief instrument description follows this section while a complete description of the SSPM payload can be found in a USAF Space and Missile System Organization SAMSO report.[3]

For the first time, measurements of spacecraft material charging in a geomagnetic substorm event are presented. These results contain a number of interesting and unexpected features when compared with measurements from laboratory studies using typical charged particle beams to simulate the environment.

II. INSTRUMENTATION

The SSPM was one of the engineering experiments aboard the USAF P78-2 satellite launched into near synchronous orbit 30 January 1979. Each of three SSPM instruments contained four electrostatic field-meters designed to measure the potentials from material surfaces mounted at fixed positions above the sensors. The electric field between a surface and the sensor is modulated by a pair of tines vibrating at 700 Hz. The resultant AC signal is amplified and demodulated to provide both the amplitude and the polarity of the field. Positive and negative currents flowing through the sample materials are collected on the metalization backing and sent to an electrometer circuit. All measurements are digitized, accumulated, and read out every second. The current and voltage data are accumulated for 1.0 sec and 0.25 sec, respectively.

These insulating materials are typically 5 mils thick with aluminum backing the Kapton, silver backing the Teflon and in the case of the quartz fabric mounted on Teflon, a hole was cut through the entire Teflon backing so that the electric field from the fabric would reach the sensor. The collecting area for the current was determined by the size of the sample. For the currents shown in Figure 2, the area of collection is approximately 160 cm^2. Two sizes of samples were flown on the SSPM payload. With the exception of Kapton, all samples were approximately 13 cm square. In addition to the standard smaller samples, one Kapton sample of approximately 29 cm square (SSPM-2) was flown to examine the scaling effects of charging.

In order to make voltage measurements in space, a back surface technique was used by removing a small area of metalization from the back surface of spacecraft thermal-control materials (typical satellite blankets have the dielectric exposed to the environment and a thin layer of metal on the back surface). An etched hole in the back metalization, of approximately 0.6 cm, was located directly over the electrostatic sensor to measure the electric field from the dielectric material. To a first approximation, the difference between a front surface charging profile and the SSPM back surface charging profile would be due to the different charging time constants. The charging time for the front surface of these insulators is of the order of minutes, while that of the back surface is the order of tens of seconds.

The SCATHA satellite is cylindrical in shape. On orbit it rotates along its symmetry axis. The SSPM-1 and SSPM-2 instruments are mounted with the surface normal perpendicular to the satellite spin axis. The SSPM-2 instrument is approximately 180° from the SSPM-1. The SSPM-3 instrument is mounted with the surface normal along the spin axis. During normal operating conditions, the SSPM-1 and SSPM-2 instruments rotate in and out of the sun every 30 sec while the SSPM-3 remains in the spacecraft shadow. A reference band made from conductive gold plated aluminum encircles the entire lower portion of the spacecraft so 50% is always illuminated and provides a potential referenced to that produced by solar UV secondary emission during charging events when shadowed conductors can also change potential.

III. RESULTS

Results from a natural charging event near local midnight on 24 April 1979 are shown in Figure 1. Composite voltage-time profiles from aluminized Kapton samples mounted on all three SSPM instruments are plotted versus Universal Time (UT). Kapton (-1)[4] and Kapton (-2) represent voltage profiles entering and exiting the sun approximately 180° out of phase with each other due to the physical location of the instruments. Kapton (-3) measurements are made in the shadow of the spacecraft. Teflon (-3) and quartz (-3) are two other insulating samples flown on the shadowed SSPM-3.

Charging profiles in Figure 1 for Kapton (-1) and (-2) represent only the potential over the electrostatic sensor located beneath the center of each sample. Since this time interval represents only three minutes, front surface equilibrium conditions are not yet achieved. In fact, laboratory calibrations between front and back surface potentials during monoenergetic electron bombardment indicates that equilibrium is not reached over the entire front surface for the order of tens of minutes. In the space environment where the electron distributions extend over a wide energy range, a continuous charging and discharging is occurring due to the production of secondary electrons with yields greater than one caused by incident electrons with energies just above the surface potentials. The same effect has been observed in the laboratory by slowly reducing the energy of the incident beam, thereby discharging the front surface voltage by secondary emission.

Figure 1 shows that the potentials on Teflon and quartz fabric are significantly higher than those of Kapton. Since initial turn on of the SSPM experiments in February, 1979, the Teflon sample has acquired a large negative

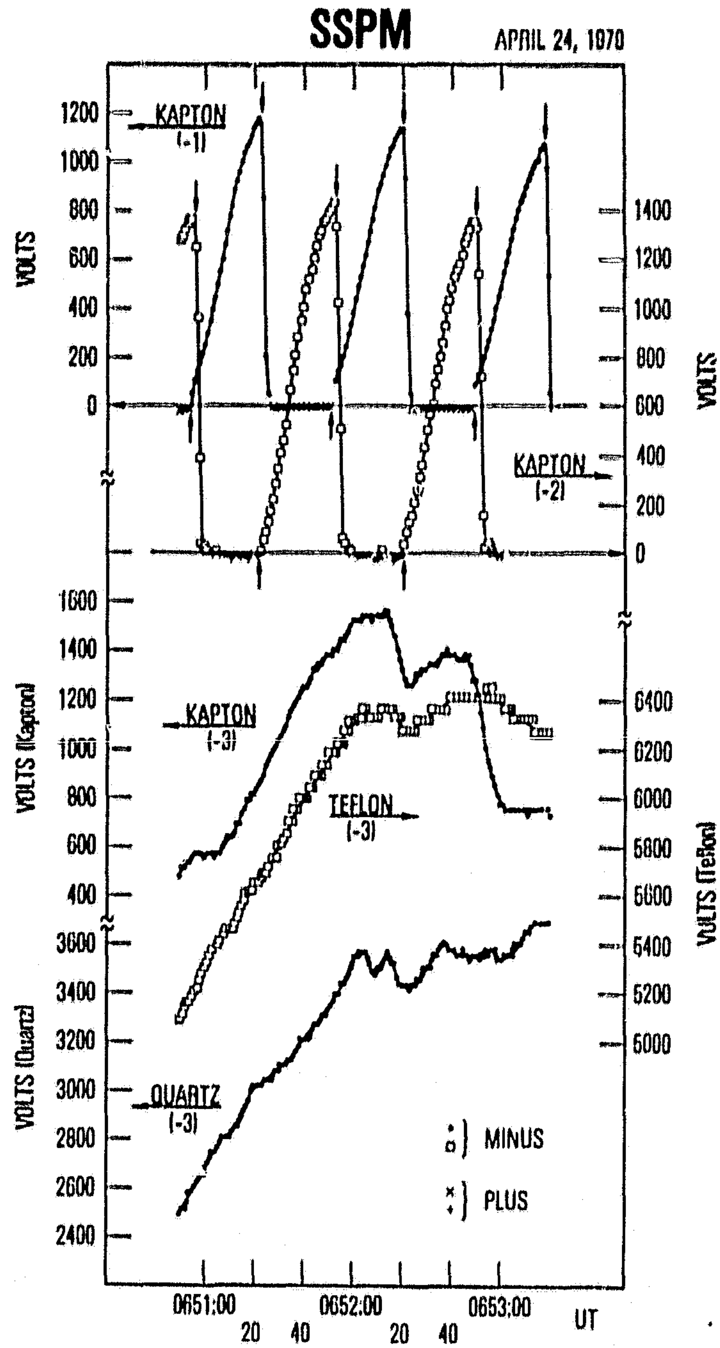

Fig. 1. Charging potentials of spacecraft materials during the natural charging event on April 24, 1979 at ≈ geosynchronous altitudes near local midnight. The top two curves are negative voltages produced when the sample enters the shadow of the satellite indicated by ↑. The ↓ symbols indicate entering the sun. The three bottom curves are for dielectric samples totally in shadow. Voltage-offsets of a −2000 and −200 should be subtracted from Teflon and quartz to determine the true charging from low energy electrons.

signal which varies from hundreds of volts to a few kilovolts. The quartz sample also has an offset of the order of 10% of the Teflon value. We believe this offset is the result of energetic electrons penetrating into the bulk of the Teflon, which in the absence of solar UV, have very limited mobility. The offsets prior to this charging event were - 2000 V and - 200 V for the Teflon and the quartz fabric on Teflon backing respectively.

Perhaps one of the most interesting observations is the high voltage level (~ 3.5 kV) that quartz fabric reaches during this charging event. From the results of previous ground simulation studies, this sample was not expected to charge significantly above a few hundred volts in the natural environment.[5)] Recent laboratory electron-beam charging experiments indicate that quartz fabric exhibits an unusual charging/discharging behavior. At high beam densities (~ 1nA/cm^2), the sample charges up rapidly but also discharges rapidly. At lower beam densities (~ 10pA/cm^2), quartz fabric can be charged to a few kilovolts for a long period of time when bombarded with 6 to 12 keV electrons. These energetic primary electrons in time will also cause the sample to discharge. Preliminary analyses of laboratory data indicate that quartz fabric is charging initially like a capacitor, i.e., the charging time constant is independent of incident electron energy but highly dependent on primary beam current. At the discharging stage, higher incident currents and lower electron energies tend to discharge the sample more rapidly.

Sample voltages and currents from the SSPM-1 are shown in Figure 2 plotted on a logarithmic scale. Kapton (-1) voltages were shown previously in Figure 1. In addition to the voltages from a gold plated conductor and optical solar reflecting (OSR) mirrors, bulk currents are also shown for each of these three samples. At the top of Figure 2, the SSPM-1 solar aspect angle is plotted to show when the angle between the instrument normal and the satel-

ORIGINAL PAGE IS
OF POOR QUALITY

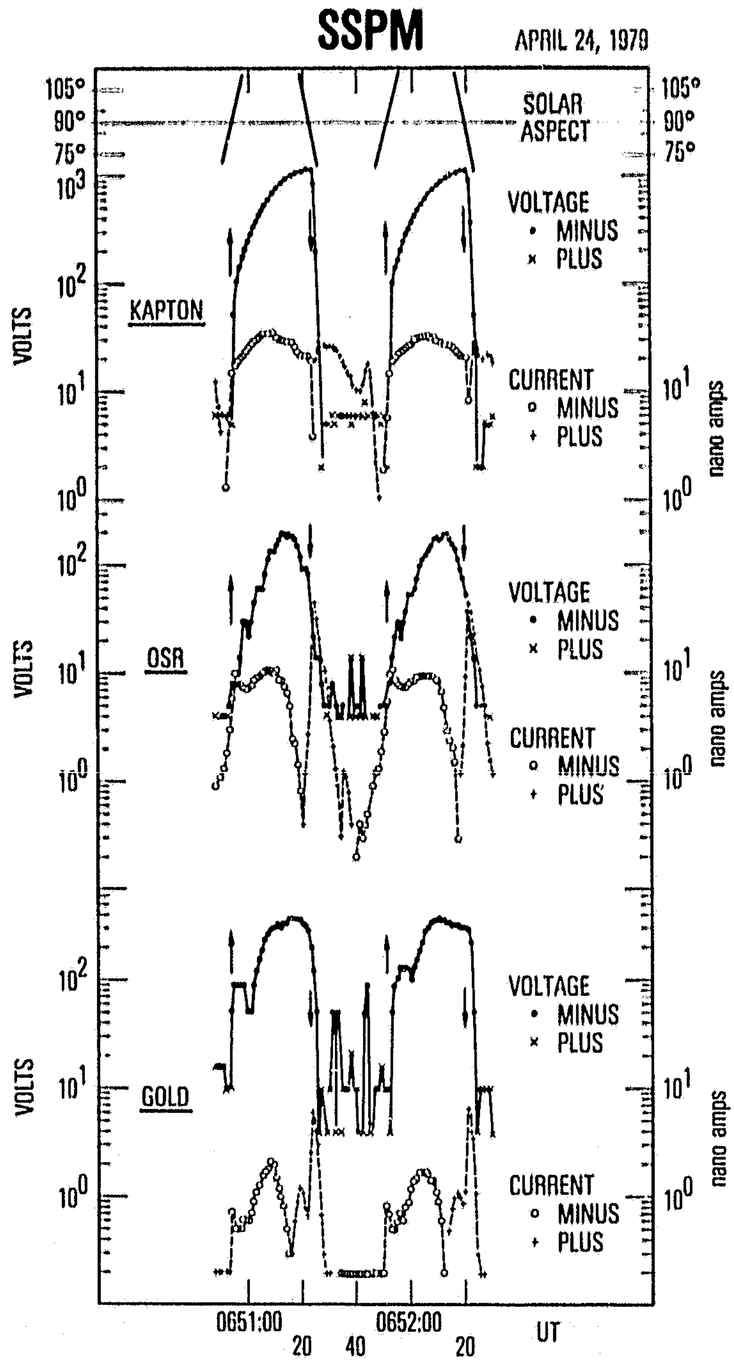

Fig. 2 Measurements of Kapton, optical solar reflectors and gold plated magnesium taken during the same time period as Figure 1 showing the rotation in and out of the satellite shadow. At the top is the angle between the satellite sun line and the normal to the samples. Arrows indicate at which time the angle crosses 90°. In addition to the logarithm of the charging voltage, the logarithm of the charging current is also shown.

lite-sun line approaches 90° from sunlight and shadow. The arrows are positioned at these times for a convenient reference. To a first approximation, the current is the time derivative of the charging voltage if the front surface and back metalization of the samples can be thought of as simple capacitor plates. Only the gold plate is electrically isolated from the current collecting surface and truly acts like a capacitor in vacuum. The charging currents of the Kapton and OSR samples in Figure 2 show a more complicated current-voltage dependence for the following reasons. The charging time constant of the total front surface is larger than that required to charge the unmetalized hole at the center of the insulating samples. Therefore the maximum current is really proportional to the maximum time derivative of the <u>total</u> surface charging potential. Only when the potential at the center of each sample and the total surface potential change with time in a similar fashion will the current profile agree with the time derivative of the voltage plotted in Figures 1 and 2. This condition occurs only when the samples enter sunlight where the solar UV flux is intense enough to obscure the effects of differing time constants. It is interesting to note that the Kapton sample continues to measure positive current even when the potential drops to zero which probably is a measure of the photoelectron current emitted from the surface.

IV. DISCUSSION

The first natural charging event analysis from USAF satellite P78-2 using the SSPM experiment has shown a number of very interesting results. Without a detailed analysis of the particle environment at this time and equilibrium conditions to occur, a complete description of this charging event cannot be made. Nevertheless, the relative charging values of different typical spacecraft materials can be evaluated for this single event. Of the insulators on the SSPM-3 instrument, Kapton shows the lowest charging potential (~ 1600V). Quartz fabric charges to at least 70% of the potential of Teflon which charges to at least -4400V. Whether or not these ratios vary much from event to event will require more analysis.

In addition to the interest of modeling a multi-material object in a substorm plasma, spacecraft designers and engineers should be interested in these preliminary results since the quartz fabric was primarily developed as a spa·· stable thermal control material and to reduce discharge effects.[5] Its secondary emission and conductivity properties were thought to effectively reduce differential charging from electron bombardment at geosynchronous altitudes.[6] Previous laboratory results have shown that quartz fabric only charges to low values (< 200 V) when bombarded with monoenergetic electron beams up to ~ 10 keV. Our laboratory results suggest that the induced discharge mechanism, responsible for maintaining the surface of the material at low potentials, involves the formation of a positive charge layer in the fabric. This region is formed as a function of time by the emission of secondary electrons from the fabric which acts as a porous material with a large surface to volume ratio.

REFERENCES

1) S. E. DeForest, Spacecraft Charging at Synchronous Orbit, J. Geophys. Res. 77, 651, 1972.

2) H. B. Garrett and S. E. DeForest, Time-Varying Photoelectron Flux Effects on Spacecraft Potential at Geosynchronous Orbit, J. Geophys. Res. 84, 2083, 1979.

3) Description of the Space Test Program P78-2 Spacecraft and Payloads, SAMSO TR-78-24 Ed. J. R. Stevens and A. L. Vampola, The Aerospace Corp., 1978.

4) This notation signifies the instrument on which the sample is located. For example Kapton (-1) means the Kapton sample on the SSPM-1 instrument.

5) V. J. Belanger and A. E. Eagles, Secondary Emission Conductivity of High Purity Silica Fabric, Proceedings of the Spacecraft Charging Technology Conference, NASA TMX-73537, AFGL-TR-77-0051, 655, 1977.

6) W. L. Lehn, Conductive Spacecraft Materials Development Program, Proceedings of the Spacecraft Charging Technology Conference, NASA TMX-73537, AFGL-TR-77-0051, 559, 1977.