CHARGING AND DISCHARGING CHARACTERISTICS OF A RIGID SOLAR ARRAY

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SUMMARY

Two rigid solar array panels were subjected to a simulated geosynchronous orbit substorm environment. During the charging sequence, distributions of accumulated surface charge were measured under eclipse and sunlit conditions. Discharge events were characterized with respect to voltage pulse signatures and amplitudes on the solar array bus leads.

Post-exposure analysis of the solar array panels indicated that the electrical characteristics were not degraded in spite of the substantial discharge activity. However, significant cratering and discoloration of the Tedlar dielectric were observed.

INTRODUCTION

Performance characteristics of rigid solar array panels during geomagnetically quiet periods are well documented. However, during substorm conditions, the complex arrangement of dielectric and conductive elements make adequate modeling of the effects of charging and discharging processes on array functional properties very difficult.

Concerns have been raised that solar arrays may suffer degradation as a result of plasma interactions and that anomalies may develop in the spacecraft bus load. Details of the plasma interactions with the materials of construction and how that phenomenology influences solar cell electrical output are not well understood. Under orbital conditions, the surface materials which are directly exposed to the environment include the dielectric panel substrate, cover glasses and anodized aluminum panel rear face. In addition, there are the exposed conductive elements of aluminum honeycomb panel as well as positive and negative terminals and cell interconnects.

This paper describes the low-energy (20 kV) electron irradiation tests which were used as a representative simulated geosynchronous substorm environment for rigid solar array panels and presents the results and analysis of those investigations.

TEST CONFIGURATIONS

The simulation tests were conducted in the Lockheed Advanced Systems Division's Space Environmental and Research Chamber (SEARCH) located in Palo Alto, California. The vacuum chamber is cylindrical with a diameter and length of 2.4 m (8 ft) and 4.6 m (15 ft),* and is equipped with a liquid nitrogen shroud. The large chamber dimensions, relative to the test panels, minimize the interactions between the irradiated specimens and the chamber walls. A schematic representation of the test configuration is presented in figure 1. Figure 2 shows the sample mounting and electron gun arrangement on the chamber door prior to test. During test, the chamber pressure was maintained below 1.3 mPa (10^{-5} torr).

The solar cell panels consisted of eighty-eight 2 cm x 4 cm solar cells connected in series and mounted on a 2.5 x 10^{-3} cm (10^{-3} in.) thick white pigmented Tedlar substrate supported by an aluminum honeycomb structure. A resistive load and blocking diode network was provided as a simulation of a spacecraft power bus line (figures 3 and 4).

The electron flux was provided by a Kimball Physics electron flood gun operated at 20 keV. This system provided a nominally uniform circular beam pattern with a diameter of 45 cm (18 in.) at the sample plane. Beam uniformity was determined using a scanning Faraday cup and stationary calibrated Faraday buttons at a series of current densities and electron energies. During the simulation tests, the electron flux was maintained at 10 nA/cm^2 with 20 kV electrons.

Solar simulation was accomplished with a collimated water-cooled 2 kW mercury-arc lamp mounted externally, the beam being introduced to the chamber through a fused silica window. For this system, 36 percent of the radiant energy lies in the 200 to 400 nm region so that adequate UV radiation for photoemission was available. The total UV intensity was approximately equivalent to one sun. In addition, a 150 W tungsten lamp was used to provide illumination in the solar cell active spectral region so that changes in panel current-voltage characteristics could be monitored *in situ*.

Solar panel surface potentials were measured by means of a Trek Model 340 HV non-contacting voltmeter probe mounted to an x-y translating table controlled by stepping motors. Coordinates were mapped prior to test in order to index locations and locate limit switches for null adjustment. Locations were repeatable to ±0.01 cm. A ground plate was also provided as a voltage probe zero reference.

Discharge voltage pulses across the solar array were recorded by means of a Tektronics 7834 storage oscilloscope and a Micro Instruments 5201B memory voltmeter. The voltage pulses were transmitted through high voltage 100 pF blocking capacitors, as shown schematically in figure 5.

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*For the principal measurements and calculations, the International System of units (SI) was actually used.

TEST PROCEDURE

The test environments and event sequencing are depicted in figure 6. Additional tests were also conducted which simulated eclipse conditions exclusively. Duplicate panels were subjected to the entire testing sequence.

RESULTS AND DISCUSSION

Surface Charging Activity

The non-contacting voltmeter indicated significant activity took place on the surface of the solar cells and on the exposed Tedlar dielectric. Solar cell panel surface potentials fluctuated throughout the electron impingement tests during both sunlit and eclipse conditions. In addition, differences in surface potential activity was indiscernible between sunlit and eclipse conditions.

Surface potentials sometimes were greater than 18 kV for short periods before discharging. However, the potentials usually remained between 6 kV and 15 kV. Fluctuations in potential usually consisted of rapid changes as a result of continuous low level discharges (less than 100 V). However, the frequency of major surface flashovers took place on the order of one per minute which resulted in surface potential changes greater than 15 kV.

Flashovers were detected by observations through the chamber view port during eclipse conditions. Time-exposure photographs also recorded discharge activity.

Bus Voltage Activity

Bus voltage pulses were recorded by photographing the pulse signatures on the oscilloscope screen which were retraced by the oscilloscope memory. Voltage pulses were as great as 1.9 kV across the simulated spacecraft bus load. Typically the pulses had a 10 ns rise time with a duration of 1 ms. The memory volt-meter detected a considerable number of voltage spikes of magnitudes less than 100 V. All voltage pulses were positive. There was not convincing evidence that any negative pulses occurred. A typical pulse is shown in figure 7.

Panel Material Changes

Discharges from the white pigmented Tedlar film resulted in significant cratering and penetration to the aluminum substrate, as shown in figure 8. Additionally, there appeared to be discharges of opposite direction manifesting themselves as microscopic raised areas with subsurface conical voids terminating at the surface. Areas with significant discharge activity through the Tedlar showed carbonized conductive paths to the substrate. Examination of the Tedlar showed that the discharges caused melting of the aluminum substrate at the base of the craters. However, the solar cells remained electrically isolated from the honeycomb panel support. Removal of some cells after testing revealed no evidence of discharges under the cells.

Exposure to the electron environment led to a significant darkening of the white Tedlar. In areas of greatest discharge activity, the solar absorptance increased to greater than 0.49 from an initial value of 0.24. Infrared emittance remained unchanged at 0.86.

No evidence of physical or optical property changes was obtained upon examination of the individual solar cells or interconnects.

Panel Electrical Output

Comparison of pre-test and post-test electrical characteristics (current-voltage curves) indicated that no significant changes resulted from the simulation tests, despite the extensive charging and discharging activity. During exposure to the simulated substorm environment with illumination, no changes in solar panel electrical output were observed.

CONCLUDING REMARKS

Exposure of rigid solar array panels to simulated geosynchronous substorm conditions resulted in no apparent change in their photovoltaic characteristics. However, significant discharge activity into the power bus was observed. Electical discharges on the Tedlar insulation led to multiple breakdowns with creation of conductive paths to the honeycomb substrate support. From the limited exposure period it is not possible to conclusively determine the probability that cell shorting could result from long-term discharge activity.

In conjunction with the creation of multiple craters in the Tedlar dielectric, the large change in solar absorptance has serious implications. The increased solar absorptance will result in an increase in solar array operating temperature with concomittant reduction in electrical power output.

The high voltage spikes associated with the observed discharges may be propagated into the solar array power conditioning system of a spacecraft via the array buses. These transients may be difficult to filter because of their high energy, high voltage and short duration. In addition, the radiated energy from these pulses can result in significant electromagnetic interference with communications, command and control and logic operations.

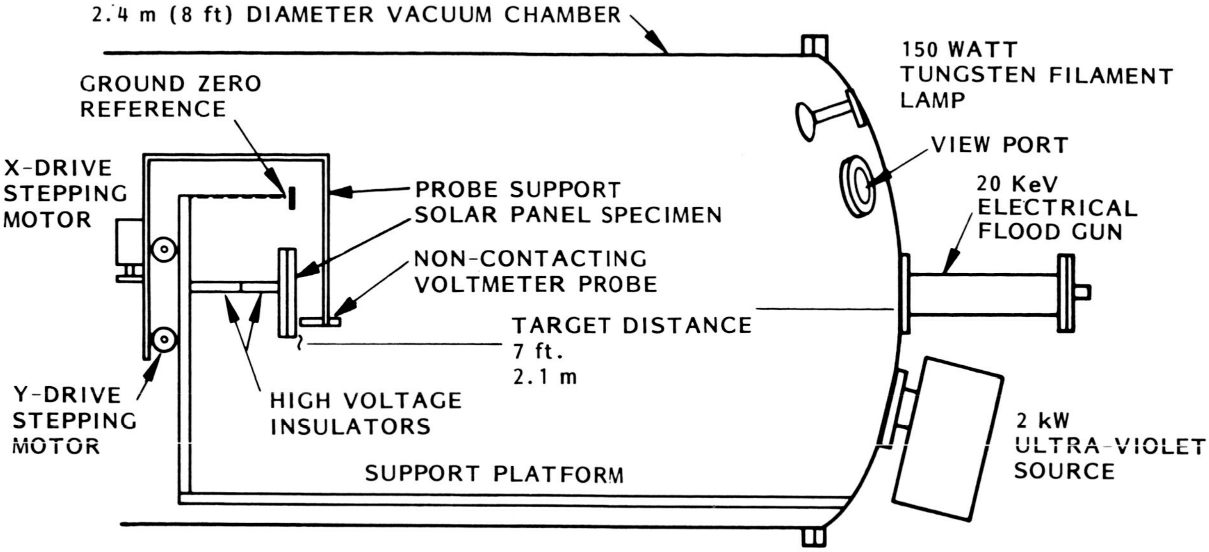


Figure 1 - Schematic Representation of Simulation Facility

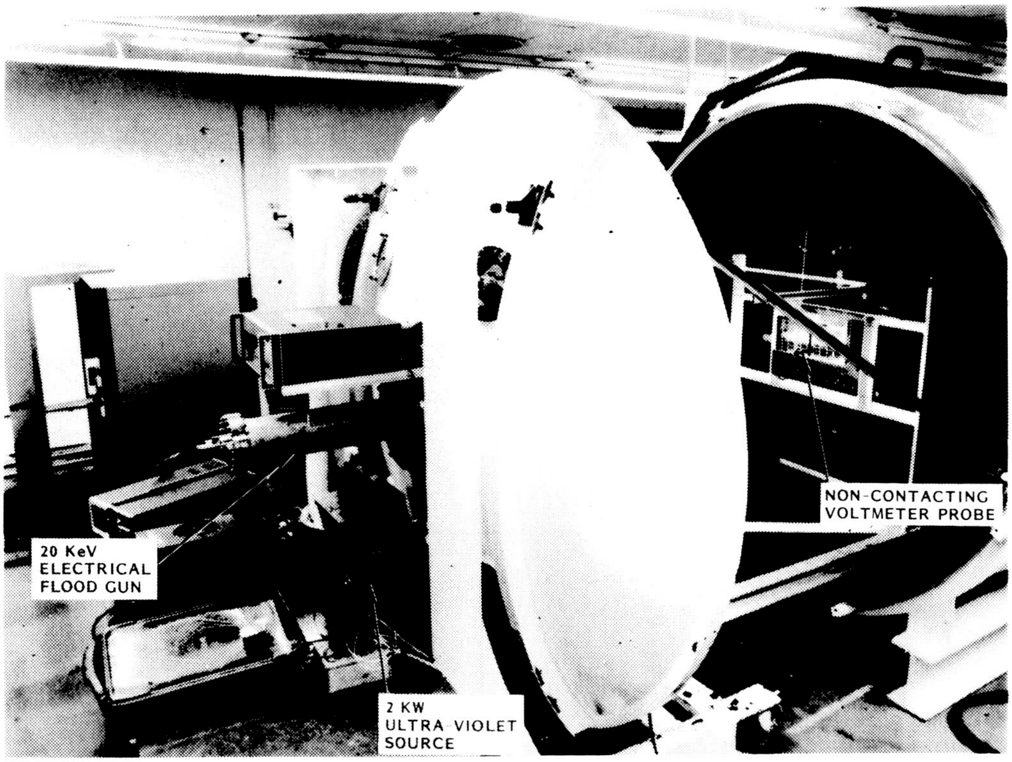


Figure 2 - Solar Panel Mounting and Irradiation Configuration

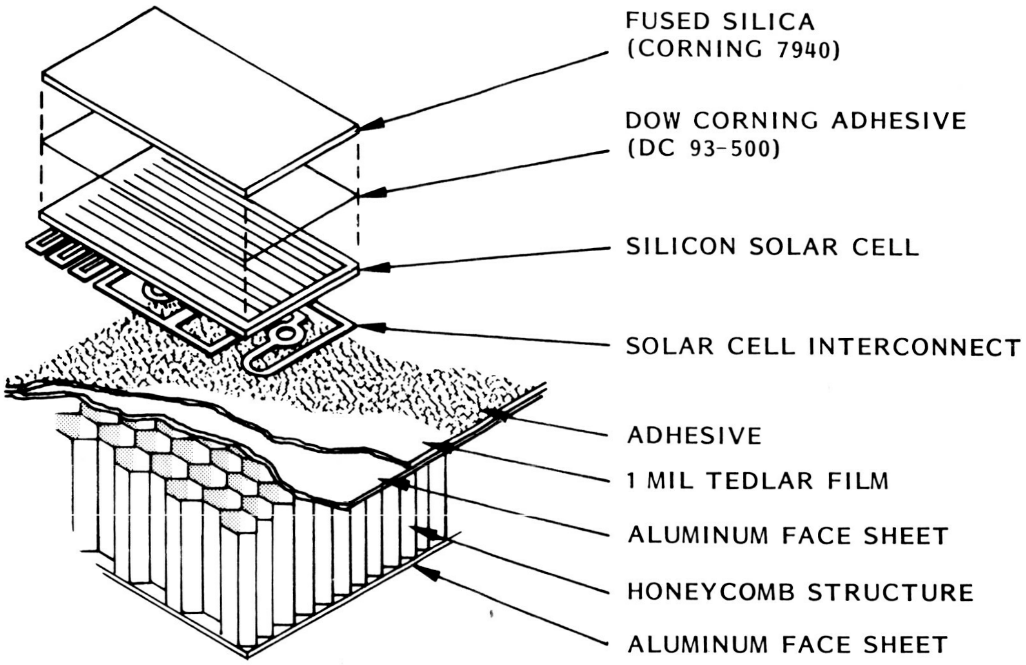


Figure 3 - Solar Cell Panel Construction

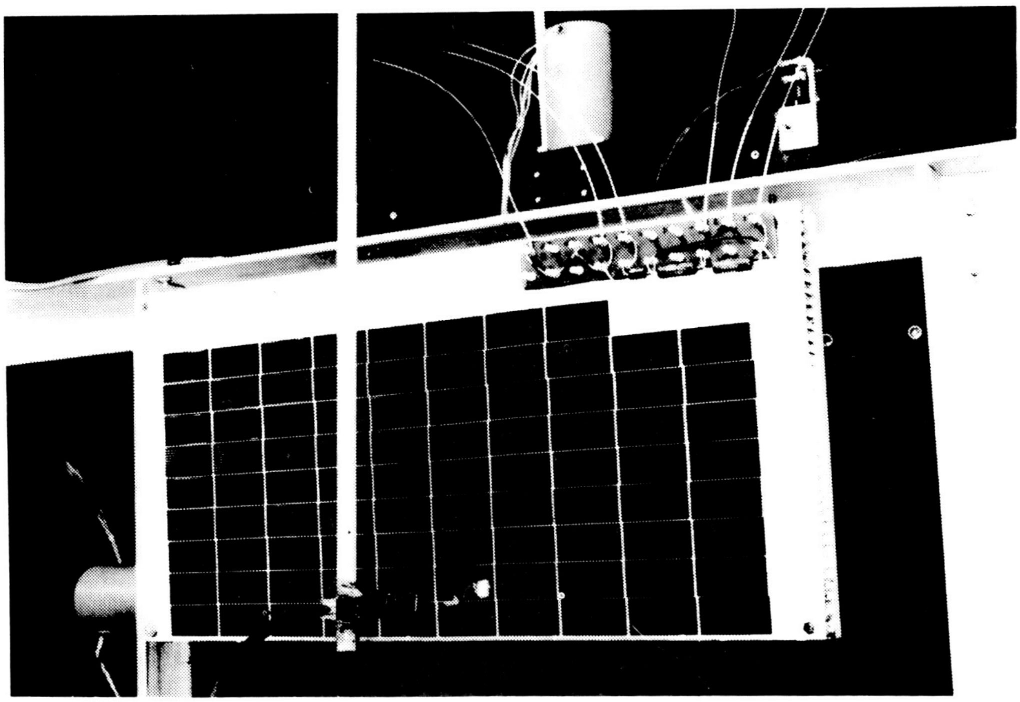


Figure 4 - Solar Panel

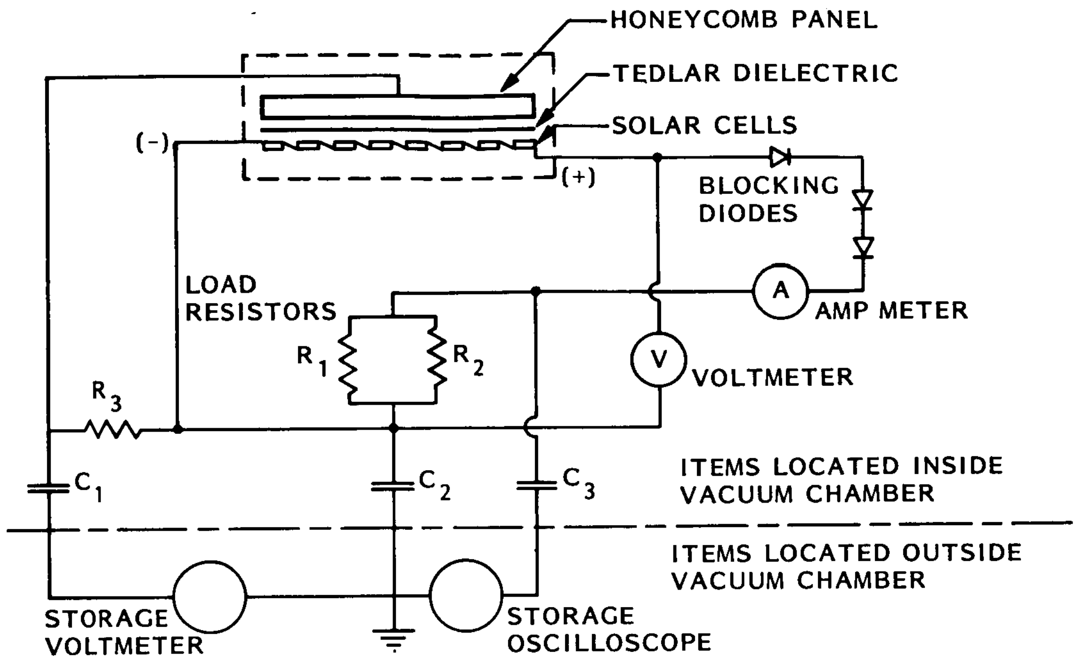


Figure 5 - Electrical Test Network

I. VACUUM CHAMBER: SET FOR VACUUM CONDITIONS OF LESS THAN $1 \times 10.^{-5}$ TORR

II. ECLIPSE DURING ELECTRON IMPINGEMENT ACTIVITY
   - A. SUN ON AT t_0=0. MINUTES
     SUN REMAINS ON UNTIL t_{60}
   - B. ELECTRON GUN ON AT t_5
     ELECTRON GUN REMAINS ON UNTIL t_{180}
   - C. SUN OFF AT t_{60}
     SUN REMAINS OFF UNTIL t_{120}
     TIME EXPOSURE PHOTOGRAPHS TAKEN AT THIS TIME
   - D. SUN ON AT t_{120}
     SUN REMAINS ON UNTIL t_{210}
   - E. ELECTRON GUN OFF AT t_{180}
   - F. SUN OFF AT t_{210}

III. ELECTRON GUN CAPABILITY: 20 K VOLTS 10 NANOAMPS/cm^2

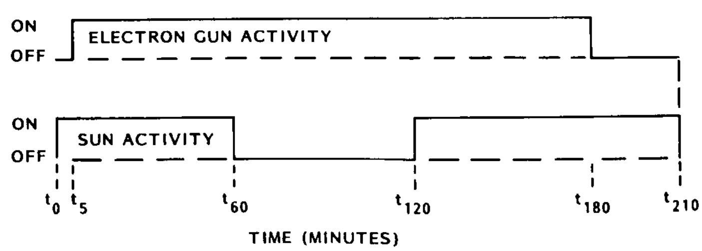


Figure 6 - Simulated Environment Test Sequence

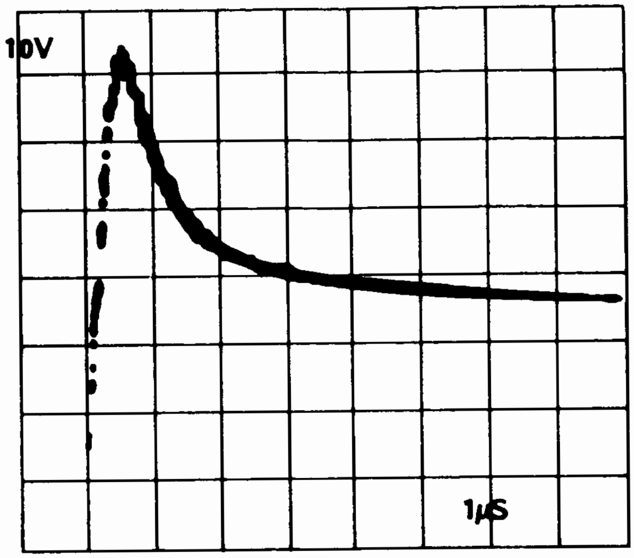
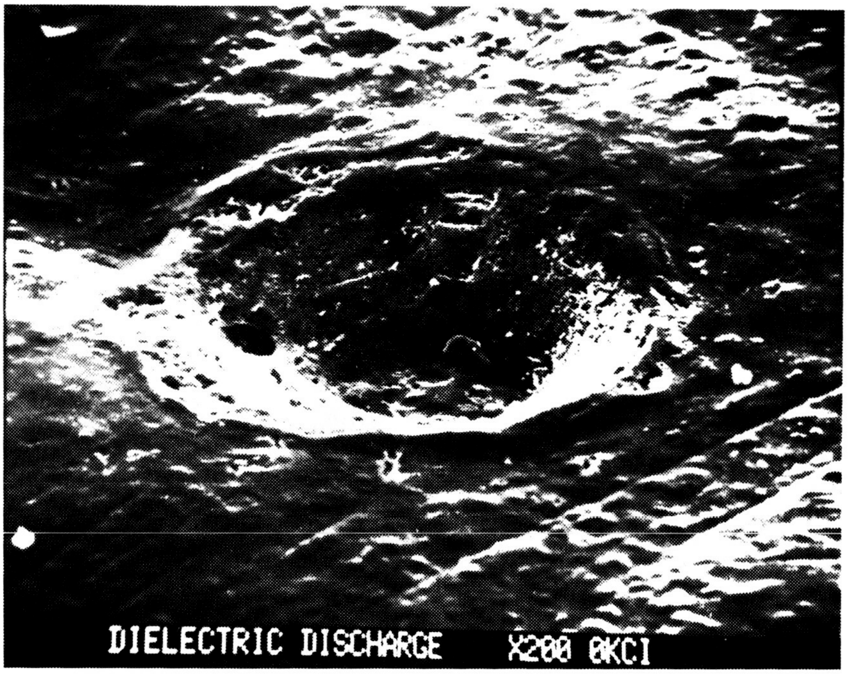
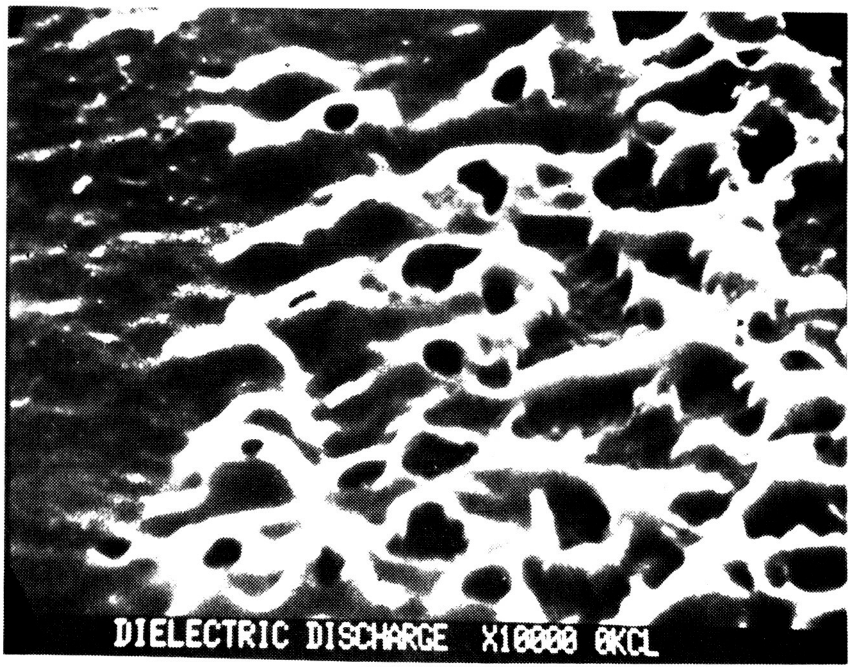


Figure 7 - Typical Discharge Pulse



(a) Crater in Tedlar (200 x SEM Magnification)



(b) Surface Melted Aluminum Substrate at Crater Base (10,000 x SEM Magnification)

Figure 8 - Discharge Cratering in Panel Isolation