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Contents

7. Surface Micro-Discharges on Spacecraft Dielectrics

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Abstract

Extensive measurements on Teflon and Kapton in a scanning electron microscope indicate the existence of a well-defined family of surface micro-discharges characteristic of the dielectric material. The measurements are of the current flowing to a conducting pedestal supporting the dielectric, and carried out in both the time and frequency domains using a sampling oscilloscope and a spectrum analyzer. For a given small region exposed to the 16-20 kV electron beam, the strongest discharge pulses are similar in shape and amplitude. For Teflon, typical pulse durations are 2-3 ns, rise and fall times are sometimes as low as 0.2 ns, current amplitudes are approximately 100 mA flowing down to the pedestal (electrons flowing up), and the pulses are unidirectional with no ringing. The use of a rapid-scan electron microscope with a secondary-electron imaging system reveals complex charge distributions resembling Lichtenberg figures on a supposedly flat homogeneous dielectric surface. These patterns undergo extensive alteration at each micro-discharge pulse and indicate that both the charging and discharging processes are highly nonuniform over the dielectric surface. The use of a flood-beam (instead of the scanned spot-beam) causes the occurrence of larger-scale macro-discharges, in which a typical peak current is 40 A with a duration of 120 ns.

1. INTRODUCTION

The scanning electron microscope (SEM) has been used extensively to study charge accumulation on spacecraft dielectrics[1] and also to study the resultant discharges and their spectra.[2] These measurements have indicated that accumulated negative charge from the SEM electron beam spontaneously and very rapidly discharges from time to time, causing a downward current to flow in the conducting pedestal supporting the dielectric sheet, and resulting in a burst of electrons from the dielectric surface. A beam accelerating voltage of at least 16 kV was required to produce the above impulsive discharges, and measured spectra suggested discharge current rise and fall times of the order of a few nanoseconds.

The observed discharges had proper''es suggesting that they were initiated by the mechanism proposed by Meulenberg wh. unique and fundamental work[3] demonstrates that breakdown could occur between a submerged layer of electrons and a positive surface layer caused by secondary emission. Events subsequent to this initial breakdown remain a mystery although arc propagation through the submerged layer as described by Gross[4] is a possibility.

2. RECENT RESULTS

2.1 Interpretation of Previous Measurements

The discharge-current spectra reported earlier[2] were measured on a slowly-sweeping spectrum analyzer so that each discharge appeared as a dot on the oscilloscope display. The pattern of dots gave an indication of the discharge spectrum, but little attention was paid in the earlier publication to a significant property of the dot patterns, namely that most of the patterns taken had well-defined upper limits. This upper-limit property shows that the strongest discharge current pulses have the same spectra. Furthermore the spectra did not change appreciably as the highly focussed electron beam was moved from point to point on the specimen, nor did the spectra change more than a few dB as the spot beam was defocussed and enlarged to a cross-sectional area of 1 mm^2 (and a current density of 10 nA/cm^2).

2.2 Pulse Measurements With a Sampling Oscilloscope

A sampling oscilloscope can be used in a mode in which the time separation between triggering and sampling is increased by a small time interval after each pulse is sampled. This time interval is independent of the time between pulses, so that a regular pulse envelope will be displayed on the oscilloscope for randomly occurring pulses, provided that all the pulses have the same shape. Such measurements were carried out mainly on Teflon specimens because of their high rate of discharge occurrence. When the triggering level was set to be reached only by the strongest pulses, regular pulse envelopes were measured as for example in Figure 1. Moving the electron beam from point to point on the specimen produced changes in the details of the pulse shape but had little effect on its peak amplitude of about 100 mA or on its duration of 2 to 3 ns. The fastest variation measured using a 4 GHz sampling oscilloscope was the 0.2 ns fall time in the pulse outline of Figure 2.

Similar measurements were carried out on Kapton H (Polyimide). Regular pulse leading edges were fairly easy to record, and the indicated rise times and pulse amplitudes were similar to those for Teflon. However, the Kapton pulse measurements exhibited a great deal of scatter for 5 to 10 ns following the initial rise. The most probable explanation for this is the occurrence of a succession of small discharges, each triggered by the one before.

Some sampling oscilloscope measurements were carried out on Teflon specimens given a prior heating to 38°C in air and transferred quickly on a heated base to the SEM chamber. These specimens produced discharges similar in shape to those already described at room temperature, but the pulse amplitudes for the heated specimens were smaller by factors of 3 to 4.

The fact that it is possible to get regular pulse outlines in most situations using the above techniques shows that the strongest pulses are virtually identical in shape, at least for Teflon and to a more limited degree for Kapton. Because these pulses are so similar, it seems reasonable to think of them as members of a well-defined family of micro-discharges.

2.3 Macro-Discharges

Large-scale discharges on dielectric surfaces have been produced and studied by a number of researchers.[3, 5, 6, 7, 8] A proper understanding of the small-scale (micro) discharges requires their comparison with the large-scale (macro) discharges in a similar experimental environment. By the use of a large electron beam aperture and by the proper adjustment of the magnetic lenses, a scanning electron microscope can be made to produce a nonscanned relatively uniform flood beam of electrons more than 5 cm in diameter, with a current density of the order of 50 nA/cm^2. Such a beam has been used to charge Mylar specimens measuring $48 \times 26 \times 0.12$ mm. The resultant discharges are readily visible to the naked eye as "lightning" flashes which dart in irregular paths across the specimen, usually terminating at its edge. Figures 3 and 4 are photographs of such discharges which are visible as white lines in the central region of the specimen. The ray-like patterning around the edge of the specimen is luminescence due to electron impact

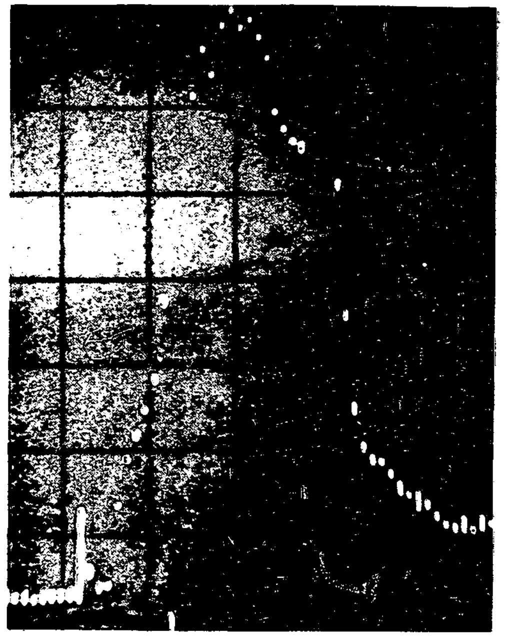

Figure 1. Micro-Discharge Current Pulse as Measured With a Sampling Oscilloscope. The upward direction corresponds to current flowing downward from the pedestal on which rests the Teflon specimen, measuring $10 \times 10 \times 0.5$ mm. The 18 kV electron beam is highly focussed and only a small area of the Teflon is exposed to it. Horizontal scale 1 ns/div and vertical scale 100 mA/7 div

Figure 2. Micro-Discharge Current Pulse Measured Ur · Same Conditions as Figure 1, Excep -hat the Spot Beam has been Moved to a Different Area on the Same Specimen

Figure 3. Macro-Discharge on Surface of Mylar Specimen 26 × 48 × 0.12 mm. The primary arc discharge goes from the central bright spot (due to filament illumination) to the lower edge of the specimen. The other bright areas are luminescence. The beam accelerating voltage is 20 kV

Figure 4. Macro-Discharge Under the Same Conditions as Figure 3. The arc can be seen crossing the central illuminated area

with the dielectric immediately following the discharge, when there is not enough negative surface charge left to repel the incident beam. The large bright spot in the centre of each photograph is due to light emitted by the SEM filament. Note in Figure 4 that this illuminated region is traversed by the discharge path indicating that the light intensity is not sufficient to discharge the specimen through photoemission.

The macro-discharge current to the conducting pedestal as measured in a 275 MHz bandwidth oscilloscope is shown in Figures 5 and 6. The peak current downward into the pedestal is consistently very close to 40A and the duration varies from 80 to 150 ns. The current flows into a 12.5 ohm load (three 50 ohm shunts plus 50 ohm attenuator) so that the peak instantaneous power is 20 kW and the total energy is of the order of 2 mJ. The total energy stored in the accumulated charge could be as high as 50 mJ (for a 20 kV beam); conceivably part of the energy difference could be dissipated in the discharge arc itself as it propagates across the specimen and over its edge to the pedestal.

2.4 Observations With a TV-Type Scan

Rapid scanning with a television-type raster and secondary-electron detection produces real-time images of submerged charge distribution (because the negative submerged charge increases the probability that secondary electrons will escape from the dielectric surface). Observations of this type indicate complex charge distribution patterns which change slowly in response to changes in the region being viewed and very rapidly in response to impulsive discharges. These observations suggest that an apparently clean and smooth dielectric surface may be very nonuniform with respect to charge accumulation, on a scale as small as a fraction of a millimeter. Also noted during these experiments was a tendency for discharge initiation to occur along the borders between relatively charged and uncharged areas.

3. CONCLUSIONS

Surface micro-discharges on thin sheets of dielectric at room temperature are readily identifiable as producing 100 mA, 2-3 ns pulses into a grounded backing conductor. On the other hand, surface macro-discharges are both stronger and longer in duration, by about two orders of magnitude for both peak current and pulse duration in the experiments described. The area exposed to the electrons (and thus the area discharged) seems to be the factor that distinguishes the two types of discharge. There is also a possibility that a succession of micro-discharges could make up (or at least trigger) a macro-discharge. Certainly the

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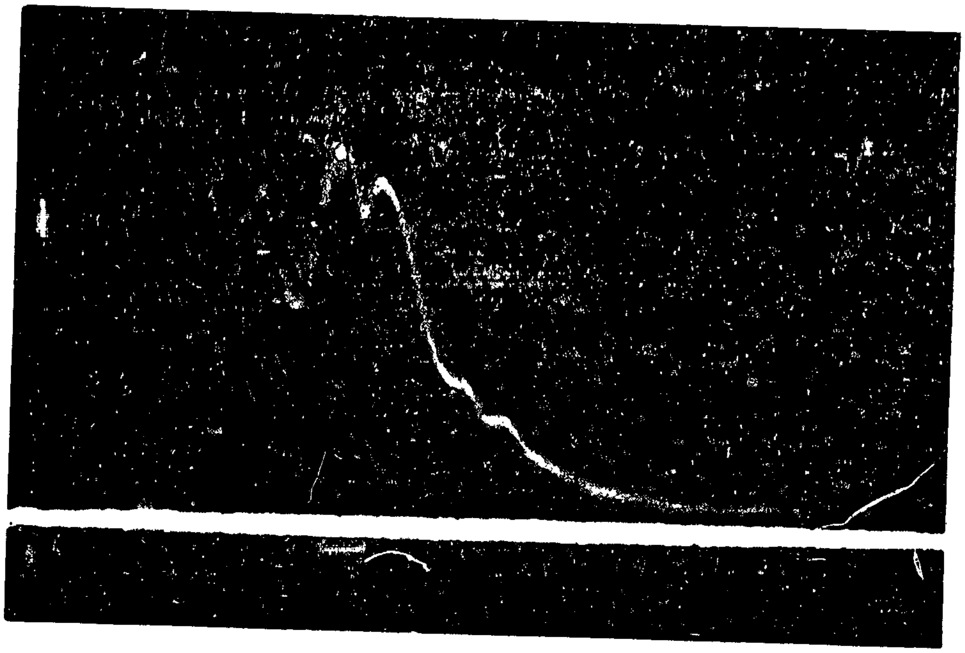

Figure 5. Macro-Discharge Current into the Conducting Pedestal Supporting the Mylar Specimen of Figures 3 and 4. Horizontal scale 50 ns/div and vertical scale 13A/div

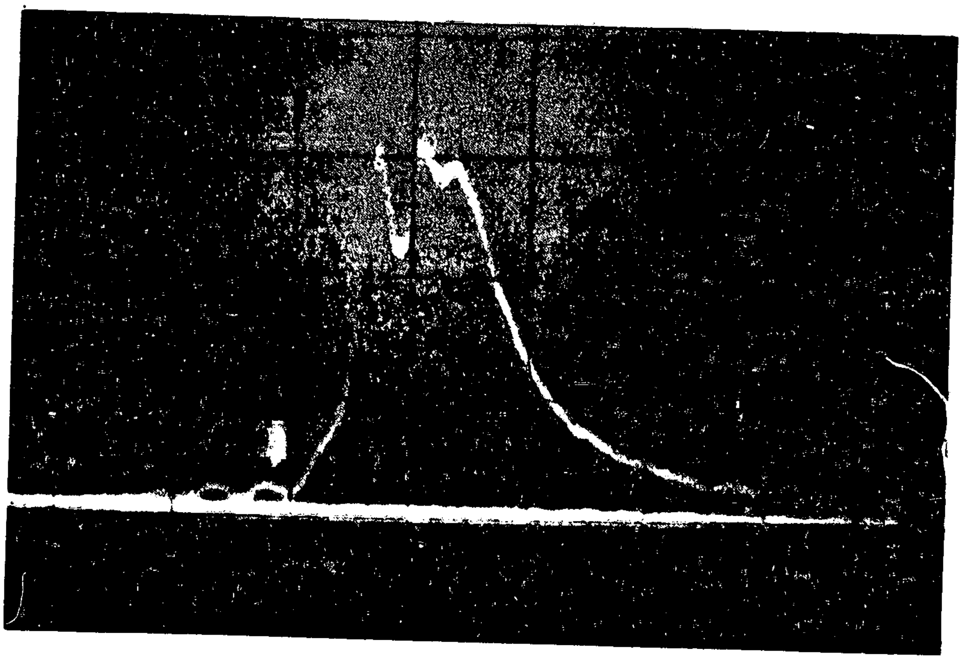

Figure 6. Macro-Discharge Current Under Same Conditions as Figure 5 (for Another Discharge)

nonuniformity of the observed charging patterns and the irregularity of the observed discharge paths indicate that the phenomena under study are very complex in terms of their detailed behaviour.

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References

1. Balmain, K.G. (1973) Charging of spacecraft materials simulated in a scanning electron microscope, Electronics Letters, 9:544-546.
2. Balmain, K.G., Orszag, M., and Kremer, P. (1976) Surface discharges on spacecraft dielectrics in a scanning electron microscope, Progress in Astronautics and Aeronautics, 47:213-223.
3. Meulenberg, A. (1976) Evidence for a new discharge mechanism for dielectrics in a plasma, Progress in Astronautics and Aeronautics, 47:237-246.
4. Gross, B. (1958) Irradiation effects in plexiglas, Journal of Polymer Science, 27:135-143.
5. Stevens, N.J., Lovell, R.R., and Gore, V. (1976) Spacecraft-charging investigation for the CTS project, Progress in Astronautics and Aeronautics, 47:263-275.
6. Hoffmaster, D.K., and Sellen, J.M. (1976) Spacecraft material response to geosynchronous substorm conditions, Progress in Astronautics and Aeronautics, 47:185-211.
7. Adamo, R.C., and Nanevicz, J.E. (1976) Spacecraft-charging studies of voltage breakdown process on spacecraft thermal control mirrors, Progress in Astronautics and Aeronautics, 47:225-235.
8. Walther, F.G. (1974) private communication.