CHARGING OF SPACECRAFT MATERIALS SIMULATED IN A SCANNING ELECTRON MICROSCOPE

Indexing terms: Electric charge, Electron-microscope examination of materials, Insulating materials, Space vehicles

The scanning electron microscope has been used to apply electric charge to spacecraft insulating materials, and to photograph the resulting patterns of charge distribution. Anomalies, possibly microscopic discharges, have been observed, usually associated with strong differential charging between adjacent regions of the same material. In thin materials, electron-beam penetration, temporarily induced conductivity and permanent subsurface damage have been identified.

The experimental results of de Forest[1,2] show that a satellite in synchronous orbit can develop a static negative charge, producing a potential as high as 12 000 V with respect to the surrounding plasma medium. The required conditions are the presence of energetic charged particles associated with magnetic substorms and also the passage of the satellite into the earth's shadow (into eclipse), thus preventing photoemission, which is the principal mechanism of charge removal. In addition to whole-satellite charging, it is also possible to have differential charging, either between conductors and dielectrics or between differently charged parts of the same dielectric: these are caused, for example, when some part of the satellite casts a shadow on another part. Other experimental observations are those by Fredricks and Scarf,[3] who studied the occurrence of anomalies in the subsystems of synchronous satellites. These anomalies were found to occur in the midnight-to-dawn sector of the satellite orbits, and correlate with the injection of energetic electrons and protons. Fredricks and Scarf also carried out laboratory vacuum breakdown tests, using electrodes attached to various spacecraft materials.

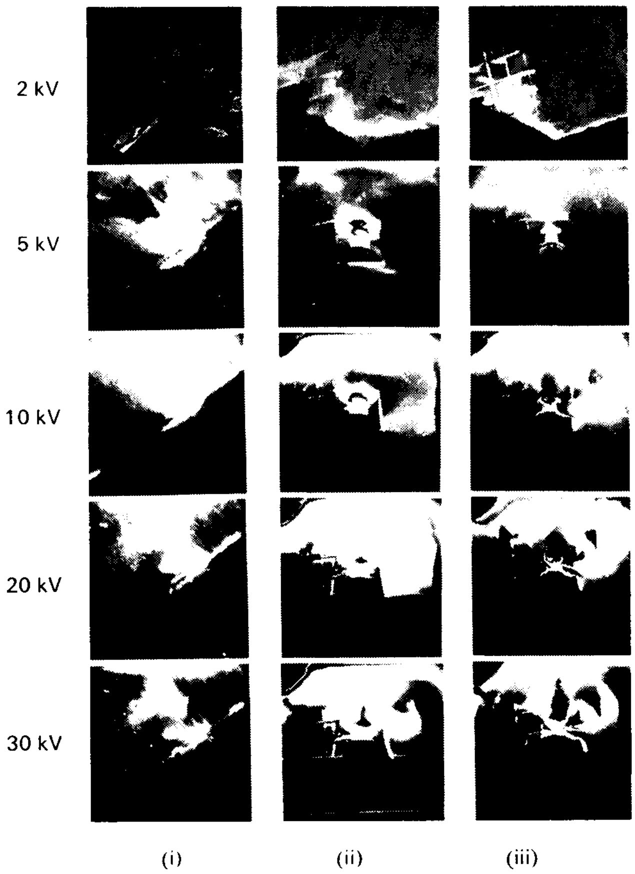

Fig. 1 *Scanning electron micrographs of spacecraft materials that are normally exposed*

(i) Solar cell with electrical contact tab (magnification decreasing)
(ii) Thick Kapton (magnification increasing)
(iii) Thick Kapton (magnification decreasing)

The purpose of this letter is to suggest that a more realistic method for simulating spacecraft charging is to place samples of spacecraft insulators in a scanning electron microscope (s.e.m.). The electron energies in a typical s.e.m. (1–30 keV) are comparable to those encountered by satellites under the conditions already mentioned. In addition, the s.e.m. offers photographic capability, variable magnification, variable scan rate and auxiliary instrumentation such as the X ray microanalyser. From the point of view of microscopy, the subject under study is specimen charging a well known and usually deleterious phenomenon discussed in the References on the s.e.m.[4,5]

With the specimen in place, the electron-beam scan rate is set to a high value to permit easy visual inspection. The basic procedure involves setting the s.e.m. at a fairly high magnification, and reducing the magnification in steps to a final low value, at which point the scan rate is reduced for photography. Charge buildup shows as light regions in the photograph, and,

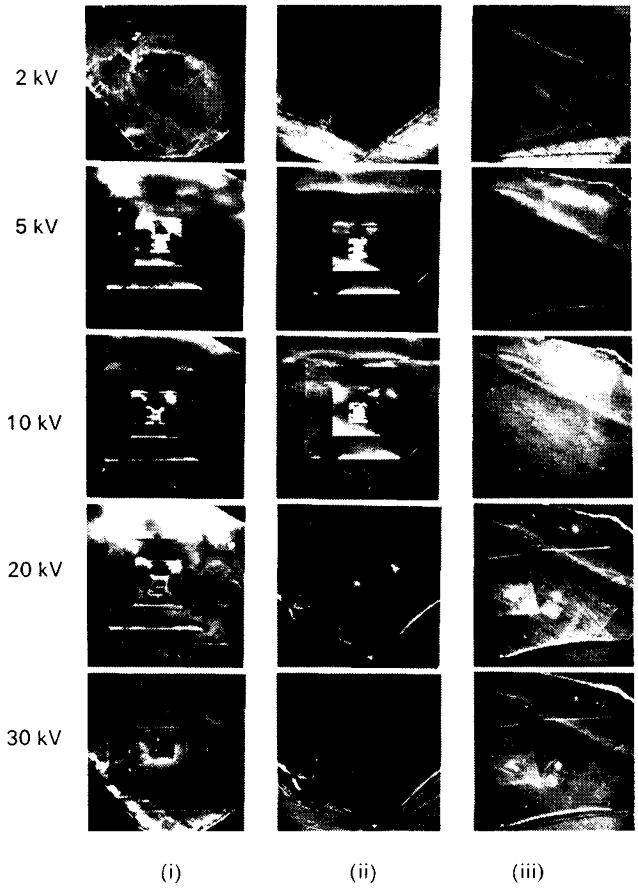

Fig. 2 *Scanning electron micrographs of spacecraft materials that are normally covered*

(i) Thin Kapton (magnification decreasing)
(ii) Thin Mylar (magnification decreasing)
(iii) Thin Mylar showing permanent subsurface damage patterns (no magnification stepping)

in the absence of charge diffusion, these regions tend to be arranged in the concentric rectangles actually exposed to the electron beam at the various steps in magnification. In the photographs to be shown, all the samples are tilted at 45° with the top of the sample farthest from the electron gun. Each scan is from left to right, and there are 1000 scan lines per frame, progressing from top to bottom in the photographs. Beam current was kept constant at 180 μA, and the detector was set to respond to both primary and secondary electrons. The magnification steps employed were $\times 2000$, $\times 1000$, $\times 500$, $\times 200$, $\times 100$, and $\times 50$, with the $\times 50$ magnification used for photography.

Fig. 1(i) shows part of a solar cell covered with an 100 μm thick, 5% CeO-doped microscope coverglass, which has an MgO antireflection coating. The photographs show clearly one of the electrical contact tabs, half of which has been scraped clean of a room-temperature-vulcanising insulating compound. At an accelerating voltage of 2 kV no charging is evident, probably because of a high production of secondary electrons. At higher voltages, various diffuse charging patterns are observed with the expected concentric-rectangle charge distribution completely diffused, apparently by a small but finite conductivity in the materials. No macroscopic damage and no anomalous phenomena were observed.

Figs. 1(ii) and 1(iii) show thick Kapton (125 μm) with an aluminised backing, a material commonly employed as the outer layer of a 'thermal blanket' used to wrap parts of satellites. One corner of the material has been scored in a crosshatch pattern as an aid to focusing and to simulate accidental surface scratches. At 5 kV and higher, very strong charging appears and the concentric-rectangle pattern is clearly in evidence. The central part of the sample is so highly charged that there appears to be appreciable beam deflection away from it, towards the top of the picture. The beam scan is horizontal with a charge-enhancing hesitation at both ends of every scan and particularly at the bottom of each frame; this is shown most clearly at 5 kV in Fig. 1(ii). At 20 kV and especially at 30 kV when the slow photographic scan reaches the most heavily charged lower segment of the rectangle, a streak appears all the way across the picture and lasts for several scans. This streak is clearly associated with a narrow highly charged region and could be the result of a momentary discharge that either emits electrons over an appreciable time or emits an electromagnetic pulse that interferes with the instrument circuitry. Further streaks are also visible towards the bottoms of the photographs for the two highest-voltage cases. No macroscopic damage was apparent, either by visual examination under a $\times 30$ power binocular optical microscope or during the course of subsequent s.e.m. experiments. Only a very small amount of beam penetration to the aluminium backing was revealed by X ray microanalysis at 20 kV and 30 kV.

Fig. 2(i) shows a thin sample of Kapton (25 μm) with aluminised backing, which is the layer of a 'thermal blanket' and is usually nearest to the satellite. In this sequence, note the dark central spot at 20 kV, and the dark central rectangle outlines at 30 kV. For sufficiently high energy, exposure density and exposure time, there appears to be beam-induced conductivity that drains off the charge-concentrations, which result from subsequent exposures. This conductivity is definitely temporary, because it was not visible in later s.e.m. experiments; no damage was visible optically. Some beam penetration to the aluminium backing was indicated by X ray microanalysis at 20 kV and 30 kV.

Fig. 2(ii) shows a sample of thin Mylar (10 μm) with aluminised backing, one of the inner layers in a typical 'thermal blanket'. Some charging is clearly indicated at 5 kV and 10 kV, but at 20 kV the charge pattern is greatly faded and at 30 kV it has disappeared almost completely. Presumably this is due to easy beam penetration of the dielectric, which means less charge deposited during magnification stepping and almost complete removal of that charge by induced conductivity during the photographic scan. X ray microanalysis showed weak beam penetration at 10 kV, definite penetration at 20 kV and strong penetration at 30 kV.

To search for permanent damage, a sequence of micrographs was taken on a part of the thin Mylar sample previously exposed to the electron beam. The results are shown in Fig. 2(iii), which is not complicated by stepping the magnification. At 20 kV and 30 kV, a detailed record of beam damage is evident from several experiments over a period of about one month. Some damage is visible at 10 kV, but none can be seen at 2 kV or 5 kV. Therefore, it is clear that this is subsurface damage, probably occurring at the interface between the Mylar and the aluminised backing.

Additional tests (not shown) were carried out on a flexible glass-fibre material sometimes used to support large arrays of solar cells. The charge patterns were moderately diffuse, and very definite interference streaks were noticed at 10 kV, 20 kV and 30 kV.

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