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전자빔 조사에 의한 폴리머 내의 공간 전하 분석

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Space Charge Analysis in Polymer Irradiated by Quasi-Monoenergetic Electron Beam

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Abstract : Spacecrafts such as most of commercial satellites that are operating in the geostationary orbit can be subjected to intense irradiation by charged particles. The surface made of dielectric materials can therefore become probable sites for damaging electrostatic discharges. Thanks to a specially equipped chamber, the spatial environment can be reproduced experimentally in the laboratory. In this paper, the behavior of high energy electrons injected in polymers such as PolyMethylMetaAcrylate (PMMA) and Kapton is studied. Results obtained by surface potential technique, pulse-electro acoustic device and a cell based on the split Faraday cup system are analyzed and discussed.

Key Words : Spacecraft, Geostationary orbit, Charged particle, Dielectric material

1. Introduction

The space environment in which satellites evolve has been broadly characterized [1]. It has been shown that the various charged particles trapped in the magnetosphere interact with dielectric materials covering spacecrafts. These materials can therefore become probable sites for damaging electrostatic discharges [2]. In order to reduce or to get a better control on the discharge initiation phenomena it is necessary to clarify the nature, the position and the quantity of stored charges with time. Polymers irradiated by a quasi-monoenergetic electron beam have been investigated. Actually, these studies have been made in a specific irradiation chamber, initially only equipped only by a surface potential probe. Recently, additional measurement techniques such as the Pulsed Electro-Acoustic (PEA) system and the surface current cell detection based on Split Faraday Cup (SFC) method have been installed into the chamber. Measurements performed with the three methods will be introduced in this paper and their complementarities shown.

2. Experimentals

Materials used for space equipment must be tested under specific conditions. As it is costly and awkward to get back materials after a journey in space, it is of major importance to be able to reproduce this peculiar environment in the laboratory. Among all the irradiation chambers. This chamber has been built to reproduce the electronic geostationary environment described by a reference spectrum named Kp>5 [3]. Quasi mono-energetic electrons produced by a Van de Graaff accelerator in the range 0-400 keV and by an electron gun in the range 30-40 keV are diffused through a specific complex window. During these studies, in order to start with a

simple arrangement, only the impact of quasi-monoenergetic irradiations was studied. To do so, one source was turned on at a time and only one diffusion foil was used to enlarge the signal and produce a homogeneous 5 cm radius irradiation zone perpendicular to the beam.

Between two periods of irradiation and during the relaxation under vacuum, it is possible to record the surface potential by using an electrostatic probe that is shifted a few millimeters in front of the sample. Initially, the data obtained was used to follow the charging state of the sample in order to stop the irradiation before a discharge occured. In addition, here the data is also used to make a rough estimation of the charge depth penetration.

The arrangement of the classical PEA device that has been described many times in the literature [4], has been modified and introduced in the irradiation chamber to record the charge distribution not only during the irradiation but also during the relaxation. To keep the irradiation face free, both excitation and detection units are located at the back of the sample. The pulse probe voltage is applied through a thin metalized electrode that goes through one edge of the sample (Fig. 1).

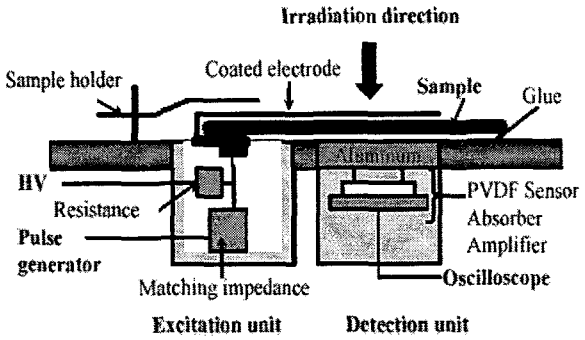

Fig. 1. Set-up for in-situ measurements.

Recently the irradiation chamber has been implemented with a current detection cell based on the SFC technique (Fig. 2). During the experiment presented here, both currents from the front (i_1) and rear (i_2) faces are recorded at the same time. Measurements are always performed during the irradiation as well as during the relaxation. It is checked that the sum of both currents is equal to the current collected from the controlling Faraday cage located near the detection cell. This set-up is small enough to be introduced in the chamber at the same time as the PEA detector and allows us to record data simultaneously on samples irradiated under similar conditions.

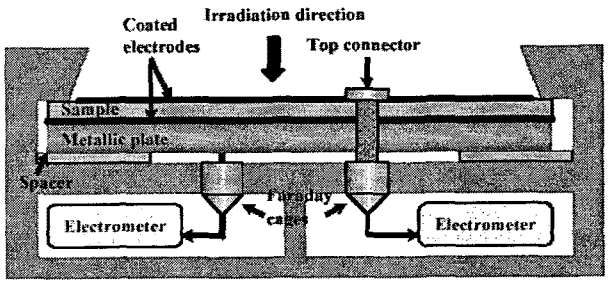

Fig. 2. Current detection system based on the SFC set-up.

Two types of materials (Kapton® and PMMA) have been tested during the measurement campaign. Initially, a Kapton® film 225 μm-thick has been irradiated by a 120 keV electron beam for 15 mn, then by a 150 keV electron beam for 30 mn with a flux of 125 pA/cm^2 in both cases. During the irradiation and during the relaxation, PEA data was recorded. In order to prevent the photo conduction phenomena to occur on the very sensitive Kapton® sample, the set-up was kept in the dark during the whole experiment.

Next, a PMMA sample 250 μm-thick was tested. It was irradiated under three different energies for 40 mn each. For the first irradiation, a 100 keV electron beam delivered by the Van de Graaff accelerator was used. After a 5 h relaxation, the second irradiation under a 5 h relaxation, the second irradiation

under a 130 keV electron beam was applied. Then after 17 h of relaxation the last irradiation under 160 keV was performed. In all cases the flux was fixed at 50 pA/cm^2. In addition to surface current data record, PEA measurements were performed. Surface potential data obtained on a thicker sample irradiated under similar conditions will was also used to determine the charge penetration depth. Results obtained by these techniques will be analyzed and compared in the following section.

3. Results and Discussion

During the irradiation, PEA measurements were recorded every 2 mn. Already after the first minute of irradiation a negative peak due to the injected charges is detected at about 113 μm from the irradiated surface. Two positive peaks of induced charges appear simultaneously at the interface sample/electrode. As expected, all the peaks grow in amplitude with the irradiation time. Besides, after a 5 mn irradiation another negative peak appears close to the irradiated surface. This peak could be due to lower energy electrons resulting from secondary emission produced in the chamber. When the energy is increased up to 150 keV, the negative peak detected is shifted deeper in the bulk.

After 15 mn of irradiation, the position stabilized but the peak amplitude continued to increase. The negative peak detected near the surface continued to grow with time.

As it can be seen, the relaxation of the charges is a slow process (Fig. 3). Actually, after 11 days there is still a large amount of charges in the bulk. If the electric field is analyzed, it is observed that just after the end of irradiation the electric field is negative from the irradiated surface up to about 178 μm. In this area, the charges subjected to the negative field tend to be extracted toward the irradiated surface. The irradiated zone conductivity increased by the electron injection makes the charge displacement easier. Thus, after one week of relaxation most of the charges previously detected in this part have disappeared. At the same time, the negative electric field limit has been shifted to 192 μm. Charges located in this extra 14 μm can therefore be extracted toward the irradiated bulk. After 10 days, the negative electric field is quite small and the relaxation becomes really slow.

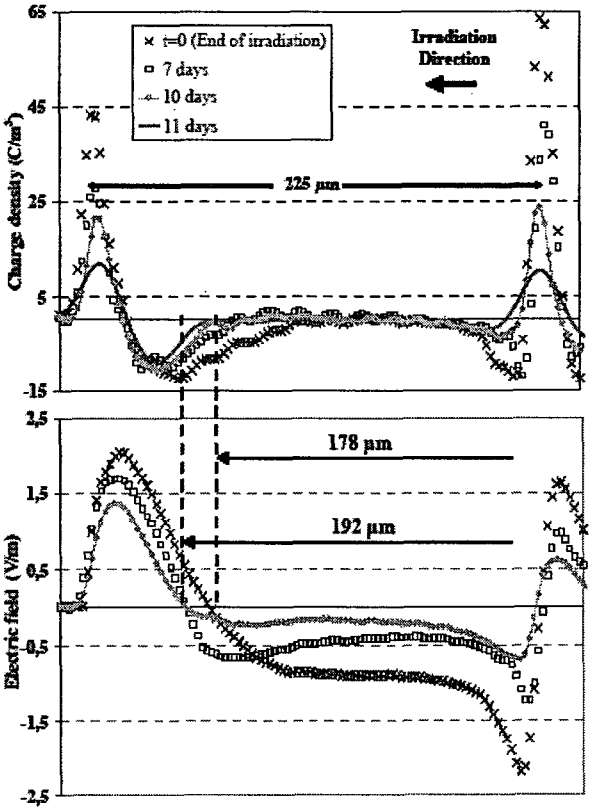

Fig. 3. Kapton sample 225 μm -thick charge density recorded by PEA and electric field calculated during the relaxation after 30 mn irradiation under 150 keV with a flux of 125 pA/cm^2.

PEA measurements were recorded during the irradiation (Fig. 4). After the first irradiation period under 100 keV, a broad negative peak was detected. The maximum was estimated at about 80 μm from the irradiated surface. During the relaxation time, the amplitude and the shape of the peak are not modified significantly. It is observed that when the electron energy is increased up to 130 keV, a second negative peak is detected at about 149 μm whereas the previous peak still remains. In fact, a large amount of charges is stored at 149 μm but an important quantity of electrons is also stored in the whole irradiated zone. The third irradiation was performed after a longer period of relaxation during which a part of the charges was extracted from the irradiated zone following the same process previously described for Kapton® material. Under 160 keV, charges accumulate mainly at about 175 μm.

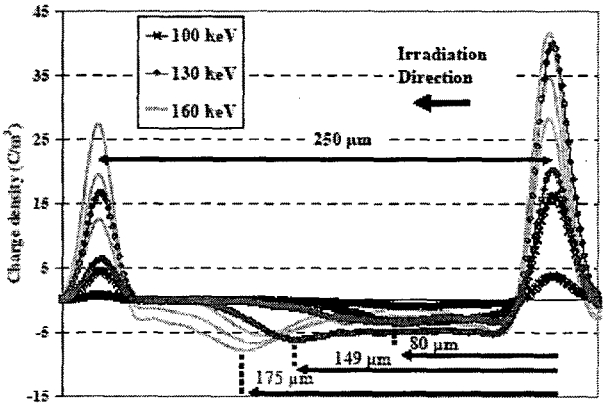

Fig. 4. PEA measurements recorded on a PMMA sample 250 µm-thick during three periods of 40 mn irradiation a) 100 (crosses), b) 130 (open circle) and c) 160 keV (single line) with a flux of 50 pA/cm^2.

It is possible to determine approximately the electron penetration depth by estimating the non-irradiated zone capacitance. This calculation method has already been exposed in previous publication. In figure 2, these results in addition to the ones obtain by PEA have been plotted. There are good correlations between PEA and surface potential data. These data remain lower than the ones obtained by ESTAR software that gave the maximum penetration depth of the electrons versus the energy.

As the amount of stored charges by PEA and current data differ by a factor of two, it was decided to proceed using the same calculation with the sample irradiated at 130 and 160 keV. Results are reported in Table 1. The same difference between results observed indicates that it is probably coming from a calibration factor and not from a physical effect. Some extra work must be performed to clarify the origin of the discrepancy.

Table 1. Injected charge quantity estimation from PEA measurements and surface current data obtained on PMMA material after 40 min irradiation.

Energy (keV)	100	130	160
Q_{PEA}(nC/cm^2)	33	78	93
$Q_{back\text{-}current}$ (nC/cm^2)	12	38	51

4. Conclusion

In this paper, data recorded during an electronic irradiation on PMMA and Kapton materials by PEA, surface current and surface potential have been presented. The built-up of charges and the position of storage is clearly identified by PEA. These results are in good agreement with the ones obtained from surface potential data. However, when a quantitative analysis is made, there is a constant discrepancy between results obtained by PEA and current measurements, which probably requires an improvement in calibration.

감사의 글

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