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Internal Space Charge Measurement for Space Environment Monitoring

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Abstract: Dielectric materials used in space environment have been investigated in an irradiation chamber which reproduce spatial environment. Under irradiation, polymeric materials are able to store charges inside as well as on the surface. A new pulsed electroacoustic space charge measurement unit has been recently developed. It can be mounted in an irradiation chamber to perform measurements in situ. Thanks to this system it is possible to observe internal space charge accumulation of polymers under irradiation as a complement to the in situ surface potential measurement. In this paper, the new system is introduced with experimental results obtained on acrylic sheet. Additionally, a floating electrode was applied to examine the specimen configuration with various specimens, such as polyimide and fluoro-ethylene propylene. The combination of in situ observation of the surface potential and the internal space charge behaviour can give valuable information to investigate the materials used in the space environment.

INTRODUCTION

Materials used in space environment, such as the ones that are covering spacecraft and satellites, are exposed to various charged particles. When submitted to an irradiation, polymeric materials are able to store charges in the bulk as well as on the surface. This accumulation of charges can initiate electrostatic discharge, resulting in perturbation on electronic devices that are present in satellites [1]. Most of the studies performed up to now concentrate on the electrostatic consequences by measuring surface phenomena using a surface potential probe as a tool. We have developed a new space charge measurement unit that can be mounted in an irradiation chamber by using the pulsed electroacoustic (PEA) method [2]. The irradiation chamber used in this work is specially equipped with an electron gun and a Van De Graaff accelerator. Thanks to a combination of diffusion foil, electrons of various energy are produced and their quantity fit the spectrum that represent the spatial environment [3]. This mounted PEA system can observe internal space charge accumulation of polymers under irradiation, it is therefore a complement to the in situ surface potential measurement device. Experimental results obtained with PMMA sheet proved that the dominant peak of charge accumulation was in good agreement with the theoretical electron penetration depth [4, 5]. Additionally, a floating electrode is applied to examine the specimen configuration with various specimens, such as polyimide and Fluoro-Ethylene-Propylene (FEP), and Poly-Tetra-Fluoro-Ethylene (PTFE).

MOUNTABLE-PEA UNIT

In order to apply the PEA method in space environment monitoring, i.e., to observe space charge behaviour in a vacuum irradiation chamber or on a satellite, it is essential to make the equipment as small and as light as possible. It is also necessary to built the entire system simply. Fig. 1 shows the configuration of the mountable-PEA electrode unit. The unit was a modification of the portable PEA system [6] that was already a miniaturised version of the original set-up. However the principle of use remain the same whatever the configuration. In the present case as a consequence of the reduction of the detection circuit, the output signal is very small, therefore the whole device must be properly shielded. The voltage application electrode unit, on the left hand side in the Fig. 1, includes an impedance matching circuit, and the case is filled with

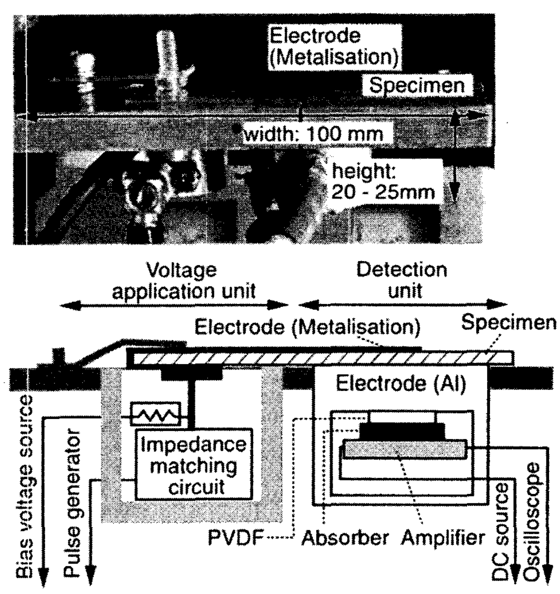

Fig. 1 Mountable PEA unit for a vacuum chamber.

epoxy resin to avoid surface or partial discharges, so that this unit can be used by applying a dc bias voltage up to 10 kV. The detection electrode unit, on the right hand side in the same figure, is equipped with a piezoelectric device made with a polyvinylidene fluoride (PVDF) film (9 microns thick) attached to the electrode by pressing with a rubber absorber and is connected to an amplifier board (35 dB). A tested specimen has evaporated electrodes on the both sides to make possible the application of a pulse voltage for the measurement and a bias voltage if necessary. This bias voltage is generally only applied when the reference signal is recorded before the irradiation is performed. Therefore during irradiation and after the end of the irradiation a pulsed electric field is applied to the metalised 'top' electrode on the surface of the specimen. The bottom side, the opposite side of irradiation surface, is attached to the electrode with an adhesive to allow a good contact and therefore the proper transmission of the acoustic wave signal.

The PEA unit has already been used into the irradiation chamber SIRENE (Multi-energetic vacuum chamber developed at ONERA with CNES support), shown in Fig. 2. Fig. 3 shows the space charge profiles during and after irradiations. The thin solid line (1) shows the charge accumulation being irradiated at 200 keV, 1 nA/cm^2 for 4 minutes. After that, the specimen was kept under vacuum without irradiation for 13 hours as relaxation, then some charge remains in the bulk as the broken line (2) in the figure. After the measurement (2), an additional new irradiation was performed at 300 keV, 1nA/cm^2 for 4 minutes, the charges accumulated at deeper position from the irradiated surface as the thick solid line (3). These results prove that the mountable PEA unit can be applied for in situ space charge observation in a vacuum chamber.

APPLICATION TO VARIOUS MATERIALS

The pulsed electroacoustic system detects the acoustic waves that propagates through the specimen and the detection electrode, the crucial technical point in the measurement procedure is the contact between the specimen and this electrode. In order to evaluate the adhesion, we used an ordinary PEA system (Fig. 4) with a gap between the top electrode and the specimen, in other words, the pulsed voltage was applied through the air gap. As the sample under test has not been irradiated yet, in order to detect a signal a bias voltage of several kV is applied. When the specimen is properly attached to the lower electrode, the acoustic signal from the surface can be detected, so that the peaks from both interfaces of the sample are detected. On the contrary, when the specimen is detached, the acoustic wave from the specimen cannot be observed because it is not properly transmitted to the sensor, so that only the signal from the lower electrode is observed.

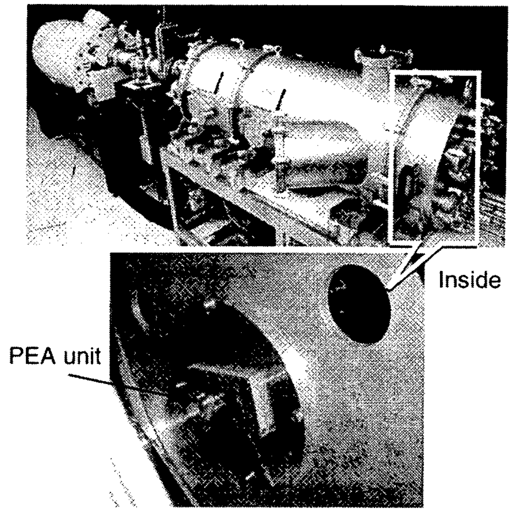

Fig. 2. Irradiation chamber SIRENE with the PEA unit.

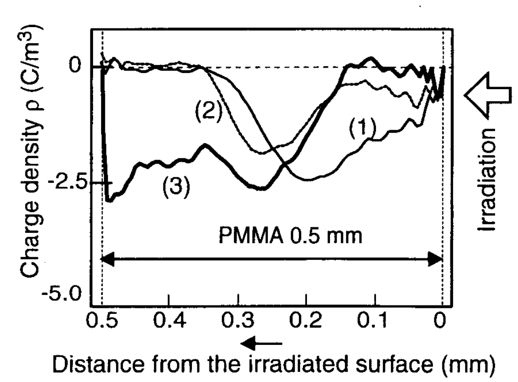

Fig. 3 Space charge profiles of a PMMA sheet under and after irradiations.
(1) 200 keV, 1 nA/cm^2, 4 min.
(2) after 13 hrs without irradiation
(3) 300 keV, 1 nA/cm^2, 4 min.

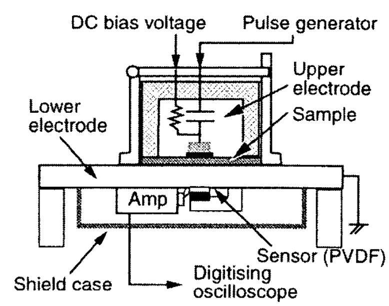

Fig. 4 PEA system.

By using this floating electrode, various specimens and adhesives listed in Table 1 were examined. In all the cases, the specimens were stuck to the electrode and the measurements were performed when the glue was properly cured or dried. It is thought that the surface active agent might affect the surface of PMMA, PS, PET and PI, a slight modification of the colour of the sample could be observed after it has been removed from the detection electrode support. To examine the contact under the vacuum, the specimens were kept under the vacuum at 10^{-4} Pa for 1 hour. PMMA, PS, PET, and PI were stuck by all the adhesives therefore the use of the active agent can be avoided. PTFE, on the other hand, was stuck by cyanolite with or without active agent, and FEP was stuck only by cyanolite with active agent.

One of the good combination, PTFE and cyanoacrylate with active agent, was applied to the mountable PEA to observe a fundamental signal obtained by applying a dc bias voltage. As shown in Fig. 5, the signal was clearly observed although the peak from the top evaporated electrode was broadened due to the dispersion and attenuation of acoustic waves while propagating through the thick specimen (500 μm).

These experiments prove that in situ space charge measurement in the irradiation chamber can be applied to various materials used in the space, such as polyimide, FEP and PTFE. Moreover, the floating electrode might be applied to observe space charge accumulation in a specimen without evaporated electrode, after irradiation by using a mobile arm inside the chamber. Both configurations are under studies and might provide interesting experimental results in the near future.

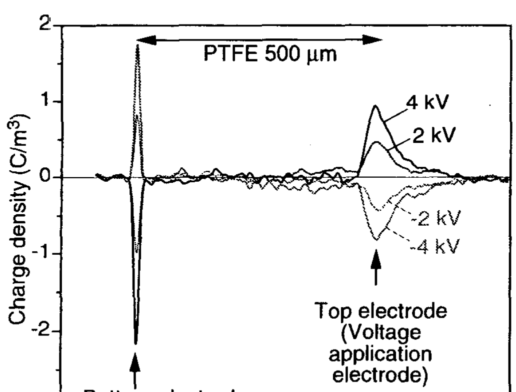

Fig. 5. Charge profile of a PTFE sheet with the mountable PEA under dc voltage application.

Table 1: Specimens and adhesives

Specimen	Thickness (μm)	Relative permittivity
Poly(Methyl MethAcrylate): PMMA	500	2.46
PolyStyrene: PS	250	2.95
Poly(Ethylene Terephthalate): PET	100	1.47
PolyImide: PI	125	3.40
Fluoro Ethylene Propylene: FEP	500	2.20
Poly(Tetra Fluoro Ethylene): PTFE	500	2.00

Adhesives
Epoxy resin
Cyanolite
Cyanolite with active agent pre-treatment
Semi-conductive glue

CONCLUSIONS

We have developed a mountable PEA system and was applied for space charge observation under irradiation in a vacuum chamber. The system can measure various materials used in the space. It is a complementary tool to surface potential measurements currently performed in irradiation chamber to characterise polymeric materials.

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