In Situ Space Charge Measurement in Dielectrics for Space Industry

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The in situ internal space charge measurement system of dielectric materials under irradiation has been developed by using the pulsed electroacoustic method. This system can observe space charge profiles in dielectric materials under irradiation, and was applied to an irradiation chamber at Office National d'Etudes et de Recherches Aérospatiales, Centre de Toulouse, supported by Centre National d'Etudes Spatiales. Space charge profiles in a several kinds of polymeric materials were clearly observed under and after electron beam irradiations. Negative charges accumulated at the position corresponding to the energy of the electron beam in all the specimens. The in situ observation of the internal space charge behaviour can give valuable information for the investigation of charging and discharging phenomena and of ageing mechanisms of dielectric materials used in the space.

Key words: In situ, Space charge, Irradiation, Pulsed electroacoustic method

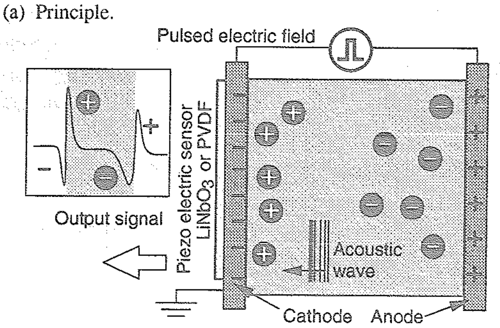
1. Introduction

Materials used in space environment are exposed to various charged particles. Upon irradiation, polymeric materials store charges which can affect the function of the equipment or the materials themselves [1, 2]. Most of the studies performed to date have focused on electrostatic phenomena on the surface of materials. High energy particles, however, penetrate deeply into dielectric materials, and the internal charge (deep charge) can produce high surface potential or may cause breakdown. There are some early works on internal charge measurement of polymers after electron-beam irradiations [3-5], by the pressure wave propagation (PWP) method and pulsed electroacoustic (PEA) method. The PWP method uses a pressure wave that is produced either by a piezoelectric device or by a pulse laser to a specimen, and detects the induced current. The PEA method, on the other hand, uses a pulsed electric filed to a specimen. The details are explained in the following section. In order to apply the PEA method in space environment monitoring, i.e., to use it in a vacuum chamber or on a satellite, we have developed a small PEA unit [6] and was modified to a mountable PEA unit for an irradiation chamber and observed space charge behaviour in polymers under electron-beam irradiation.

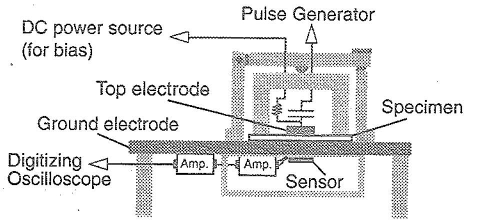
2. Pulsed electroacousitc (PEA) method

The PEA method was originally developed by T. Maeno in 1980s, and has been used by many research groups [7]. It might be useful to briefly introduce the PEA method here. Figure 1(a) shows the schematic diagram of the theory of the PEA method. When a pulsed electric field is applied to a specimen that has charges, the pulsed electric field and charges (internal charge and induced charges on the electrodes) generate forces, resulting in acoustic waves. The acoustic waves propagate in the specimen, and are detected by a piezoelectric sensor; made with

(a) Principle.



(b) Normal setup.



(c) Fundamental profiles.

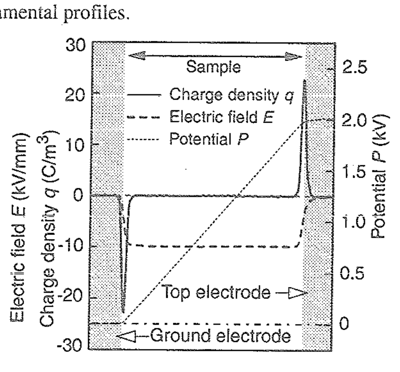


Fig. 1 The PEA method.

polyvinylidene fluoride (PVDF) or lithium niobate (LiNbO3), attached to the electrode, and are observed by an oscilloscope. The amplitude of the signal is proportional to the charge quantity, and the delay indicates the distance from the sensor, i.e., the position of the charge. In this manner, space charge distribution is measured quantitatively and nondestructively. All the details including the calibration method were explained in previous publications [3,8].

Figure 1(b) shows a typical electrode setup. The sample is sandwiched by two electrodes, and the piezoelectric sensor was attached to the ground electrode enclosed in a shielding box to reduce the noise. Figure 1(c) shows an example of charge, electric field, and potential distributions obtained by applying a dc bias voltage to a polystyrene sheet. As the specimen does not contain internal charge, only induced charges on the electrode were observed as shown by the solid line q. By integrating the charge profile, the electric field distribution is obtained as the broken line E, then by integrating the field, the potential distribution is obtained as the dotted line P. These three profiles give the fundamental performance of the individual system.

3. Mountable PEA unit

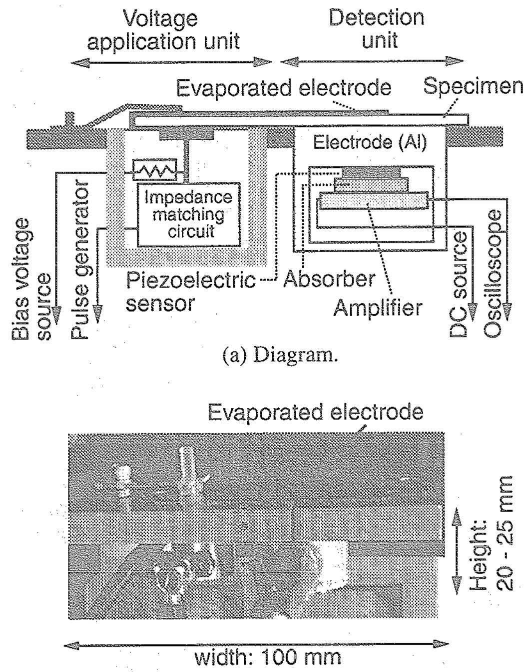
In order to apply the PEA method in space environment monitoring, i.e., to use it in an irradiation chamber in this study, we have developed a small PEA unit, and was modified as shown in Figure 2 to observe space charge profiles in situ under irradiation. The two electrode units were placed in a line to avoid covering irradiation surface. The pulsed electric field is applied to the specimen from the voltage application unit (left hand side in Figure 2) through the evaporated 'top' electrode. The acoustic waves generated by the applied pulse and charges are detected by the piezoelectric sensor of the detection unit (right hand side in Figure 2).

This mountable-PEA unit was mounted onto a vacuum chamber that is called SIRENE [9] at ONERA-CERT as shown in Figure 3. The spatial resolution in the thickness direction was about 15 μm.

3. Charge accumulation under iradiation [10]

Figure 4 shows the space charge profiles in a PMMA sheet under and after electron-beam irradiation. Firstly the specimen was irradiated at 200 keV, 1 nA/cm^2, and the charge profile appeared as the thin solid line in Figure4. By leaving the specimen in vacuum without irradiation, the charge decayed during 13 hours and became the broken line in the figure. With additional irradiation at 300 keV, 1 nA/cm^2, the charge accumulated at deeper position. These results prove that the mountable PEA unit can be applied for in situ space charge observation in a vacuum chamber.

Common materials used in the space, such as polyimide, have been also used as specimens. Figure 5 shows charge accumulation in a 125 μm thick polyimide film under electron-beam irradiation of 95 keV, 220 pA/cm^2. The charge profile obtained immediately after beginning the irradiation is shown as the broken line indicated as 0 min. The negative internal charge increased with time, and the profile was changed into the solid line after 20 minutes of irradiation. This space charge behaviour will be discussed in the near future with more precise numerical simulation.



(a) Diagram.

(b) Photograph.

Fig. 2 Mountable PEA method.

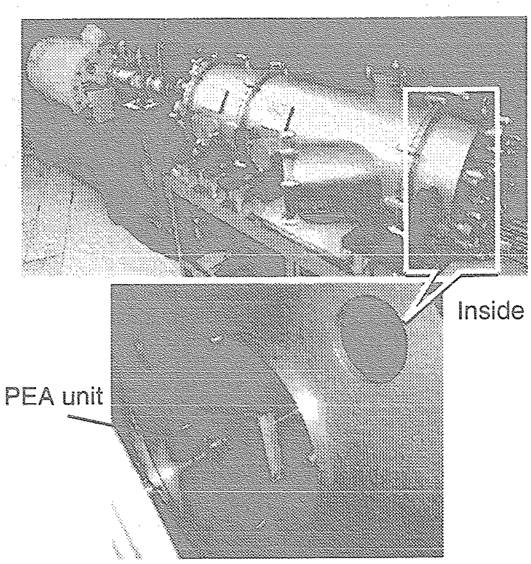


Fig. 3 Mountable PEA method and irraidation chamber 'SIRENE'.

4. 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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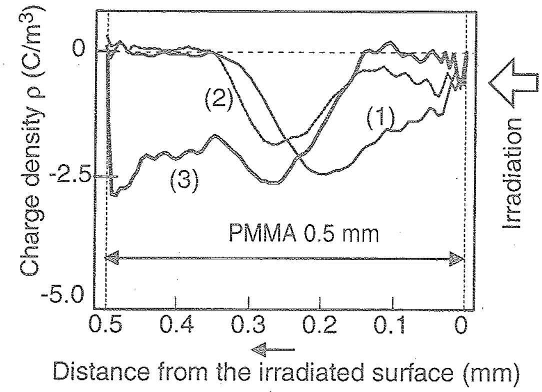

Fig. 4 Space charge profiles of a PMMA sheet under and after irradiations. (1) 200 keV, 1 nA/cm², 4 min., (2) after 13 hrs without irradiation, (3) 300 keV, 1 nA/cm², 4 min.

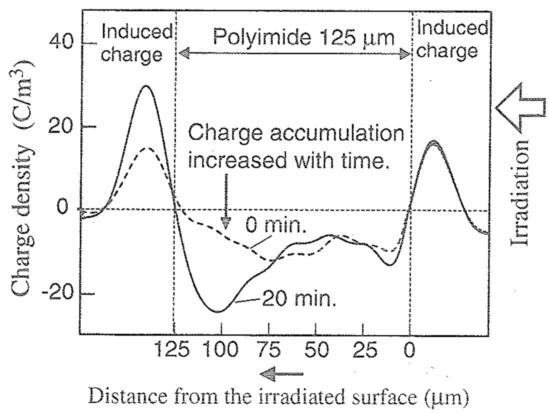

Fig. 5 Space charge profiles observed with a polyimide film under electron beam irradiation of 95 keV for 20 minutes.

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