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Review

Non-contact in-situ pulsed electro acoustic method for the analysis of charge transport in irradiated space-used polymers

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The characterization of dielectric materials in space environment requires to understand and predict their electric behaviour, taking into account ionisation, and ageing effect (through electron or UV radiation, thermal cycling, …)

For this purpose, new methods have been developed for the characterisation and qualification of space materials and satellite structure. These studies led initially to the development of dedicated facilities for the simulation of representative irradiation conditions. This work is focused on a new non-disturbing technique for the measurement of charge distribution within space irradiated polymers. This technique named PEA (Pulsed Electro-Acoustic) has been implemented in the irradiation facility for in-situ and real time measurement during irradiation and relaxation of polymer materials. Implementation and validation of this technique are presented and discussed in this paper.

1. Introduction

Dielectric materials are frequently used in satellite structures for electrical insulation, mechanical support or temperature control systems. These materials have to cope with intense charged particle irradiation that induces charging and potential electrostatic discharges on these elements, which may cause satellite anomalies. In order to prevent catastrophic failures, the effects of the charges on the system and their influence on the physical properties have to be investigated. One of the prime requirements for material qualification and physics analysis in the laboratory is to be able to irradiate specimens with electron beams representative of the energy spectrum encountered in space. Irradiation and test under high vacuum conditions are necessary to understand charging and discharging activities [1].

A multi-energetic vacuum chamber called “SIRENE” has been developed for simulating the spatial electron geostationary environment during periods of intense geomagnetic activity [1]. “SIRENE” is equipped with a non-contact surface potential measurement system (Kelvin probe). This method allows a good qualification of space materials and put into evidence physical processes steering material charging in space, for instance Radiation Induced Conductivity [2]. However, a comprehensive understanding of these physical mechanisms requires the use of complementary characterisation techniques, especially for the measurement of charge distribution in the material. Different techniques have been developed for this purpose during the last 15 years, e.g., thermal [3], pressure wave [4] or Pulsed Electro Acoustic (PEA) method [5–7]. Some of these have been applied for measuring the distribution in open air after irradiation, meaning that the samples have to be removed from the irradiation chamber [8]. These ex-situ measurements have severe drawbacks. The effect of compensating charges from gaseous molecules, such as water vapour, which could affect the relaxation of the irradiated material [8], does not prevail in vacuum. The applied field acting on the trapped charges is moreover expected to be different in amplitude and direction depending on the measurement configuration. In-situ measuring of charge distribution in the irradiation chamber should provide more useful information to understand the phenomena involved in space. Among several space charge measurement techniques applied for in-situ observations [9–11], it has been decided to develop a non-contact PEA system in the SIRENE irradiation facility.

The objective of this work was to implement this technique and operate a PEA in-situ device in this irradiation chamber able to

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reproduce the energy distribution of electron beams encountered in space environment. The system has to work under vacuum and measurements have to be performed during and after electron irradiation without vacuum break-up. The measurement bench has been tested and validated through high energy electron irradiation of fluorine polymers. In a first part of this paper, we present the implementation and operation of PEA cell that has been installed in the irradiation chamber. The second part described the validation process of this method which lied on charge distribution measurements in irradiated polymers (with varying incident energies).

2. Experimental set-up

Two basic and distinct components are described (a) the irradiation facility that reproduces the spatial environment with an assembly of special equipments and (b) the PEA device that provide information on the evolution of the implanted charges in materials.

2.1. Irradiation chamber

The SIRENE experimental simulation facility, installed at ONERA (Toulouse, France) and funded by the French space agency (CNES), reproduces the distributed electron spectrum encountered in space in the range 0–400 keV and allows the assessment of charging potential and electric properties of space materials in GEO orbit conditions. The electron spectrum simulation is achieved by use of two monoenergetic electron beams (20 and 400 keV), these two beams being diffused in energy and angle to produce a space-like electron flow with a good flux homogeneity in a diameter equal to 20 cm on the sample holder. Fig. 1 shows the electron beam spectral characteristics of the SIRENE facility with an energy spectrum approaching that of the geostationary charging environment.

The advantage of SIRENE is that it combines low energy electrons (that impinge and are implanted within the material bulk and induce electric charging) with higher energy electrons which go through the material without causing any charging but which contribute to modify its conductivity through the radiation induced conductivity mechanism [2]. The nominal fluxes used for the 20 keV monoenergetic beam and the distributed 400 keV one are respectively equal 250 pA cm^{-2} and 50 pA cm^{-2} but can be raised respectively up to 1 nA cm^{-2} and 200 pA cm^{-2}. The temperature of the sample holder (which size is 20 by 20 cm) can be controlled in the range [−180 °C, +250 °C] allowing to reproduce the temperature variation of materials on flight. The distance between the samples and the chamber walls is approximately 20 cm. A pumping system allows experiments at vacuum of around 10^{-6} hPa. Due to this flexibility and representativeness, the SIRENE facility then allows a good and realistic prediction of charging levels at geostationary orbit as well as a good understanding of the different involved physics mechanisms. A contact-less electrostatic probe (Kelvin probe TREK 3455ET coupled with an electrostatic voltmeter TREK 341B), combined with a X–Y motion system, scans the samples at around 3–8 mm from their surface and allows the evaluation of the surface voltage of the materials. Surface potential is then continuously recorded during the experiments allowing the assessment of the electric conductivity as a function of relaxation time and electric field using the relation:

$$\sigma(E) = \varepsilon_0 \varepsilon_r \frac{\dot{V}_s}{V_s} \quad (1)$$

where ε_0 and ε_r are, respectively, the vacuum and the material relative permittivity, and V_s represents the surface voltage of the material. This relation is derived from the electric potential relaxation after irradiation by modelling the sample as a parallel combination of a capacitor and a resistor.

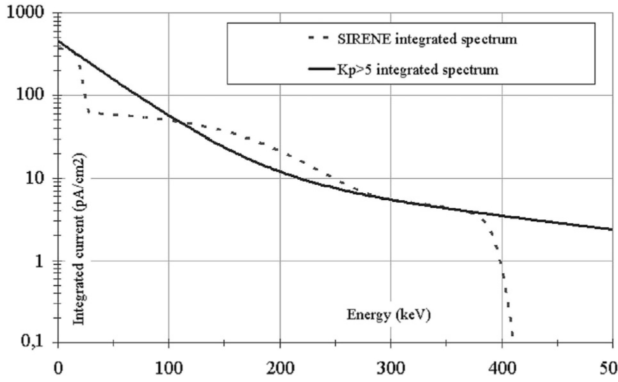

Fig. 1. SIRENNE standard spectrum and reference KP > 5.

2.2. PEA classical device

The PEA method was developed by the research group of Takada et al. [12] and was analysed by Bernstein [13]. Only a brief description of the principle of this technique is done in this section, Fig. 2.

The tested dielectric material is placed between two electrodes. A semi-conducting layer (carbon black-reinforced polymer)—SC—film is inserted between the excitation electrode and the sample in order to ensure a better acoustic impedance adaptation. Charges within the sample are stimulated applying a voltage pulse on the upper electrode. The pulse creates a Coulombian force exerting a motion of charge around their equilibrium position. This motion generates an acoustic wave, which propagates through the lower electrode and piezoelectric sensor. Then, the piezoelectric sensor converts the acoustic wave into an electric signal. The obtained voltage signal is amplified (RF amplifier with a gain of 30 dB) and finally, with a suitable deconvolution method, the distribution

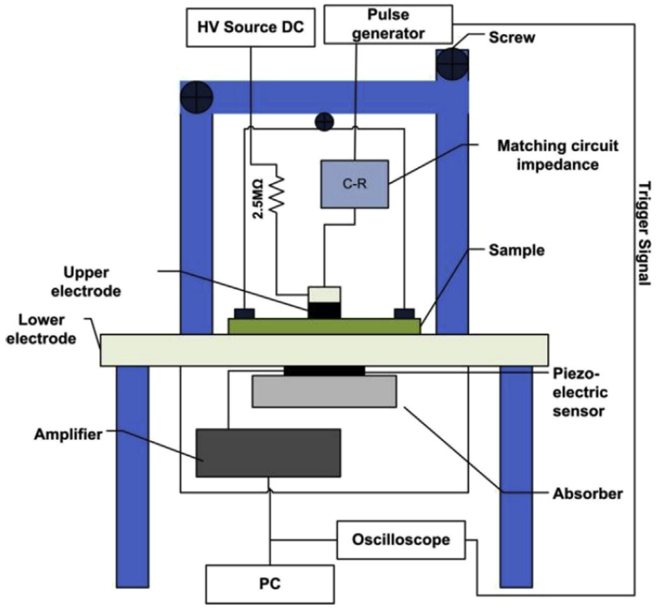

Fig. 2. PEA with contact cell device.