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Study of radiation induced conductivity and photoconduction phenomenon for materials used in space environment

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ABSTRACT

Dielectric materials used in space on satellite structure may have to cope with strong levels of charging under electron irradiation in space environment. This could lead to potential hazardous electrostatic discharges and consequent anomalies on the satellite, such as electromagnetic disturbances or, in worst case, the destruction of some on-board systems. These materials need to be tested on-ground to assess their electric behaviour and predict any risk of failure in space environment. The SIRENE facility, installed at ONERA (Toulouse, France) allows the simulation of geostationary orbit electron environment and the evaluation of charging capabilities of material samples. In this work, we study radiation induced conductivity for Teflon® FEP (fluorinated ethylene propylene) and Kapton®. Photoconduction processes have also been analysed on Kapton® and results are presented in this paper. The experimental analyses have been performed through non-contact PEA technique. This technique was implemented in SIRENE to better understand charge carrier transport in dielectric materials used in space application.

1. Introduction

Dielectric materials used in space on satellites have to cope with significant charging risks under the effect of space environment. Indeed, in geostationary (GEO) orbit, the electron flux (up to around 2×10^{10} electrons s^{-1} cm^{-2}) and energy levels (from a few keV to around several MeV during storm events [1]) are likely to induce high levels of charging for some materials. Actually, charging behaviour in these space conditions strongly differs from one material to the other. Some materials, like polyimide (Kapton®), do not strongly charge after a long period in flight, due to the elevated induced conductivity initiated by space radiation, while other materials, like Fluorinated ethylene propylene (FEP), can reach high and hazardous charging potentials due to a steep rise of their electric induced resistivity with the increasing radiation dose. Charging of space components on satellite is nowadays of great concern for satellite designers and manufacturers since this process can lead to elevated electric potential differentials between neighbour elements (due to strong discrepancies in electric properties of space materials) inducing then electrostatic discharges or permanent arcs on electric active elements (such as the solar panel cells). This discharge occurrence must bring on strong electromagnetic disturbances and false commands, and, in extreme cases, damages, destruction or loss of some satellite systems [2]. It is therefore of great importance to avoid any potential high charging levels and to protect satellites from electrostatic discharges. In order to assess the risk of charging, it is necessary to understand and model charging physics as well as radiation dose and ageing effect on the different space used materials.

Charging behaviour of polymers used in space environment is very specific, as we can see in Fig. 1. The charging process is performed using a mono-energetic electron beam of 20 keV coupled with a multi-energetic electron beam with an energy range between 0 and 400 keV. These materials usually present steady evolution of their charging potential along the irradiation duration due to several physical processes occurring under high energy electron irradiation. Ionisation processes initiated by these particles going through the material induce an enhancement of the effective electric conductivity (called Radiation Induced Conductivity [RIC]) that evolves with radiation dose rate and total radiation dose (proportional to the irradiation duration) [4–6]. Some materials, like polyimide, can also be strongly ionized under UV and visible photon radiation and their conductivity is enhanced drastically:

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this is called photoconduction. Description of radiation induced conductivity and photoconduction of space polymers is of high importance for a good and realistic prediction of charge build-up in space by these materials.

A multi-energetic vacuum chamber called “SIRENE” [7], installed at ONERA (Toulouse, France) and funded by CNES, was developed for simulating the spatial geostationary electron environment during periods of intense geomagnetic activity, in the energy range [0–400 keV]. “SIRENE” is equipped with a non-contact PEA (Pulsed Electro Acoustic) device to analyse the evolution of charge distribution. This device, coupled with surface potential measurements performed with non contact Kelvin probe (KP) method, has been applied in this current work to study and understand radiation induced conductivity processes on two polymers used in space (Teflon® FEP and Kapton®) and photoconduction mechanism on Kapton® polyimide.

FEP and Kapton are used due their presence in satellite structure. Different irradiations are used in order to simulate the real GEO irradiation conditions and to have several charging scenarios in order to understand the physics underlying charge transport. Photoconduction is only studied in the case of Kapton since it has been previously demonstrated that FEP material do not present any significant photoconduction process.

2. Experimental set-up

2.1. Irradiation chamber

A unique feature of the SIRENE experimental simulation facility is that it simulates the charging effects produced by the electrons in space environment with spectrum in energy ranging from 5 to 400 keV. This is achieved by the use of two monoenergetic electron beams (20 and 400 keV), the initial beams being diffused in order to get a space like electron radiation configuration. Fig. 2 shows the electron beam spectral characteristics of the SIRENE facility with an energy spectrum approaching that of the geostationary charging environment. The major interest of SIRENE is that it combines low energy electrons (those stopped within the material bulk and responsible for charging) with higher energy electrons, which go through materials, induce ionisation and activate therefore radiation induced conductivity.

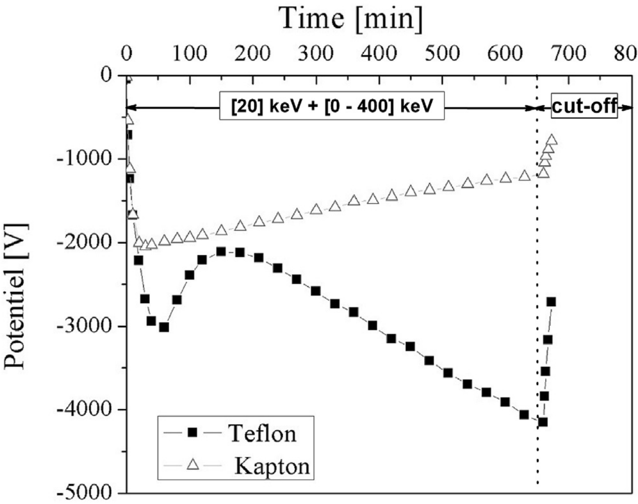

Fig. 1. Evolution of surface potential for Teflon® (FEP) and Kapton® submitted to geostationary electron irradiation [20 keV, 250 pA cm^{-2}] + [0–400 keV, 50 pA cm^{-2}] during irradiation and after beam cut-off [3].

Predicting charge levels at geostationary orbit is much more realistic with SIRENE than with classical monoenergetic electron guns. In the context of this study, three electron beams (20, 70 and 400 keV) have been used in sequence (not simultaneously) in monoenergetic mode. The 20 and 70-keV electron beam was used to charge the samples at the surface or in the bulk, then it was cut off, and PEA measurement was recorded. For RIC studies, the 400-keV electron beam was used to stimulate the potential decay and characterize therefore radiation induced conductivity through KP and PEA measurements. For photoconduction studies, after the sample (Kapton) has been charged using 20 and 70-keV in full darkness, it was exposed to light radiation with an halogen lamp of 500 W for a given period of time then the characterization of this phenomenon has been performed using PEA.

2.2. Non-contact PEA device

PEA is a technique used in the field of space charge measurements. The principle is based on the interaction between high voltage pulses and charge layers accumulated in the insulators to generate acoustic pressure waves which move across the material. Detailed reviews on the PEA technique can be found in the literature [8–15]. To summarize, acoustic pressure waves are produced by the application of an external electrical pulse which interacts with charge layers at the electrodes and/or in the material. The acoustic waves, which are proportional to the charge layers, are converted into an electrical signal by a piezo-electric transducer then this signal is amplified and captured with a digital oscilloscope. Then the charge distribution is estimated using a suitable PEA signal processing. PEA classical system can only be used outside the chamber and allows measurements at the end of irradiation in air. This system has been modified to run in situ measurements in the SIRENE facility.

In the modified PEA device (see Fig. 3), the detection unit is still located at the back of the sample but the voltage pulse is applied on a moveable electrode placed at few millimetres from the tested sample. Pulsed voltage is generated with a high voltage pulse generator FPG 5-05NM20 (from FID GmbH Germany). The generator is designed to produce voltage pulses from 1.6 kV to 5 kV into 50 Ω load. The rise time of the pulse is about 1 ns and the pulse duration at 90% of amplitude is between 3 and 20 ns In the measurement position, the moveable electrode is located just above the sample surface, the irradiation being switched off for a short period. The electrode then is transferred to the rest position for irradiating the sample. The sample is glued to the detection unit electrode to provide a good contact and to ensure a proper transmission of the

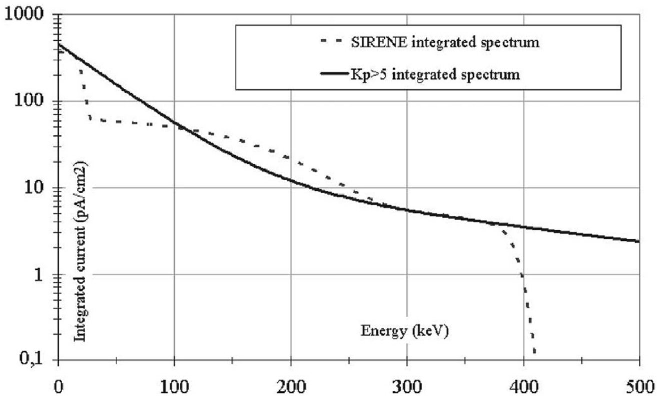

Fig. 2. SIRENE electron beam spectral characteristics (integrated spectrum delivered by a complex window and Kp > 5 integrated reference spectrum).