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Electrostatic behaviour of space used materials in regard of internal charging met on spacecrafts

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A B S T R A C T

This paper is dedicated to the characterisation of charging behaviour of space used polymers in space electron environment. Spacecrafts are indeed submitted in Medium Earth Orbit (MEO) to severe fluxes of electrons with energies ranging from a few keV to several MeV. For qualification of materials used on satellites and the prediction of their electrostatic behaviour in space environment, it is therefore important to tests these materials in representative environment. These experiments have been carried out at ONERA, The French Aerospace Lab (Toulouse, France) in the SIRENE facility. Different polymers (PEEK, ETFE, Kapton®, polyurethane and silicone varnish, polyurethane based paint) have been characterised to extract the main electric parameter that steer their charging behaviour in space environment: the radiation induced conductivity (RIC). These materials have then been tested in representative environment so as to study the evolution of their conductivity and charging behaviour as a function of the received radiation dose (for low and high dose levels). From these experiments, it was possible to extract the physical parameters that steer RIC and assess numerically their charging levels in specific MEO environment.

1. Introduction

Materials used on spacecraft have to cope with strong level of electron and protons fluxes. These charged particles impinge on the external surfaces of the spacecraft. The high energy particles can come through the first external surfaces to get implanted within the inner dielectric parts of the spacecraft (see Fig. 1). This irradiation process induces internal electric charging on the insulating and dielectric parts of the spacecraft, with potentially high charging kinetics (if strong electron fluxes are met, like in MEO [Medium Earth Orbit] environment for instance for GPS [Global Positioning System], GLONASS [Global Navigation Satellite System] or Galileo spacecrafts) [1,2]. Different anomalies ascribed to internal charging and consequent electrostatic discharges induced by the environment have already been observed on different spacecrafts [3,4]. The electric potentials built up at the surface of the irradiated materials depend on the electric properties of these materials (bulk and surface electric conductivity, dielectric permittivity, secondary electron emission yield). Electron irradiation can therefore yield to significant potential differences between adjacent elements, which can generate high electric fields and the initiation of surface or bulk electrostatic discharge and electric arc that may induce different anomalies in the spacecraft: electromagnetic disturbances, damages on electronics and alteration of the electric properties of dielectric materials.

Space used dielectric materials present very specific behaviour in space environment due to the effect of high energy particles that come through the material and affect their electric properties due to ionisation and ageing processes. Strong differences between polymer materials like Kapton® and Teflon® have been observed experimentally under representative GEO (Geostationnary Earth Orbit) electron irradiation [5]. For instance, Kapton is highly conductive in this condition and becomes more and more conductive with the increasing radiation dose. On the contrary, Teflon Fluorinated Ethylene Propylene (FEP) exhibits a non-monotonous charging behaviour with a radiation induced conductivity that tends to decrease with the increasing radiation dose after a given dose threshold. We can then notice very specific behaviour under GEO like irradiation in comparison to what could be observed when materials are only irradiated with low energy electrons [5].

Most of the polymers tend to become more conductive with irradiation. The electrical conductivity is enhanced by high energy electron irradiation through ionisation processes; this is commonly referred to as radiation induced conductivity (RIC) [6,7,8]. The induced conductivity in polymers is well documented both experimentally and theoretically [5–13]. Space material are therefore submitted to charge implantation (due to low energy electrons) and ionisation process that tends to further charge leakage.

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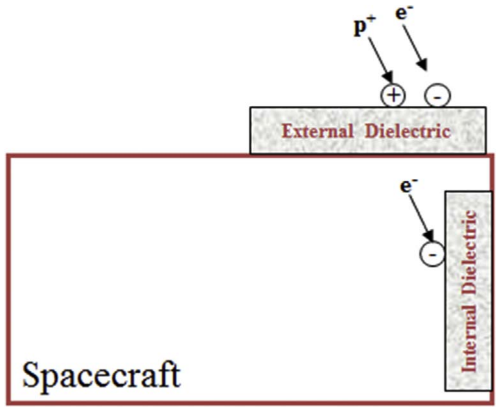

Fig. 1. Overall view of surface and internal charging process on irradiated spacecraft.

Radiation induced conductivity evolves with radiation dose rate and radiation dose injected within the material. In most conventional code, RIC is supposed to be only dependent on radiation dose rate and follows the relation below [6]:

$$RIC = k_{RIC} \cdot (dD/dt)^{\Delta} \quad (1)$$

for which k and Δ are empirical parameters depending on the irradiated material, D the injected radiation dose and dD/dt the radiation dose rate.

RIC has been described through specific physics models used for the prediction of charging behaviour of space materials under continuous and long electron irradiation [5,8,9]. High energy electrons transfer a large quantity of energy within the irradiated material that allows extracting electrons from the Valence band to the conduction band (the remaining electron shortage in the Valence band is named a "hole"). Both charged particles (electrons and holes), once injected and generated in the conduction band, can get trapped in physical and chemical defects, detrapped from these defects and get recombined with an opposite charge carrier. The kinetics of trapping, detrapping and recombination of both charge carriers (electron and holes) strongly varies from one material to the other yielding to very specific behaviour for each tested material [2]. Furthermore, free charge carrier can dwell for a long period of time (up to several years) with the material. Effect of radiation dose does then prevail after the end of the irradiation process: we speak about delayed RIC (DRIC) [10,11]. DRIC can keep up high levels for Kapton® for a long period of time while it fades away quite quickly for Teflon® FEP. Successive irradiations can then present different profiles depending on DRIC relaxation kinetics: for Teflon® FEP, for instance, DRIC fades away quite quickly. But this quick decline does not induce total recovery: electron trapped during previous irradiations act as recombination centers for the following irradiations, leading to a decrease of the effective generation rate and therefore to a decline of RIC [12]. For Kapton however, decline of DRIC is very slow and Kapton keeps up therefore high conductivity for a long period of time without any reversed RIC since trapped charge carrier can get detrapped easily: this material tends therefore to get more and more conductive [13].

The charging behaviour of space used materials can therefore be very different from one material to the other. It is thus important to take great care on the characterisation process of the different involved materials for a good and realistic prediction of their charging level in space environment.

The objective of the current study performed at ONERA (Toulouse, France) is then to assess the conductivity level of space used insulating materials in representative electron flux and calculate, through a dedicated model, the charging of materials in representative electron environment. The characterisation step includes extraction of intrinsic bulk conductivity and radiation induced conductivity (RIC). The effect of delayed RIC (DRIC) on the long term charging behaviour was also analysed on different space used materials. The influence of these different conductivities has been assessed on all defined materials so as to be able to predict charging behaviour in very different irradiation conditions. The physical model used for charging prediction will be presented followed by a validation and the use of this model for charging prediction of PEEK in averaged MEO conditions.

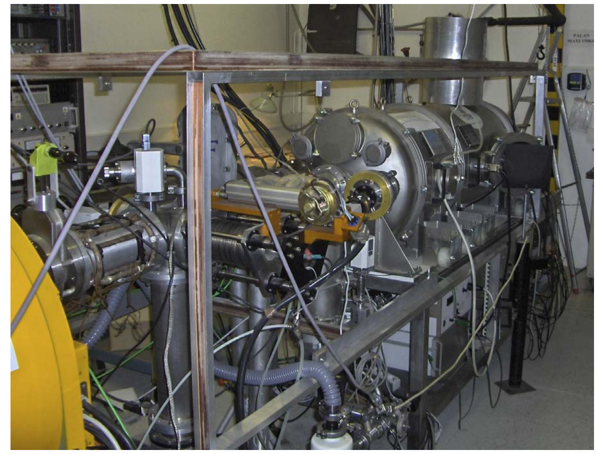

Fig. 2. View of the SIRENE irradiation facility.

2. Experimental set-up and protocol

2.1. Irradiation facility

SIRENE (Fig. 2) is a sophisticated and unique test facility especially designed for the study of surface and internal charging of space materials and satellite components under extreme environment (usually geostationary orbit radiation conditions). This facility is able to reproduce the geostationary electron spectrum (in the energy range [0–400 keV]). It allows realistic assessment of potential built up in geostationary orbit. Its flexibility allows the simulation of extreme environments different than the geostationary one (eg, MEO, LEO [Low Earth Orbit] or other planetary radiation environments). This facility is widely used as well for the characterisation of radiation induced conductivities of space materials in vacuum. Using the high energy electron beam and a high incoming flux on the sample (up to 10 nA cm^{-2}), we are able as well to perform radiative ageing on the material. Space materials, such as polymers, adhesive or coverglasses can then be aged in SIRENE with equivalent flight durations equal to several months or years. The electron spectrum simulation is achieved by the 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. The nominal integrated fluxes used for the 20 keV monoenergetic beam and the distributed 0–400 keV one are respectively equal 250 pA cm^{-2} and 50 pA cm^{-2} but these different fluxes can be changed independently. The temperature of the sample holder can be controlled in the range [-180 °C, +250 °C] allowing to reproduce the temperature variations of materials on flight. A pumping system allows experiments at vacuum of around 10^{-6} hPa. It is instrumented with a contact-less electrostatic probe, current measurement systems and non-contact PEA [Pulsed Electro-Acoustic] device. Thanks to these different experimental specifications (bulk conductivity and RIC characterisation, temperature effect) and its spectrum flexibility, the SIRENE experimental facility is highly relevant for the current study, especially regarding the characterisation of bulk conductivity and RIC as well as delayed ionisation effects (DRIC) dose on the different selected materials. SIRENE can be connected as well to a Transfer Unit which enable the transfer of samples irradiated in SIRENE to a vacuum storage unit or to other irradiation facilities. This sample transfer is performed under