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Characterisation of charging kinetics of dielectrics under continuous electron irradiation through real time electron emission collecting method

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ABSTRACT

Dielectric materials used for spacecraft applications are often characterised under electron irradiation in order to study their physical and electrical mechanisms. For surface potential measurement, a small removable flat device based on the secondary electron spectrometer method has been developed and installed in the CEDRE irradiation test facility at ONERA (Toulouse, France). This technique was developed to get rid off specific issues inherent to the Kelvin Probe technique. This experimental device named REPA (Repulsive Electron Potential Analyser) allows in situ and real time assessment of the surface potential built up on dielectric materials under continuous electron irradiation. A calibration has been performed in order to validate this experimental setup. Furthermore, to optimise its efficiency, the physical behaviour of this device has been modelled and numerically simulated using Particle In Cell (PIC) model and a dedicated numerical code called SPIS (Spacecraft Plasma Interactions System). In a final step, electrical characterisations of a charged dielectric have been carried out under continuous electron irradiation with this new method. These results have been compared with measurements performed in same experimental conditions with conventional Kelvin Probe method. The experimental results have been discussed in this paper. To conclude, advantages of this experimental setup in regard of this application will be emphasised.

1. Introduction

In space conditions, dielectric materials, used on spacecraft, have to cope with strong electron radiation levels that may lead to strong charging and discharging hazards as well as material degradation and the alteration of their physical properties. Accurate electrical characterisations and the use of dedicated experimental techniques are of high importance for thorough extraction of the electric properties of the material. One of the main issues is the measurement of electric potential built up at the dielectric surface by electron radiation. The use of conventional measurement techniques such as non-contact Kelvin Probe (KP) method [1–3] can become insufficient and inconvenient if the tested dielectric material presents a large electric conductivity. During the KP procedure, the electron beam is indeed switched off by the probe during measurement. This process may cause a significant relaxation of charges. Moreover, the low measurement frequency of this technique may also result in an underestimated measure of the surface potential.

This paper describes the development, operation and optimisation of a new measurement device called REPA (Repulsive Electron Potential Analyser) and devised at DESP (ONERA Toulouse, France) to characterise the charging kinetics of dielectrics under continuous electron radiation in a vacuum test chamber. The principle of this experimental device is based on secondary electron (SE) spectrometer method [4,5]. Several kinds of detector based on this method have been designed and used since many years and especially in the Scanning Electron Microscope (SEM). Secondary electron spectrometers allow studying the secondary electron yield (SEY) of materials. Some spectrometers operate by electrostatic deflection and others by retarding field. The second kind of spectrometers is commonly called Retarding Field Analyser (RFA) [6] and its operating principle is similar to the REPA method. Their geometry is often hemispherical but the design, the biasing of grids and their distance between them vary from one device to another [3,7]. Different architectures and technologies of spectrometer

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have likewise been adapted especially in SEM in order to investigate the quantitative voltage contrast of specimens or Integrated Circuits (IC) [8]. Indeed, some devices operate by using radial electrostatic deflection fields [9,10] and others are based on pre-acceleration and retarding fields [11,12]. Other physicists have developed and optimised this kind of experimental setup with grids, named RPA (Retarding Potential Analyser) that allows determining ions energy [13].

Different spectrometers have therefore been used in several application domains since the first development of this analytic method. Thus, this paper explains the adaptation and the optimisation of such device that allows determining the evolution of surface potential of irradiated dielectrics over continuous radiation time. This new apparatus is non hemispherical, small and easily removable. A calibration process has been performed in order to validate both the measurement method and the developed prototype. The calibration process is described in this paper. For the development of this kind of equipment, it is important to consider the geometrical parameters such as space between the grids or the influence of their biasing. Thus, numerical simulations (PIC model) have been performed in order to understand the electrostatic configuration of this experimental setup in operation and ultimately optimise it. Consequently, we detail the adopted development approach as well as the different numerical tests performed with the SPIS software (Spacecraft Plasma Interactions System [14]). Experimental validation tests have then been carried out on glass samples with both measurement techniques: Kelvin Probe and REPA methods.

2. Experimental set-up and method

2.1. Overview of irradiation test chamber (CEDRE)

The CEDRE facility is one of the many high vacuum electron irradiation test chambers localised at ONERA Toulouse. CEDRE means in French: "Chambre d'Etude De Revêtements Electrisés". In fact, this facility has the capability to be versatile and easily adjustable to characterise surface potential of electron irradiated dielectrics through several instruments (Fig. 1). Therefore, it is possible to assess the charging and discharging kinetics of spacecraft materials in space representative conditions. The vacuum level during tests is approximately equal to $5 \cdot 10^{-7}$ hPa. Chamber vacuum pumping is performed thanks to a dry pump group in order to limit contamination. An electron source is available to irradiate samples by controlling the flux and the energy of the electron beam. Another source such as a UV lamp can be easily installed if necessary. A ceramic heating element sustains the sample holder which can be whether floating or grounded. This experimental assembly developed at ONERA allows controlling the temperature in the range between 20 °C and 400 °C. The heating element can be used to assess the temperature influence on the conductivity. It also allows outgassing the samples before the irradiation tests. It has been used as well to discharge the samples after the irradiation test. The REPA instrument that is the focus of this paper is directly mounted on the sample holder. This assembly is installed on one of four faces of a rotating cube. Other instruments such as Faraday cups are installed on other cube faces. Thus,

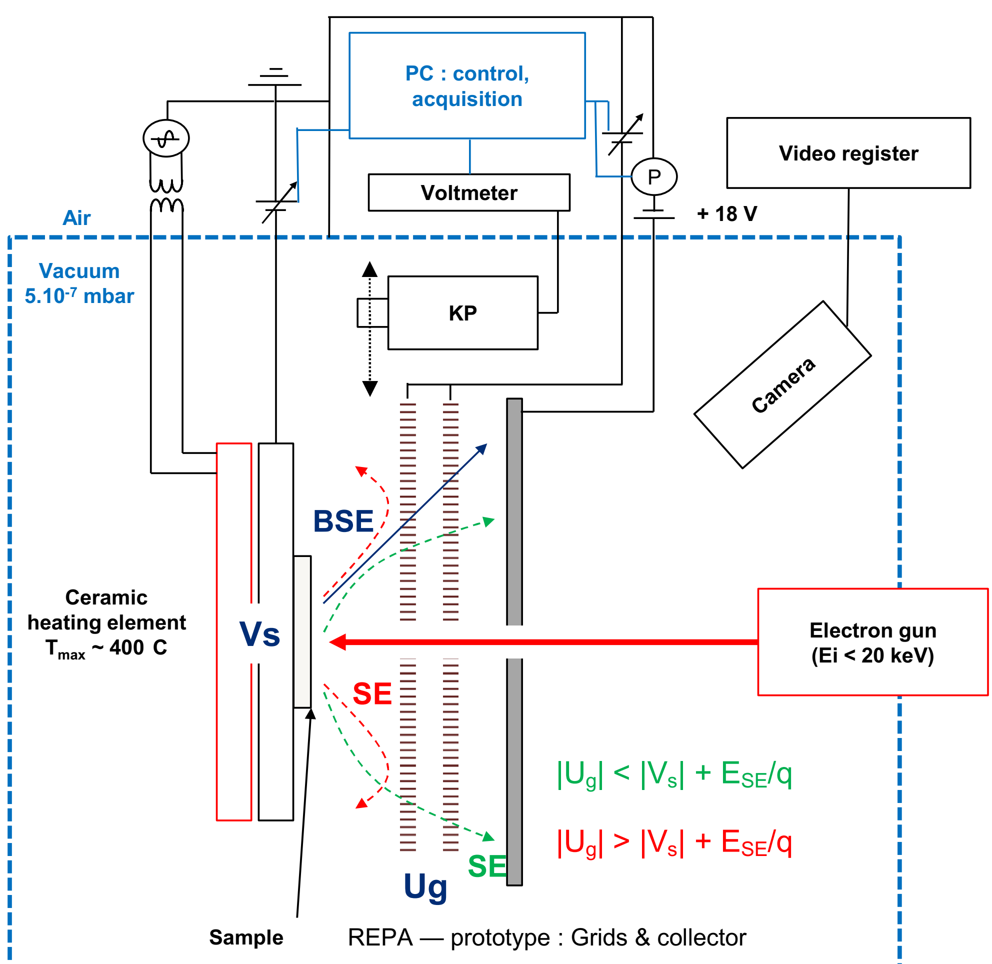

Fig. 1. CEDRE instrumentation and experimental device principle (side view).