201

INFLUENCE OF THE INJECTED CHARGE POLARITY ON THE ELECTRICAL BEHAVIOR of CMX 100-AR COVER GLASS SUBMITTED TO ELECTRON IRRADIATION

M. Belhaj, T. Paulmier, N. Guibert, D. Payan, N. Balcon

***Abstract*— under electron irradiation, insulating materials may charge either negatively or positively depending on their electron emission properties and characteristics of the incident electrons. The electrical behavior of these materials is linked to the sign of the injected charge. Some spacecraft materials may be subject is some situations to negative charging and in other situations to positive charging. The aim of this work is to investigate the effect of the sign of the injected charge on the electric characteristics of CMX 100 AR coverglass. It was shown that the positive charging leads to about 4 times higher surface conductivity than negative charging. The practical consequences of these results are then discussed.**

Keywords*—electron impact, dielectrics, charging, charge transport, CMX 100 AR coverglass, Invert Potential Gradient.*

I. INTRODUCTION

Charging of insulating materials or floating conductors under electron irradiation is a commonly encountered problem in many space applications. Spacecraft charging due to solar and cosmic radiations may lead to critical discharge phenomenon [1]. Indeed, under irradiation (especially electron irradiation), insulators as well as floating conductors may charge negatively or positively depending on the incident electron properties (energy incidence angle, flux) and on the specific material properties (composition, surface roughness, contamination [2], temperature [3,4], etc.). The knowledge of the electrical properties (electron emission yield, conductivity and radiation induced conductivity) under electron irradiation for each material of the spacecraft is needed for spacecraft plasma interaction modeling. Several experimental methods have been developed to measure the trapped charge or the associated surface potential under and after electron irradiation. These methods are usually base on the following measurements: the absorbed or influence current [5,6], electron spectrometry and X-ray spectroscopy [7, 8], electron beam deflection [9, 11] and kelvin probe [12]. Most of these techniques are restricted to the analysis of negatively charged materials. Indeed, when electron beam is used to charge the sample, the electrical properties such as the characteristic charge relaxation time or electrical resistivity were generally extracted from negative charging situation. However, it is generally admitted that charge localization and transport properties of holes and electrons may be very different depending on intrinsic material properties and nature of defects and impurities. Hence, it is expected that, under electron irradiation, charge relaxation of insulators will be very different whether the net deposited charge is negative or positive. In many cases and in particular in the Invert Potential Gradient (IPG) frequently encountered on satellites, a net positive charge is injected. Therefore, it is necessary to make a clear distinction between electrical properties under negative charging and positive charging. A method has been developed in order asses the charging behavior of dielectrics under both electrons or holes injection [13]. This method was applied to CMX-100 AR cover glass. The reported results show that negative and positive charging lead to substantial difference on the surface conductivity

M. Belhaj, N. Guibert, K. Guerch and P. Sarrailh are with the Onera- The French Aerospace Lab FR- 31055, France (e-mail: Mohamed.Belhaj@onera.fr)

D. Payan and N. Balcon are with CNES 18 Avenue Édouard Belin, 31400 Toulouse, France (e-mail: Denis.Payan@cnes.fr)

II. EXPERIMENTAL

A. *Experimental setup*

The experimental setup is shown in figure 1. An electron beam produced by a 2 keV-22 keV STAIB electron gun is focused on 0.8 µm Al foil biased at +10 kV. The Al foil is used to diffuse the incident electron beam, allowing the irradiation of the entire sample surface. A combination of five Faraday cups can be rotated in front to the Al foil in order to check the spatial homogeneity of the diffused electron flux and to measure the incident current density. The typical current densities used in this work are in the nA/cm² range. The sample holder can be independently biased up to 6 kV (negative or positive). An electrically isolated heater is fastened on the sample holder. A Monroe Kelvin probe attached to motorized translation arm is used to measure the surface potential along the sample surface

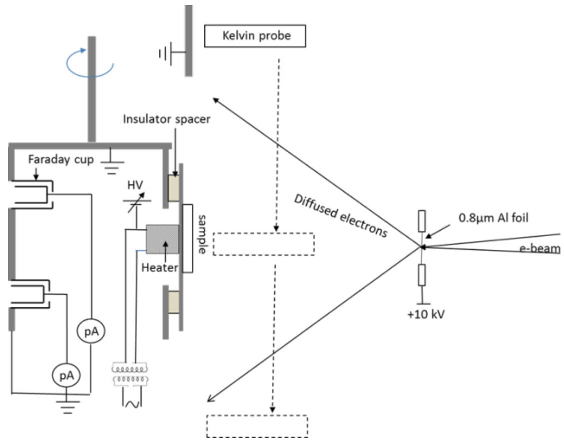

Fig. 1. CEDRE Facility

B. Sample

The studied samples are CMX-100 AR obtained from Qioptiq. The work was focused in this study on the surface conductivity. To avoid any volume conduction a Teflon sheet was placed between the sample holder and the rear side of the coverglass as it is shown in figure 2. The MgF_2 surface of the coverglass was electrically connected to the sample holder.

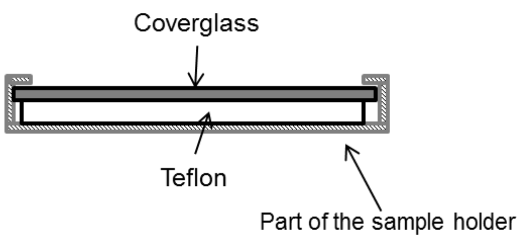

Fig. 2. The sample on the sample holder

C. Methods

The used methodology to inject both negative and positive charge at the sample surface or near surface is described in details elsewhere [13]. We recall here briefly the principle of the method. If the primary electrons (PEs) impact the insulator surface with energy comprised between the two crossover energies E_{C1} and $E_{C2,}$ the number of the generated holes is higher than the number of incoming electrons. Therefore, a positive charge builds up. However, only slight positive charging is expected due to the SEs potential barrier effect [2]. Indeed, as the surface potential becomes positive the electron emission yield (EEY) falls down rapidly resulting to a surface potential of only few volts. To overcome this charge limitation, one solution consists in applying an extraction electron field (suppressing the SEs potential barrier). In this study, this was done by biasing negatively the sample holder at few kV. It should be noted that, as the mean escape depth of SEs does not exceed few nm, the injected positive charge is located at near-surface region (the few first nm of depth of the insulator).

The straightforward way to inject a net negative charge consists in the use of incident electrons of energies higher than the second crossover energy, E_{C2}, (i.e. EEY< 1). Indeed, according to the total yield approach (TYA) higher the initial incident electron energy and higher the magnitude of charging [2]. As E_{C2} exceed few keV for most insulators, the incident electron energy must to be set at also few keV (typically 10 keV at the minimum). The maximum penetration depth of electrons of 10 keV in MgF2/SiO_2 is about 1 µm, which is much higher than the SEs mean escape depth (few nm). This will produce a negative space charge with a centroid much more generated in depth than that of the positive charge. As the main goal of this work is focused on the comparison of the electrical behaviour of the material as the function of the sign of the injected charge carrier, it is preferable to inject the negative charge at the lowest depth. Otherwise, the interpretation of the results will be complicated by the fact that in technical materials the surface properties are often different than that of the bulk. In order to inject the negative charge in the near-surface region, we used low incident energy and we had biased positively the sample holder. Thereby SEs blocking potential barrier is generated and the yield is forced to be always lower than one. This solution was already used by many auteurs [14-16] as positive charge neutralization method.

III. RESULTS

The CMX 100 AR cover glass was positively charged using the configuration shown on figure 3a. The electron gun accelerating voltage was set to 8 kV and the sample holder was biased to -5 keV. The landing energy of the incident electrons after crossing the Al diffusion foil is about 0.5 keV. In this configuration the electron emission yield is higher than 1. Therefore the number of generated holes exceeds the number of trapped electrons. Negative charging was performed using the configuration shown in figure 3b. The electron gun acceleration voltage was set at 5 kV and the sample holder was set at +2 keV, so that the landing energy of electrons was about 4 keV.

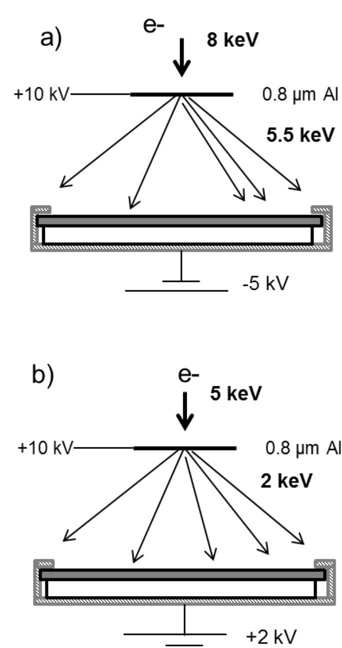

Fig. 3. The sample on the sample holder

Figures 4 shows the surface potential profiles measured on both situations during the charge relaxation step. Figure 5 shows the potential decay curves after positive and negative charge injection. The injection of positive charge (IPG situation) leads to higher discharging kinetic than the injection of negative charge. This result suggests that the hole mobility is higher than the electron mobility in the MgF_2.

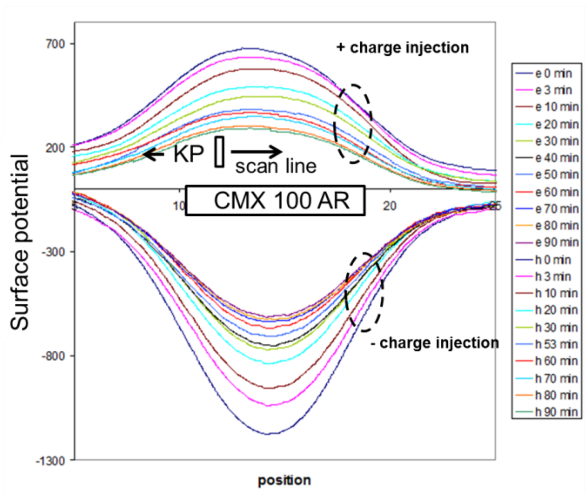

Fig. 4. Surface potential profiles measured on CMX 100 AR during the charge relaxation and after positive and negative charge injection (h= holes injevction and e=electrons injection).

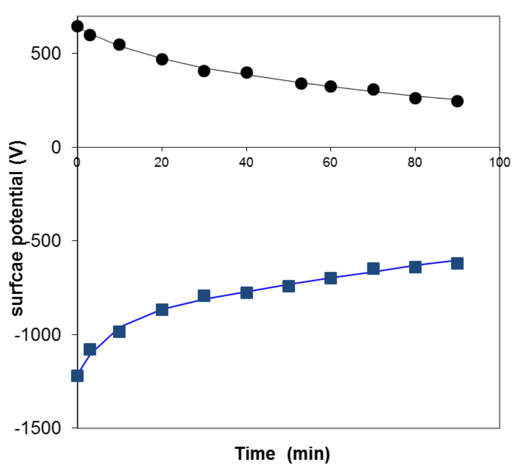

Fig. 5. Surface potential versus time on CMX 100 Ar durin the charge relaxaition after negative (bleu) and positive (black) charge injection

IV. Discussion

According to the model of a capacitor relaxing its charge through a resistance the resistivity is proportional to:

$$V_S \Big/ \left(\frac{dV_S}{dt}\right) \qquad (1)$$

The evolution of the expression 1 as function of the surface potential magnitude is plotted for negative and positive charge injection in figure 6. This figure illustrates perfectly the fact that negative and positive charging situations could not be described by common physical parameters.

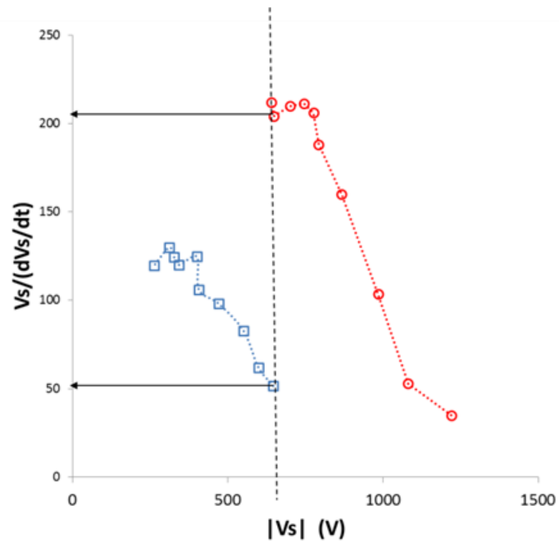

Fig. 6. Vs/(dVs/dt) curves as function of the magnitude of the surface potential after negative (red) and positive (bleu) charging.

It should be pointed out that in our community (space charging of spacecraft) the conductivity of insulating material is frequently extracted from surface potential decays experiments. To our knowledge, under e-irradiation, these data are often obtained using a charging beam of tens keV, that produces a negative charging. In many situations and in particular the situation of IPG: a net positive charge is injected into the material. The results presented here on CMX 100 AR show that the surface potential decay characteristics for a given material are highly dependent to the sign of the injected charge. The results highlight the fact that the electrical conductivity measured under negative charging could be very different from that measured on the same material but positively charged. For instance, at surface potential magnitude of 650 V (+ or -), the positive charging leads to a surface conductivity 4 times higher than the negative charging. This may be explained by the fact that the hole mobility in MgF_2 is higher than that of electrons. It was recently shown, that the ESD triggering voltage on IPG configuration is highly sensitive to proprieties of the surface charge transport of the coverglass [17]. According to this work, reducing the surface resistivity of CMX AR cover glass by a factor of 2.6, leads to 30% increase of the ESD triggering voltage. Accordingly, for better prediction in representative conditions, material conductivity should be assessed in respect with the polarity of the injected charge.

ACKNOWLEDGMENT

This work was performed in the framework of CNES R&T programs. The authors thank Qioptiq that provided the samples.

REFERENCES

[1] J-M. Siguier, V. Inguimbert, V, P. Sarrailh, D. Sarrail, G. Murat, J. Mateo-Velez, D. Payan, and N. Balcon, IEEE Trans. on Plasma Scient. , vol 40, 311, 2012.

[2] J. Cazaux, J. Appl. Phys. , vol 85, 1137, 1999.

[3] J. B. Johnson and K. G. McKay Phys. Rev. , vol 91, 582, 1953.

[4] M. Belhaj, T. Tondu, V. Inguimbert, P. Barroy, F. Silva and A. Gicque, J. Phys. D: Appl. Phys., vol 43, 135303, 2010.

[5] Z. G. Song, C. K. Ong, and H. Hong, J. Appl. Phys., vol 79, 7123, 1996.

[6] O Jbara, S Fakhfakh, M Belhaj, J Cazaux, EI Rau, M Filippov, MV Andrianov, Nucl. Instr.and Methods in Phys. Res. B, vol 194, 302, 2002.

[7] G. F. Bastin and H. J. M. Heijligers, in Electron Probe Quantification, edited by K. F. J. Heinrich and D. E. Newbury Plenum, New York,1991 p. 193.

[8] O Jbara, M Belhaj, S Odof, K Msellak, EI Rau and MV Andrianov, Rev. Scien. Instr., vol 72, 1788, 2001.

[9] M. Brunner and E. Menzel, J. Vac. Sci. Technol. vol B 1, 1983.

[10] B. Vallayer, G. Blaise and D. Treheux, Rev. Sci. Instrum., vol 70, 3102, 1999.

[11] M. Belhaj, S. Odof, K. Msellak, and O. Jbara, J. Appl. Phys., vol 88 2289, 2000.

[12] P. Molinié, M. Goldman, J. Gatellet, J. Phys. D, vol 28, 1601, 1995.

[13] M. Belhaj, T. Paulmier, R. Hanna, M. Arnaout, D. Payan and N. Balcon, Nucl. Instrum. and Methods in Phys. Res. B, vol. 320, pp. 46-50, 2014.

[14] H. J. Hopman, H. Alberda, I. Attema, H. Zeijlemaker, and J. Verhoeven, J. Electron Spectosc. Relat. Phenom., vol 51, 131, 2003.

[15] M. Belhaj, T. Tondu, V. Inguimbert, and J. P. Chardon, J. Phys. D: Appl. Phys., vol 42, 105309, 2009.

[16] Ming Weng, Meng Cao, Hong-Juan Zhao, and Hai-Bo Zhang, Rev. Scient. Inst., vol 85, 036108, 2014.

[17] Pierre Sarrailh, Jean-Charles Matéo-Vélez, Jean-François Roussel, Bernard Dirassen, Julien Forest,Benoit Thiébault, David Rodgers, and Alain Hilgers, IEEE Trans. On Plasm. Scien, Vol. 40, pp. 368-379, 2012.