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Charging effect, aging and storage conditions impact on SEY of Dielectric Materials for Flight Hardware

M. Belhaj¹, S. Dadouch¹, J. Duran², J. Sinigaglia², P. Mader², J. Galdeano³, D. Raboso³

¹ONERA: The French Aerospace Lab,

²Thales Alenia Space,

juan-antonio.duran-venegas@thalesaleniaspace.com

³European Space Agency

INTRODUCTION

It is widely assumed that the multipactor threshold of RF space equipment does not evolve between qualification and flight. While the threshold of a fully metallic RF component may be somewhat stable under controlled storage conditions, flight hardware that contains dielectric piece parts in its critical areas is harder to stabilise. Non-optimal storage conditions over long periods of time, contamination and charging effect have a sensible impact on the threshold. In the framework of ESA project EVEREST [1], it was clearly demonstrated that the surface aging during the storage period of RF hardware can have a direct impact on the multipactor threshold of flight hardware.

Particle-in-cell software can make realistic predictions of the Multipactor threshold of a given device based on the TEEY curve of its materials. However, when it comes to dielectrics, the dependencies of TEEY with ageing and charge are not fully understood. For that reason, the last release of the ECSS-E-ST-20-01C [2] recommends very high security margins for thresholds in the presence of dielectric (up to 12dB).

After manufacturing, space hardware is exposed to a specific atmosphere, in that moment a layer of hydrocarbon contamination begins forming over the surface. The composition of this layer depends on the surface reactivity, the atmosphere, the temperature and the humidity. Moreover, manipulation of the materials induces a specific charge distribution that is different for each component and depends on the type of dielectric and the specific process that the material underwent. Consequently, the surface composition and charge distribution of the materials in the hardware evolves from the manufacturing, through storage to the operational environment. These evolutions affect the TEEY of the material, which in turn have an impact on the Multipactor threshold.

In the framework of the ESA TRP activity “Impact of Storage Conditions and Aging Effect on RF Breakdown” a study was started in order to test and analyse how aging affects the TEEY properties of a group of relevant materials in the most common storage conditions for space equipment. In particular, three dielectrics (Teflon, Alumina and Ferrite) are stored in four different conditions (ambient atmosphere, ISO-8 clean room, Nitrogen atmosphere and moist atmosphere). The evolution of the TEEY and the surface chemical composition of the three materials is monitored during a storage period longer than two years. In order to correlate the TEEY to the multipactor threshold, dedicated RF components have been developed and two multipactor test campaigns, one on virgin samples and one at the end of the storage cycle are performed on selected samples.

So far, it has been observed that the TEEY and the surface composition have evolved significantly for all storage conditions during the aging process. Moreover, it has been found that electric charging has a very significant effect. Indeed, the evolution of the charging state of the samples (trapped charges) affects the TEEY parameters in such manner that can screen potential effect of contamination and storage on the electron emission properties for certain type of materials.

The goal of our contribution is to present and analyse the results and its consequences. Challenges related to the Guidelines can be deduced for long time material storage of critical RF equipment.

LOGIC OF THE STUDY

In this study, the ageing process of the electronic emission of a number of different materials and stocking conditions are studied. The objective is to anticipate high power handling, in particular Multipactor, for RF material that has been stored over long periods of time prior to launch. A description of the ageing process can be found in the complementary article [3] that deals with the ageing of metallic samples.

Due to project constraints, the ageing process has been divided in two halves. A first ageing campaign of around 20 months where the samples have been stored in the Thales Alenia Space facilities, as would be the case for flight models. And another ageing campaign of 20 to 22 months where the samples have been stored both at Thales Alenia Space and ONERA, both under similar conditions.

In this paper, three different dielectric materials are analysed over the course of the two ageing campaigns. Adding up to a total of 46 months spanning from 2017 to 2021. The materials studied are:

- Teflon
- Alumina
- Ferrite

Two types of samples were designed for this project:

- Sample type #1 : only suitable for SEY measurements,
- Sample type #2 : suitable for SEY and Multipactor measurements.

Storage Conditions

The aging process has been realised in the following storage conditions:

- Storage conditions #1: Nitrogen closet
The samples are stored in a nitrogen closet inside of a clean room. The nitrogen closet constantly influxes nitrogen into the closet atmosphere and extracts air. This way an air current is ensured and all the non-nitrogen molecules are swiftly extracted should the closet be briefly open.
- Storage conditions #2: Clean Room ISO-8
The samples are placed in a clean room (ISO-8) similar to that of an integration room.
- Storage conditions #3: Shelf under uncontrolled atmosphere
The shelf mimics uncontrolled conditions. The shelf is however placed in a closed closet, far from any window.
The room has morning sun exposition, and temperature controlled by A.C. and heating during working hours. The sample are kept inside of a box. The outdoor conditions feature daily thermal cycles of about 10° and long term thermal cycles of about 35°.

Additionally, the samples under storage condition 3 also undergo the following conditions at the end of the ageing process:

- Storage conditions #4: Hot damp
These conditions are designed to mimic the ageing during qualification and the storage prior to launch. The samples underwent 14 days of 40°C at 93% HR

Campaign Logic

For each of the studied materials, the samples have been divided into three groups (one per storage conditions) and followed the ageing cycles depicted in Fig 1.

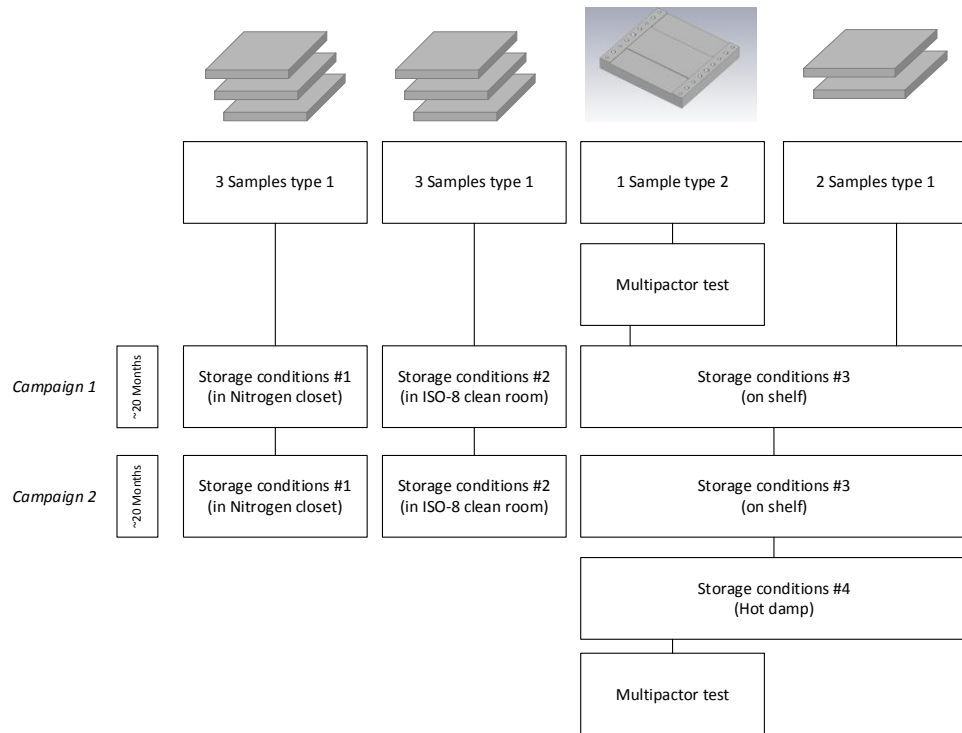


Fig 1. Ageing process for all materials

SAMPLES DEFINITION

Following a similar logic as in [3], two types of samples were designed and manufactured for this project. The sample type #1 is a parallelepiped of 30mmx30mmx2mm with a flat surface designed for SEY measurements. The sample type#2 is a sample designed to be tested in SEY and Multipactor. This way a clear correlation between an SEY curve and a Multipactor test could be drawn.

The test vehicle is composed of a metallic silver coated housing, adapted to a WR229 waveguide. Each vehicle has a deposable part in the critical gap made of the target material, this deposable part is adapted for SEY test in the ONERA facilities in Toulouse. This type of samples are inspired of the EVEREST [1] multipactor samples. See Fig.2 for a depiction of the test vehicle.

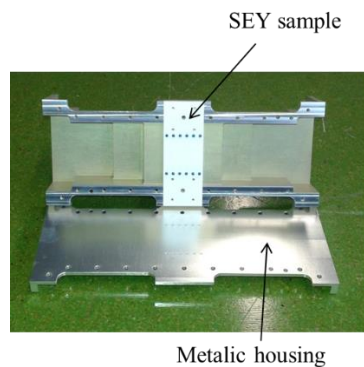


Fig.2. Type #2 test vehicle for SEY and multipactor test

MULTIPACTOR TEST

The Multipactor tests have been realised following the same protocol of calibration and test set up as for flight models. All the Multipactor tests are checked through three independent indirect detection methods:

- 3rd Harmonic level
- Phase Nulling
- Close to Carrier Noise

In order to avoid tampering with the ageing process, no bake-out is realized on the samples prior to testing. The threshold is calculated as the first power at which an event is recorded by at least one of the detection methods. Regardless whether the event is repeatable or not over time. As a warning, this may result on the detection of non-repeatable events that may not be Multipactor, but the overall tendency can be drawn from these tests. The results of the tests are presented in Table 1.

Material	To	To+46mo	Delta
Alumina 1	50.14 dBm	52.14dBm	+2dB
Alumina 2	53.14 dBm	52.14dBm	-1dB
Ferrite 1	50.14 dBm	56.14dBm	+6dB
Ferrite 2	53.0 dBm	51.14dBm	-2dB
Teflon	52.56 dBm	48.56dBm	-4dB

Table 1. First Event Threshold

The results show an important variability for ferrite and Teflon and a much smaller for Alumina. However, the ageing variation may be masked by the impact of the charging of the dielectric has on the Multipactor threshold. As exposed in this article, the effect of the charge may be too important to detect the evolution of ageing based only on two tests.

SEY MEASUREMENT

The SEY measurements as well as the surface analyses by X-ray Photoelectron Spectroscopy where performed at the ONERA in two facilities DEESSE and ALCHIMIE. These both ultra-high vacuum facilities are equipped by low energy Kimball-Physics electron guns and hemispherical electron energy analyser.

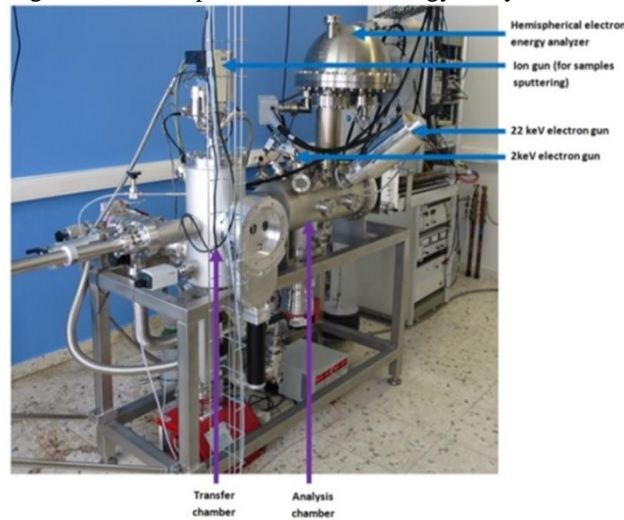


Fig. 3 DEESSE facility

DEESSE facility is an ultra-high vacuum (UHV) chamber equipped as standard with two electron guns, an ion source, an electron collector, a hemispherical electron analyser. The main features of DEESSE facility are listed below:

Vacuum: 10^{-10} mBar to 10^{-9} mBar in the analysis chamber and $5 \cdot 10^{-8}$ mBar in the transfer chamber.

Kimball Physics low energy electron gun 1 eV-2 keV and Staib electron gun 1 keV-22 keV.

- Possibility to tilt the sample from -90° to $+90^\circ$ to study effects of incidence angle.

- Surface analysis by Auger Electron Spectroscopy (AES) X-ray photoelectron spectroscopy (XPS) and Electron Energy Loss Spectroscopy (EELS).
- Temperature control of the sample holder from ambient to 200°C.
- Continuous or pulsed electron irradiation.
- Faraday cup and cylindrical electron collector.
- Ion source (Ar, Xe, H) from 25 eV -5 keV.
- Residual gas analyser (mass spectrometer)
- Kelvin probe

ALCHIMIE facility is a UHV (10^{-11} mbar- 10^{-10} mbar) equipped with :

- Low energy Kimball Physics electron gun (1 eV-2 keV), high energy Kimball Physics electron gun (1 keV-30 keV), Flood gun electron beam, a Faraday cup and hemispherical electron energy analyser and X-Ray source.
- The main features of ALCHIMIE facility are listed below:
- Vacuum: 10^{-11} mBar to 10^{-10} mBar in the analysis chamber and 5×10^{-8} mBar in the transfer chamber.
- Kimball Physics low energy electron guns 1 eV-2 keV and 1 keV-30 keV.
- Possibility to tilt the sample from -90° to $+90^\circ$ to study effects of incidence angle.
- X-Ray photoelectron surface analyses (XPS)
- Surface analysis by Auger Electron Spectroscopy (AES) X-ray photoelectron spectroscopy (XPS) and Electron Energy Loss Spectroscopy (EELS).
- Temperature control of the sample holder from -180°C to 500°C .
- Continuous or pulsed electron irradiation.
- Faraday cup.
- Ion source (Ar, Xe, H) from 25 eV -5 keV.
- Residual gas analyser (mass spectrometer)



Fig.4. ALCHIMIE facility

SEY AND CHARGING EFFECT

When a solid is impacted by an electron, the energy transfer can result in the emission of electrons. These electrons are secondary's (SEs) extracted from the outer layers of the target atoms and backscattered generated more in depth.

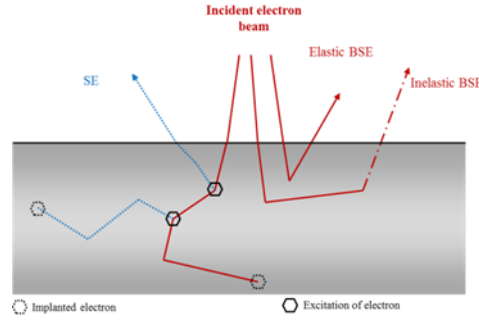


Fig.5. Electron emission process

When a grounded metallic sample is exposed to electron irradiation, the excess of injected charge is evacuated via a leakage current to the ground. For dielectric, the situation is different. Indeed, the charge carrier mobility is in most cases very low, so that a net positive or negative charge accumulated on the near surface region of the sample [4].

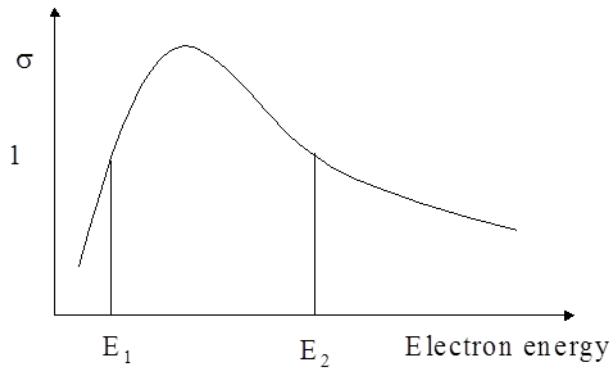


Fig.6 - Schematic shape of the two energies SEY curve. Energies E_1 and E_2 corresponding to $SEY=1$, are respectively the first and the second crossover energies

Fig.6, shows schematically the typical dependence of SEY on the landing energy of incoming electrons. If the incident electron energy, E_0 , is higher than the second crossover energy E_2 , or lower than the first crossover energy E_1 , then flux of incoming electrons exceeds that of the emitted ones and negative charge is injected in the sample. This charge gives rise to an electric field in the vacuum of the specimen chamber and inside the dielectric, which slows the incident electrons and shifts their landing energy down to $E_0 + eVs$, e being the electron charge ($e = 1.6 \cdot 10^{-19}$ C) and Vs being the negative surface potential. This decrease of the landing energy leads to an increase of the total electron emission yield. The negative trapped charge reaches its saturation value when $SEY=1$ (the electron landing energy equals, E_1 or E_2) [5]. Conversely, if E_0 is between E_2 and E_1 , the dielectric charges positively, but very low secondary electrons were attracted back to the sample so that the total charge is close to zero and the insulator is then charged to small positive potential (some volts). The Fig.7 illustrates this external charging effect.

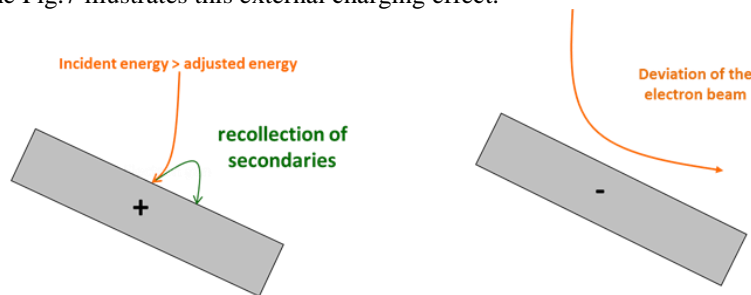


Fig.7. Effect of the external electric field on the incoming and emitted electrons

In addition to external effects of charging, the internal ones have to be also considered (Fig.8). Indeed, in addition to the external effects of charging, the internal effect has to be considered. The generated holes subsequent to the SE emission, as well as the inner electric field lead to the reduction of the SE escape probability and hence to the decrease of the EEY [6].

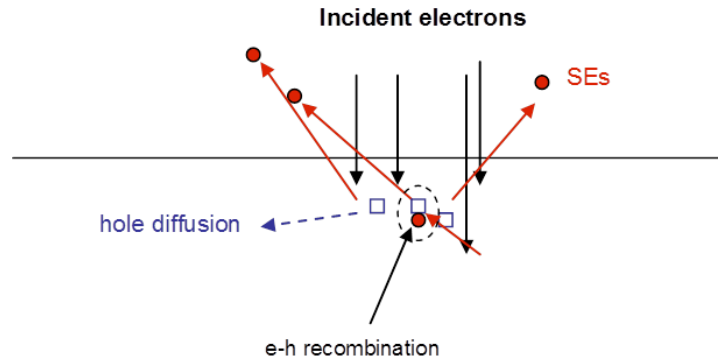


Fig.8.: Secondary electron emission attenuation mechanisms.

For dielectric sample a special care should be taken and an appropriate methodology should be applied to monitor the charging level during the SEY measurement and discharge the sample surface when the charging interferes with the SEY measurement. A long experimental time using charge neutralisation methods such as VUV light, flood electron gun and sample heating is needed to remove the trapped charge. These discharging methods are intrusive and can change the surface composition and thus negate the effects of aging. Therefore, these methods cannot be used here.

We used short electron pulses (a few μs) during the SEY measurement to limit the charging effect. Despite this, we found that the charging effect remains the major effect and completely overshadows the aging effect. An example is shown in Figure 6. The SEY measured on the virgin Teflon sample as well as the SEY measured on the stored Teflon samples under the storage conditions (1,2,3 and 4) are extremely noisy and all the SEYs are overlapping (Fig. 9)

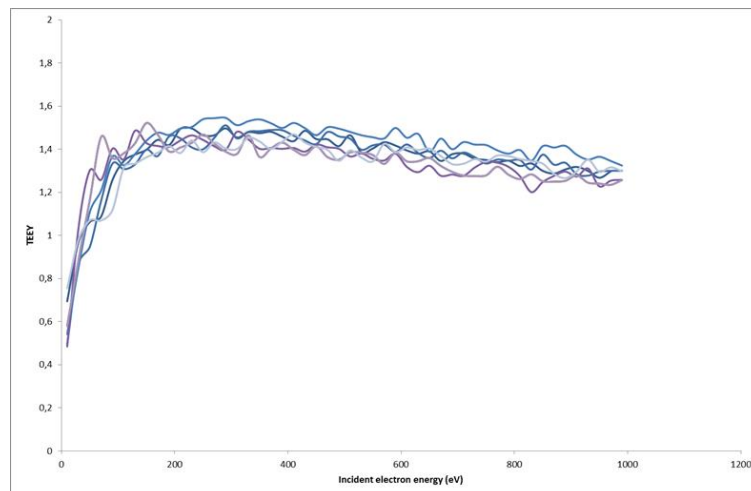


Fig.9. SEY of Teflon : virgin samples and storage conditions 1, 2, 3, 4

CONCLUSIONS

We observed substantial variability in the multipactor power threshold for ferrite and Teflon and much less for alumina. Hence, the variation due to aging may be masked by the impact of dielectric loading on the SEY and thus on the multi-factor threshold.

The SEY measured on dielectrics, particularly on Teflon, is extremely noisy due to the charging effect. Most likely, the accumulated charge affects the SEY curve. The charging artefacts make any correlation between the multipactor threshold and SEY difficult and hazardous

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