Degradation of solar absorptivity of thermo-optical materials contaminated by electric propulsion

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I. INTRODUCTION

Electric propulsion on satellites in particular for orbit rising, is the source of questioning. Interactions between the plume and the different surfaces of the spacecraft are not simple because the plume consists not only of fast ions but also of charge-exchange ions whose trajectory is easily modified by low spacecraft potentials. These ions can impact spacecraft surfaces with relatively low energies and create erosion and consequently contamination of surfaces. Many teams have measured and continue to study erosion rates of materials but contamination rates and effects are not much published. In this paper, we will describe an experimental setup usually used for erosion rate measurements which have been adapted to expose samples to the erosion of a target. The effect of this contamination on samples has been evaluated through optical measurements and surface chemical analysis. Then, these results are compared to SPIS simulations.

II. EXPERIMENTAL SETUP AND PROTOCOL

A. Facility

Samples contamination has been performed inside IDEFIXe chamber which is an Installation Devoted to Erosion by a Flux of Xe Ions. This chamber is a cylinder of 50cm in length and diameter. It is equipped with an Ion Tech. plasma source fed with Xe gaz. The ion energy can be adjusted from a few tens of eV to 1200 eV. A photograph of the chamber is presented on fig 1.

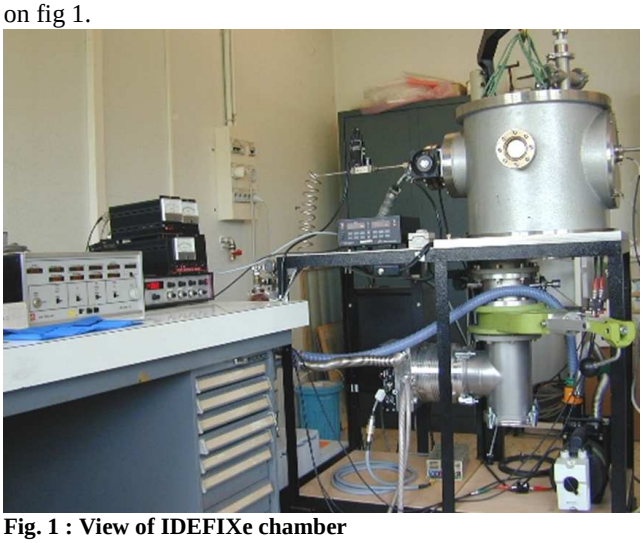

Fig. 1 : View of IDEFIXe chamber

Facing the beam a holder equipped with 13 Langmuir probes is placed to evaluate beam current and homogeneity. These measurements are performed during another test than the erosion-contamination one.

For the erosion and contamination of the samples, a target is placed to intercept the entire source beam with an angle of about 45°. A sample holder is placed below the source facing the target. On this sample holder a quartz microbalance and 3 samples are placed to be contaminated by the erosion products.

The schematics given in fig 2 shows how these different elements are placed.

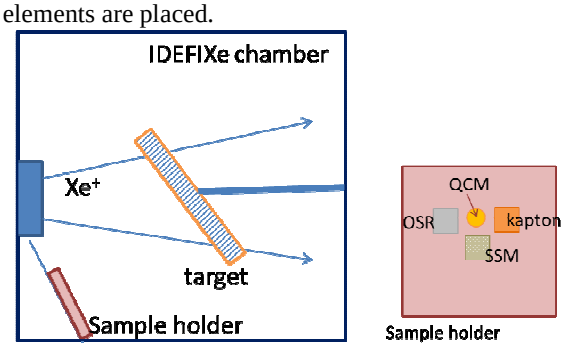

Fig. 2 : Schematics of the chamber with target and samples

B. Protocol

For each target, the same samples are contaminated three times successively. Each time, the aim is to reach a defined thickness. The first aimed thickness is 10 nm (step 1), the second 20nm by addition of 10 nm (step 2) and the third 50nm by addition of additional 30nm (step 3). In fact, there are several uncertainties on this thickness measurement. First, the deposited material is unknown, so its density. Secondly, the microbalance which is used for this estimation is not thermo-regulated even it is well-known that the oscillation frequency of quartz is sensitive to temperature variations. Concerning the first point, the QCM measures in reality a mass then material density should not be needed. However, for a question of easier reading on the QCM controller, the mass is converted by the controller into a thickness with a material density chosen arbitrary to 1. This artificial thickness is then converted to a real mass by the experimenter after the test.

Concerning the second issue, the source is started and thermally stabilized before beginning the erosion and contamination process but despite this, some extrapolations were needed to estimate properly the deposited quantities as it is shown on the following graph.

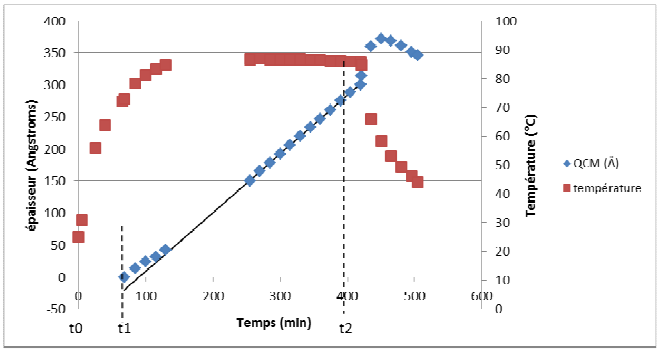

Fig. 3 : Variation of temperature and thickness of the QCM as a function of mass for step 3. At t1, the erosion starts and it stops at t2.

We see on this graph that as the temperature is not well stabilized, the mass (converted in thickness) variation is not linear. The linear interpolation in black allows us to determine the exact deposited thickness extrapolating the straight line down to t1 (some points are missing due a problem of acquisition but meanwhile the deposition was linear).

III. ANALYSES

A. *Reflectrance measurements*

For each target type, the different thicknesses deposited on the samples are given on the next tables :

Table 1 : Thicknesses of contaminant deposited on the QCM and all the samples at each step of contamination

Target : solar array type	
Estimated thickness of contaminant	Mass density of deposited material
15 nm	4.10^{-6} g/cm²
25 nm	$6.6\ 10^{-6}$ g/cm²
57 nm	$1.5\ 10^{-5}$ g/cm²
Target : Antenna type	
Estimated thickness of contaminant	Estimated thickness of contaminant
12.5 nm	12.5 nm
23 nm	23 nm
58.5 nm	58.5 nm
Target : Kapton	
Estimated thickness of contaminant	Estimated thickness of contaminant
13 nm	13 nm
32 nm	32 nm
72 nm	72 nm

At each step if deposition, the samples were characterized by measuring their reflectance in the 250-2500nm range. Some of the results are presented on the graphs of Fig. 4.

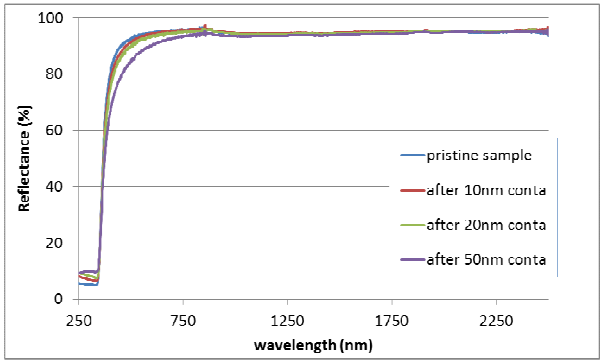

Fig. 4 : Reflectance of OSR samples before and after contamination by the erosion of the solar array-type target.

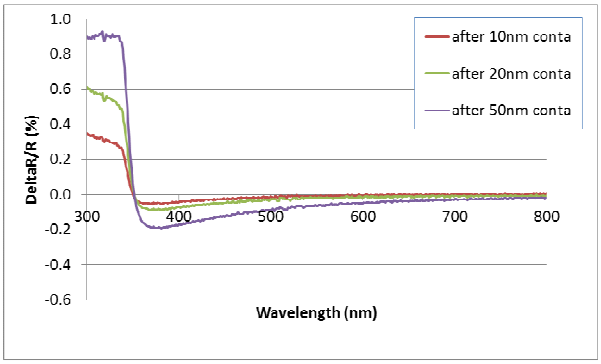

Fig. 5 : Variation of reflectance of OSR samples before and after contamination by the erosion of the solar array-type target.

The reflectance measurements were used to calculate the degradation of solar absorptivity (see poster).

B. *XPS analysis*

The samples were also analyzed by XPS after the last contamination. Some of the results are presented as an example on Fig. 6.

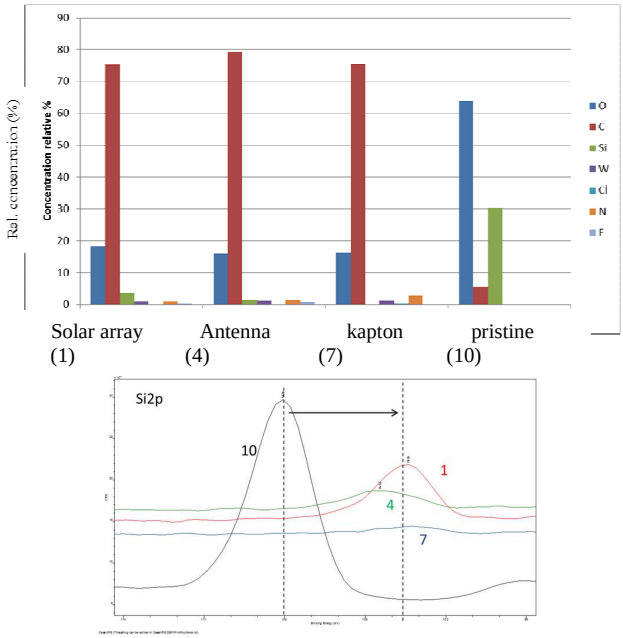

Fig. 6 : Top : Relative concentration of the different elements issued from the XPS analysis of the OSR samples before and after contamination by the erosion of the solar array-type target. Bottom : View of the silicon peak Si2p of the different samples (signification of the numbers is on the top graph) (shift of Si peak : SIO to SiC link).

The different analyses show that there is no significant difference in the effects of contamination by the different targets (all polymeric materials), with the deposition of carbon/oxygen compounds.

They also show that the substrate has no effect on the sticking coefficient of the erosion products.

C. SPIS simulations

SPIS software has been used to simulate the experiments (in the case of the kapton target).

SPIS simulation of IdefiXe experiment presents the following characteristics:

- Ambient plasma is modelled by simulating Xe+, Xe++ ions as particles and electrons as a fluid (Boltzmann distribution).
- Neutral atoms Xe emitted by the thruster are modelled as fluid population.
- Charge exchange phenomenon between Xe+ and neutral Xe is modelled and resulting populations (charge exchange Xe+ and fast neutral Xe) are modelled as particles.
- Electric field due to plasma is calculated in the vacuum chamber by solving Poisson equation in 3D.
- Surface elements polarization is taken into account depending materials they are made of.
- Erosion yield is taken into account with the Garcia-Rosales-Bodhasky-Oeshner model.

The following figure shows the geometry used for the simulation.

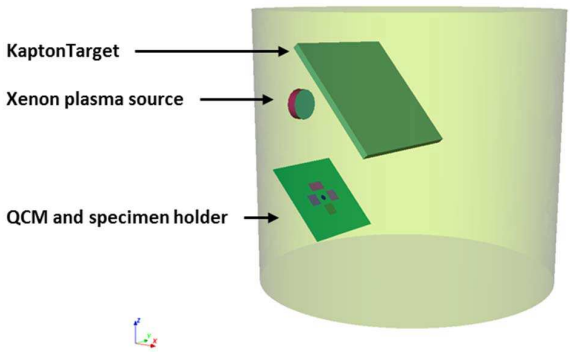

Fig. 7 : View of the SPIS geometry (source, target and sample holder)

The following figures show the density of different species which are considered during the simulations (Xe^+ ions from the source and eroded products)

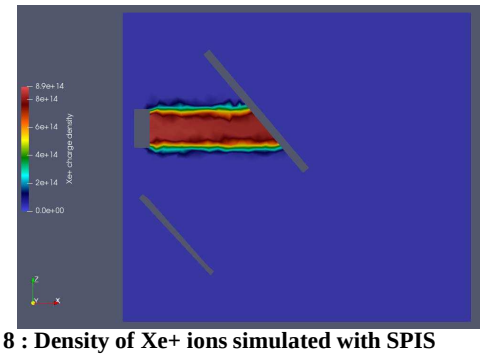

Fig. 8 : Density of Xe+ ions simulated with SPIS

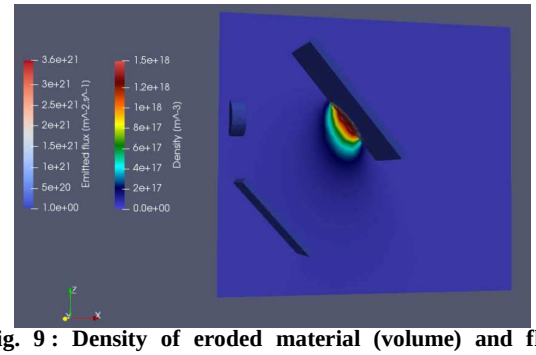

Fig. 9 : Density of eroded material (volume) and flux of eroded material from kapton target surface

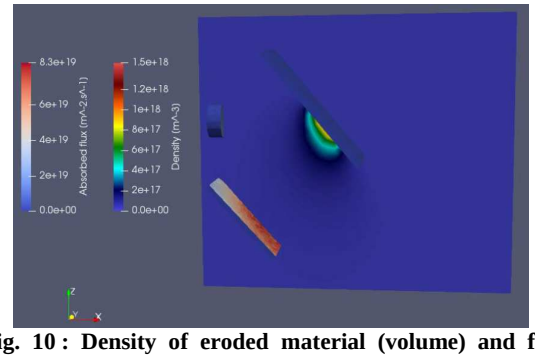

Fig. 10 : Density of eroded material (volume) and flux of eroded material deposited on sample holder

Contamination rate is higher in the simulation than in the experiment (a few 10^{18} $m^{-2}.s^{-1}$ in the simulation for 5.10^{16} $m^{-2}.s^{-1}$ in the experiments) but a lot of assumptions have been made on erosion rate, sticking coefficient.. which can explain these discrepancies.

In addition, the measured erosion yield of the kapton fit with the Garcia-Rosales-Bodhasky-Oeshner model seems to indicate that the erosion products are large fractions of the initial monomere (polyimide).

IV. CONCLUSIONS

The different analyses show that there is no significant difference the effects of contamination by the different targets (all polymeric materials), with the deposition of carbon/oxygen compounds.

The contamination issued from a target sputtering leads to a deposition which does not depend on the substrate (same deposition whatever the substrate).

The materials tested in this study induce similar contamination and effects. However, the materials tested as targets were not that much different and other targets are of interest such as amorphous materials (erosion of the thruster itself, erosion of the coverglasses). Another question is what would be the combination of erosion of different materials such as the front face of a solar array?

ACKNOWLEDGMENT

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