SECONDARY ELECTRON EMISSION OF CERAMICS USED IN THE CHANNEL OF SPT

V. Viel-Inguimbert,

ONERA/DESP 2, Avenue Edouard Belin, 31 055 Toulouse Cédex, FRANCE

1 INTRODUCTION

In the frame of the development of a plasma thruster such as SPT for spacecraft, the ceramic material used as channel has to fit with specific properties such as mechanical, electrical or thermal properties. Among these properties, the secondary electron emission yield produced by impingement of electrons from the plasma those energy is of several tens of eV plays an important role in the thruster operations. The aim of this paper is to describe the experiment built by ONERA to measure secondary electron emission yield on materials and the experimental difficulties to measure it on insulators. The experiment is then used to study the secondary electron emission yield of ceramics at normal incidence and ambient temperature. Slight excursions in angle and temperature are also tested. These measurements have to be useful for thruster model developments where walls conductivity is not well determined [1] [2] and where sheath phenomena on the walls seem to be determinant for the knowledge of the behaviour of electrons in the channel [3].

Secondary electrons are emitted from a surface by primary electrons bombardment following two steps : the creation and the emission. Most of theories lead to a relationship between σ/σ_m and E/E_m, where σ is the secondary electron emission (SEE) yield obtained for an energy E of the primary incident electrons and E_m the energy of incident electron corresponding to the maximum yield σ_m.
The emitted electrons have an energy distribution from 0 to E (energy of incident electrons) in 3 different ranges : Around the incident energy E, we find the backscattered electrons corresponding to elastic diffusions where the electrons are reflected without loss of energy. A continuous background is essentially constituted of inelastic backscattered electrons and of Auger electrons. At low energy, the “real” secondary electrons appear. Their energy is conventionally estimated below 50eV. The total secondary electron emission yield is the sum of the “real” secondary emission yield σ and the backscattering yield.
At low energy, the different populations (backscattered and real secondary electrons) quite difficult to distinguish [4] and we will use sometimes abusively the term “SEE yield” which will correspond to the measured yield.

2 DESCRIPTION OF THE EXPERIMENTAL SET-UP AND EXPERIMENTAL DIFFICULTIES

2.1 Experimental set-up

The experimental set-up is a vacuum chamber equipped with an electron gun. The figure 1 shows a schematic view of the system. The vacuum in the chamber is obtained with a cryogenic pumping system and the working pressure is about 3. 10^{-7} hPa. The incident beam of electrons generated by the electron gun impacts the surface of the sample and an electrode collects the secondary electrons. This collector is cylindrical and can be polarised to +/-9V. A Faraday cup can be used in replacement of the sample to evaluate the incident beam but during the measurement, the incident current is calculated measuring both emitted current I_s and replacement current through the sample Ir. This current is measured through a resistance of 1KΩ connected between the sample and the ground.

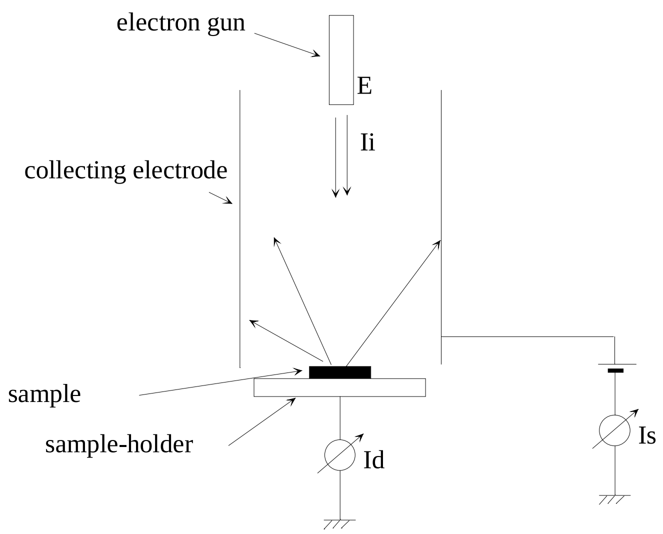

figure 1 : Schematic view of the experimental set-up.

The secondary emission yield σ is then calculated by the relation :

$$\sigma(E) = \frac{I_S(E)}{I_S(E) + I_R(E)}$$

where : I_S is the secondary electrons current
I_R is the replacement current
Ii is the total current of the incident electrons. Ii = $I_S + I_R$
E is the energy of incident electrons

Since the measurements were performed on very insulating samples, the measurement is based on a pulsed technique. The incident current has the shape of a squared signal whose duration is few tens of µs and amplitude few tens of nA, each pulse is triggered manually. The currents I_S and I_R are amplified and measured with an oscilloscope.

2.2 Particularity of measurements of SEE on insulators

The peculiarity of the materials tested in this study is their insulating nature. Their behaviour under an electron beam depends on the emission yield σ. Two cases can be separated :
$\sigma > 1$: After each pulse of current, the material becomes charged positively and the secondary electrons having a low energy are attracted and back-collected by the sample surface. This phenomenon follows on until the quantity of electrons emitted from the surface are equal to those incident. In this case, the apparent emission yield is equal to 1 and the surface potential is positive.
$\sigma < 1$: After each pulse of incident current, the surface potential becomes negative by electrons accumulation on the surface. Most of the incident electrons are reflected by the surface and the apparent yield is 1.
An example of the influence of surface potential is visible on figure 2. In this case, the material tested is AlN and the incident current of electrons is 140 nA with an energy of 100 eV. You can observe that the current collected by the electrode decreases after each pulse and reaches the value of incident current after 20 measurements. During this time, the current on the sample follows the same curve and decreases to 0. At the energy of 100 eV for incident electrons, the SEE yield of AlN is about 2, but after few measurements, this measured SEE yield decreases to reach the value of 1.

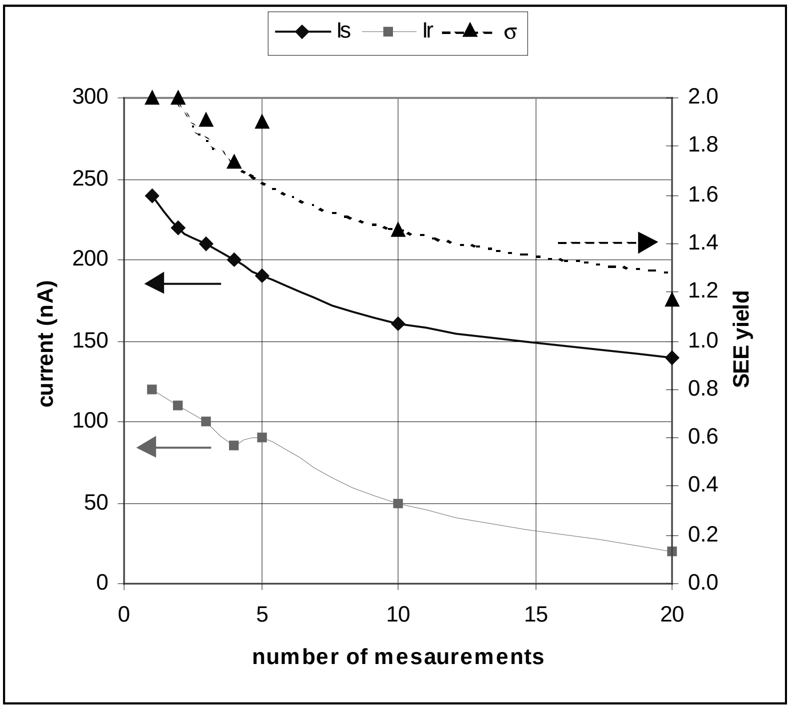

figure 2 : Currents measured on collecting electrode and replacement current on the sample (left vertical axis) and SEE apparent yield (right axis) versus the number of measurements.

This result shows that the measurement of secondary electrons emission yield has to follows two contradictory rules :

- sending electrons on the surface to generate secondary electrons
- not charging the surface

This was only solved in this experience reducing the pulse duration and amplitude but others systems could be used such as neutralisation of the sample surface by UV or ion beam.

2.3 Energy of emitted electrons

In order to understand better the influence of potential surface and phenomenon of "apparent" yield, the experiment has been modified to study the energy of emitted electrons. The cylindrical collector has been removed and replaced by an hemispherical one equipped internally with a grid whose potential can be modified. The experimental conditions are those described previously, the collecting electrode is fixed to a potential of +9Volts. The pulse of primary electrons is about 100 nA during 4 µs. This set-up allows the experimenter to select all the electrons whose energy is more than the voltage applied on the grid. As the pulses are not perfectly reproducible, the experimental results presented here are normalised, i.e. the measured current is divided by the incident current.

Two examples of results are presented on figure 3 for AlN and on figure 4 for AlNBN. During these experiments, the energy of incident electrons takes 3 values 40 eV, 60 eV and 80 eV. The grid potential is swept from 0 to – 40V but the graphs present this potential in absolute value to correlate it directly with electrons energy.

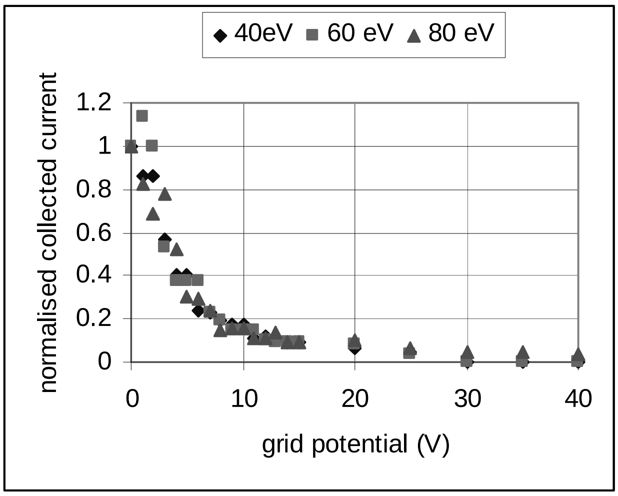

figure 3 : Electron energy distribution of secondary electrons for AlN

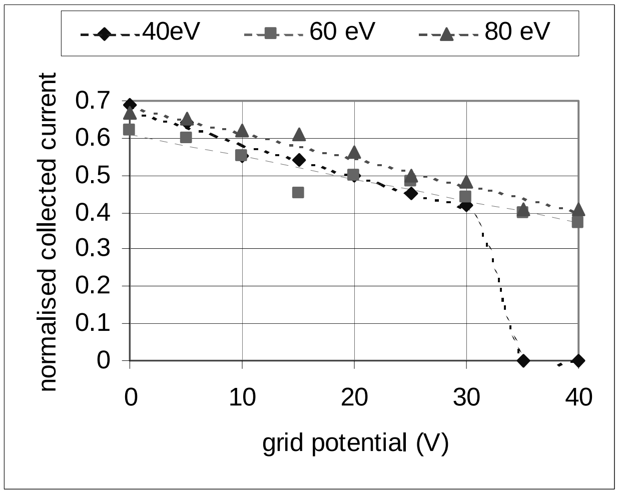

figure 4 : Electron energy distribution of secondary electrons for AlN-BN

In the case of AlN (figure 3), the shapes of the different curves are the same and in a good agreement with those observed in bibliography [4]. For this material, all the electrons emitted are real secondary electrons with a low energy and not dependant with the incident electrons energy. This is possible because the surface is positively charged which is the case when the SEE yield $\sigma > 1$ and will be confirmed by the results given in the next paragraph.

In the case of AlN-BN (figure 4), the phenomenon is totally different : it seems that all the emitted electrons are electrons reflected by the surface potential which can reach the potential of primary electrons. For example, for the energy of 40 eV, most of the collected electrons have an energy above 30 eV and the current becomes null for V_{grid} =35 V. This phenomenon is characteristic of a negative polarised surface which reflects totally the incident electrons, this is the signature of a SEE yield $\sigma < 1$ and will be confirmed by the results given in the next paragraph.

3 RESULTS ON SEVERAL CERAMICS

Different ceramics were measured during this study and the results are presented hereafter. They are : BN-SiO_2, BN-AlN, AlN, MgO, SiC, Al_2O_3 and BN.
For all these experiments, the configuration adopted is the one presented in the paragraph 3.1 with the sample not polarised and the cylindrical collector polarised to +9V.

3.1 BNSiO_2, BN, AlNBN, SiC :

These samples are bulk material of few mm of thickness. Their rear face are metallized with aluminium to realise an electric contact with the sample holder. The result of secondary electron emission of these 4 materials is shown on figure 5.

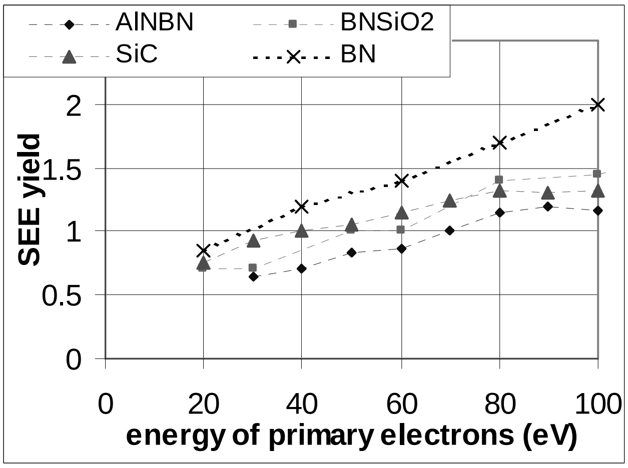

figure 5 : SEE yield of $BNSiO_2$, BN, AlNBN and SiC with respect to the primary electrons energy

For these materials, the secondary electron emission yield becomes below than 1 for an energy of the primary electrons above a threshold which varies from 30 eV for BN to 70 eV for AlNBN. Since the maximum of SEE seems to be almost reached at 100 eV for BNSiO2, AlNBN and SiC, SEE of Boron Nitrate (BN) still increases and attains 2 at 100 eV.
The incertitude of these measurements was not added on this graph to simplify but is about +/- 20%.

3.2 MgO, Al_2O_3, AlN

The samples are bulk materials of few mm of thickness. Their rear face are metallized with aluminium. The result of secondary electron emission of these 3 materials is shown on figure 6. For these materials, a SEE yield below than 1 was not measured even at low incident energy but the yield reached by Al_2O_3 is quite larger than the others since this value is 3 at 100 eV.

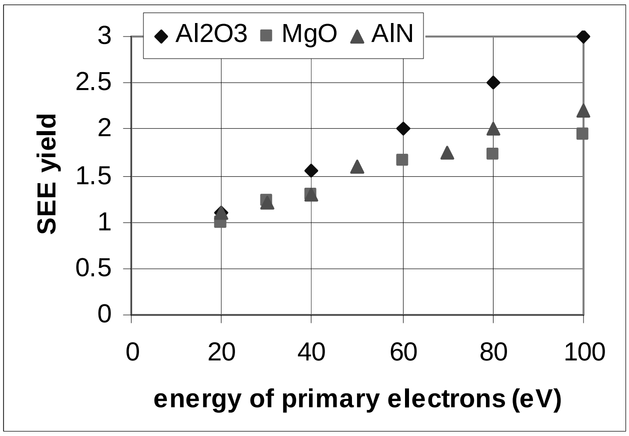

figure 6 : SEE yield of MgO, Al_2O_3 and AlN with respect to the primary electrons energy

4 EXCURSIONS IN ANGLE AND TEMPERATURE

4.1 Influence of the temperature on SEE yield.

Knowing that channel's walls in the SPT are at a very high temperature [5], it seemed interesting to know the influence of this temperature on secondary electron emission. We could imagine that the SEE yield will increase with temperature since the energy transfer of incident electron with the material's matrix will decrease. Nevertheless, Dekker [6] thinks that this effect will be masked by dependence with temperature of

mean free path which decreases while temperature increase. This is confirmed by measurements performed by Johnson and McKay on MgO [7]. These results show a decrease of SEE yield at high temperature and high incident electron energy on MgO. However, no real evidence of modification of this yield is given in the range which is under interest in this study (i. e. low energy under 100eV).
In order to obtain experimental results on this subject, the experimental set-up was slightly modified in order to increase the samples temperature. However, the maximum possible temperature without modifying completely the set-up, was only 300°C. The sample was heated with a hot element put in contact with the sample holder during the time necessary to reach 300°C. The contact was then suppress in order to proceed with the measurement. Sample's temperature was measured with a thermocouple. No real effect was measured on the different samples and 2 examples of result are presented on figure 7 and figure 8.

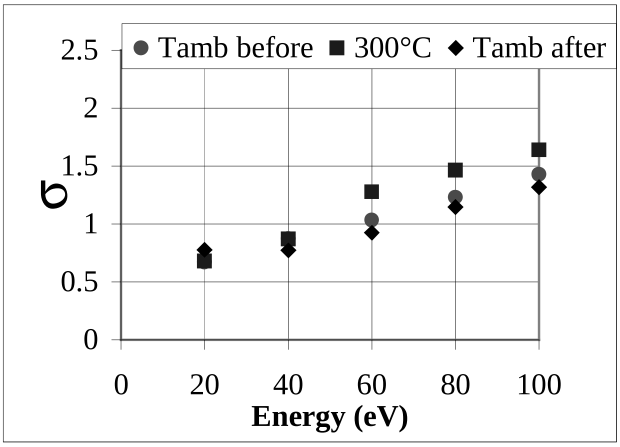

figure 7 : SEE yield measured on $BNSiO_2$ at ambient temperature before and after heating and SEE yield at 300°C.

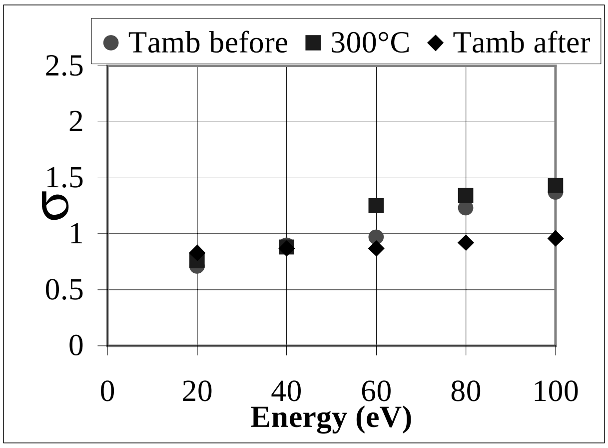

figure 8 : SEE yield measured on MgO at ambient temperature before and after heating and SEE yield at 300°C.

We observed on these results that the SEE yield at 300 °C increases of about 15% and that there is also a variation of the yield at ambient temperature after the heating. Since the dispersion of the measurements is about 20%, the variation observed in SEE at 300°C is negligible. Concerning the measurement at ambient temperature after heating, this evolution is very slight and could be eventually attributed to a modification of surface's sample like simple cleaning while heating.

4.2 Influence of incidence angle on SEE yield

This aspect was more studied in bibliography than the influence of temperature. Shih [4] had tested the influence of the angle of incidence of primary electrons on SEE yield on Molybdenum and the result is an increase of SEE yield when increasing the angle but this influence is not very important at low energy (less than 10% at 100 eV and 20% at 400 eV). Vaughan [8] has given empirical laws to describe this effect and these relations integrate the roughness as a parameter. The roughness can effectively play an important role in the effect of angle of incidence. To evaluate this effect, we oriented one sample (SiC) to an angle of 20° which is the limitation of the set-up. The result is presented on figure 9. The graph presents also the fits obtained applying empirical laws from Vaughan [8]. We observe that the effect of the angle is very slight at low energy and becomes to be sensitive above 300 eV.

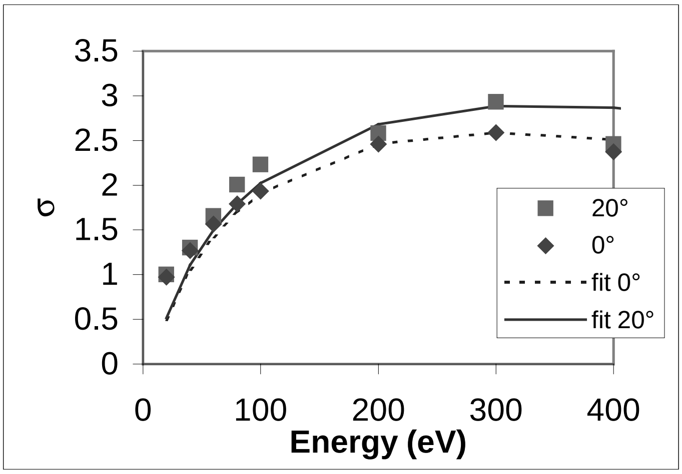

figure 9 : Result of SEE yield obtained on SiC at 2 different incidences; the lines are fitting curves given by Vaughan laws [8]

5 CL

We studied here the SEE yield of different ceramics which can be used as thruster channel. This study has shown the differences of behaviour of these different materials and these results can now be used in models to predict the interest of one or others of these materials in thruster operation or yield. This study has also shown the difficulties to measure the secondary electrons emission on insulating materials. The main problem comes from the surface potential which appears on the surface as soon as an electron beam reaches the surface and modify the apparent SEE yield.

6 ACKNOWLEDGEMENTS

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