

Secondary electron emission at Langmuir probe surface

M. L. SOLOMON*, S. TEODORU, G. POPA

Plasma Physics Department, Faculty of Physics, "Al. I. Cuza" University, Association EURATOM-MEdC, 11 Carol I Blvd., 700506-Iasi, Romania

The phenomena of secondary electron emission appear as a result of interaction between high energy particles and different solid state materials. The present work reports on the study of the secondary electron emission at a Langmuir probe surface bombarded with a mono-kinetic electron beam. A stainless steel plane probe with a diameter of 10 mm was used. The mono-kinetic electron beam with a current intensity of the order of 10 mA was provided by an electron gun. The phenomena of secondary electron emission at the probe surface were studied through the changes in the ion part of the I-V characteristic of the probe, for different kinetic energy of the electron beam, in the range of 50 - 400 eV. PIC simulations accompanied the experimental measurements.

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1. Introduction

The secondary electron emission (SEE) [1] at the probe surface and its contribution on the probe characteristics are considered either in experiment or in numerical simulations [2]. This process has to be considered in any plasma diagnostic techniques by electrical probes if fast electrons are present. Typical examples are the negative glow plasma of a d.c. glow discharge [3] and ionosphere plasma because of the large speed of the satellite or high energy particles of the solar wind. Nowadays, the electrical probes are used for Tokamak plasma diagnostics where both ions and electrons have enough energy to produce SEE [4]. The SEE discussed in this paper is produced by probe surface bombardment with a mono-kinetic electron beam.

2. Experimental and simulations

In the numerical calculations, the probe was considered to be placed in low temperature plasma in which an electron beam is also present and may perpendicularly bombard the probe. The intensity of the probe current produced by the fast electrons considered as an isotropic population can be written as:

$$I_b = -(n_b e A v_b / 4) \times [1 - (eU/E_c)]. \quad (1)$$

For an anisotropic electron beam impinging perpendicularly the probe surface, the upper expression becomes:

$$I_b = n_b e A v_b \quad (2)$$

where v_b , n_b are primary electron velocity and density, A is the collecting area of the probe, U is the probe potential measured with respect to the plasma potential ($V_p = 0$) and

E_c is the energy of the primary electrons at the probe surface,

$$E_c = E_b - eU \quad (3)$$

where E_b is the kinetic energy of the primary electron of the beam. We assume that the secondary emission yield $\gamma(E)$ has the expression:

$$\gamma = A + B_1 E_c + B_2 E_c^2 + B_3 E_c^3 + B_4 E_c^4 + B_5 E_c^5 \quad (4)$$

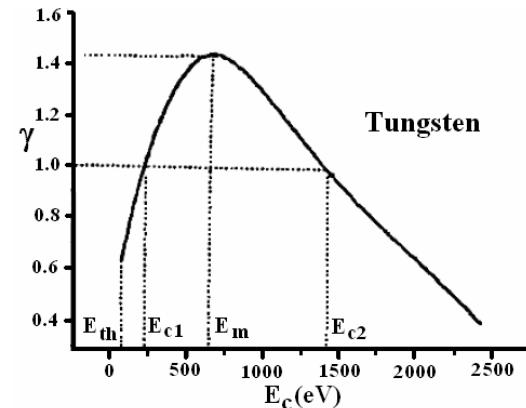


Fig.1 Secondary electron emission yield of tungsten

where $A = 0.36832$, $B_1 = 0.00408$, $B_2 = -5.148e-6$, $B_3 = 2.45e-9$, $B_4 = -4.77e-13$, $B_5 = 2.35e-17$, for a clean tungsten surface which is presented in figure 1 [5].

The following energies of the primary electrons are defined in figure1: a) E_{th} – the threshold energy of the primary electrons for which the SEE may be produced; b) E_{c1} and E_{c2} are the lower and upper limits of the kinetic

energy of the primaries for which $\gamma = 1$; c) E_m is the kinetic energy of the primaries for which γ has its maximum value, γ_m . The secondary electron current I_{es} can be written: $I_{es} = \gamma I_b$ as long the probe potential is negative with respect to plasma potential and all secondary electrons produced at the probe surface are attracted by plasma.

The emission of the secondary electrons is studied experimentally [6] using an electrostatic plane probe, a stainless steel disc of 10 mm in diameter. The process is induced at the probe surface by a mono-kinetic electron beam, produced by an electron gun.

The scheme of the gun is presented in figure 2. The electrons are thermo-emitted by a heated filament. They are accelerated and extracted due to the negative voltage applied on the filament with respect of a metallic grid. The accelerating potential is of the order of hundreds volts. The electrons leave the gun as a mono-kinetic beam. This beam is directed perpendicularly to the probe surface.

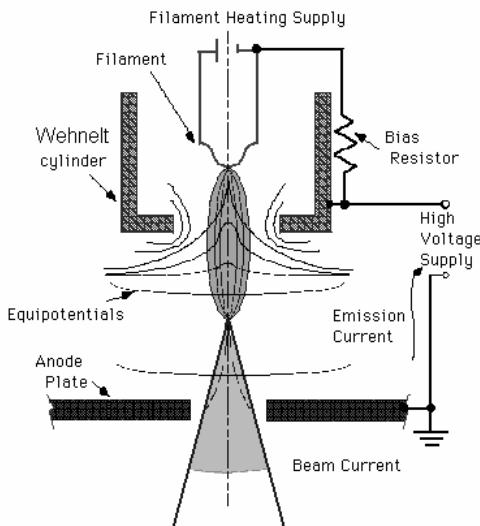


Fig.2 Scheme of the electron gun used to produce a mono-kinetic electron beam

The probe and the electron gun are mounted inside a magnetically multipolar plasma confinement device (similar with a DP machine, but with only one chamber). The cylindrical vacuum vessel is made of nonmagnetic stainless-steel, having 32 cm in diameter and 40 cm in length. The chamber wall is electrically grounded. Multidipole magnets of line cups type are mounted for plasma confinement on the wall vessel. All the experiments were realized in residual gas at a background pressure in the range of 10^{-5} - 10^{-6} Torr, with no gas inserted in the vessel.

The electric circuit designed for studying the SEE at the plane probe surface (figure 3) is composed from a high-voltage amplifier, an isolation amplifier and a power supply. The high-voltage amplifier multiplies the saw-

tooth signal generated by a data acquisition system up to -400V \div 0V.

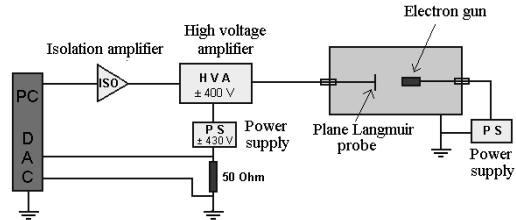


Fig.3 Scheme of the electric circuit designed for studying the secondary electron emission at the plane probe surface

This high-voltage signal is applied on the probe as polarisation potential. Using the same data acquisition system, the ion part of the probe current-voltage characteristic can be obtained in the presence of SEE at the probe surface. The isolation amplifier separates the high-voltage amplifier from the data acquisition system. The electron gun was placed at 10 \div 20 mm in front of the plane probe

3. Results and discussions

In the negative region of the probe bias, the deceleration of the primary electrons can not be neglected and the relation (3) has to be used. That means the E_c is a linear function of the probe bias. But, generally γ is a nonlinear function of the E_c which depends on the probe material. Referring to a tungsten probe, the γ coefficient is given by (4) and ion component of the probe current in the presence of SEE phenomena (figure 4), can be explained as following:

i) $U < U_B$, or $|eU| >> E_b$ (figure 4). According to (3) $E_c < 0$ which means that the beam electrons can not hit the probe and the current collected by the probe is pure ion saturation current (region AB of the probe characteristic in figure 4).

ii) $U_B < U < U_C$, $E_c > 0$ and the primary electrons may hit the probe but they don't have sufficient energy to produce secondary electrons on the probe surface ($\gamma = 0$), because $E_c < E_{th}$, where E_{th} represents the threshold of the primary electrons from which the secondary emission can be produced. The E_{th} depends on the material of the probe.

iii) $U_C < U < U_D$, that corresponds to $E_c \in [E_{th}, E_{c1}]$ (figure 1) and the SEE can be produced, but $0 < \gamma \leq 1$, (region CD of the characteristic in figure 4). The E_{c1} is the lower limit of the kinetic energy of the primary electrons for which $\gamma = 1$.

iv) $U_D < U < U_E$ (point D, figure 4) for $E_c \in [E_{c1}, E_m]$, $1 \leq \gamma < \gamma_m$ and the secondary electrons give an electron current which adds to pure ion saturation current of the probe and the total current of the probe increases as an equivalent "ion" current (region DE, figure 4).

The E_m corresponds to the maximum of the secondary electron emission ($\gamma = \gamma_m$).

v) $U_E < U < U_F$ the $E_c \in [E_m, E_{c2}]$ and $\gamma_m > \gamma \geq 1$ and correspond to descending of the γ with increasing E_c above E_m and the "ion" current decreases to the pure ion current of the probe (point F, figure 4). The E_{c2} is the upper limit of the primary electrons for which $\gamma = 1$.

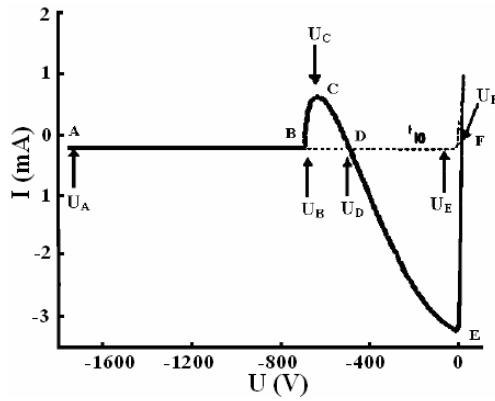


Fig.4 The ion saturation current of the probe and the influence of the SEE phenomena

I-V probe characteristics [7] obtained from simulation and from analytical theory are compared in figure 5. The agreement is good, with only small differences due to overestimation of the fast electrons flux in the probe potential range [-550V, -300V]. For a qualitative idea about the SEE effects on the plane probe characteristic, we have also

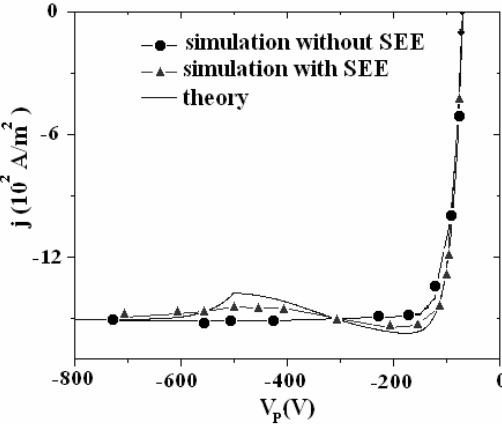


Fig.5 I-V characteristics (magnification for negative probe biases), simulation and theory.

plotted in figure 5 a characteristic without SEE effects, obtained from simulation [8].

In some cases, depending on the value of fast electron energy E , the probe characteristics can pass three times

through the current zero. The fast and secondary electrons introduce modifications on the probe characteristic in the potential range [-700V, -100V].

Using the experimental set-up presented in figure 3, probe characteristics were plotted under the bombardment of a mono-energetic electronic beam. The beam energy was constant but adjustable in the range of 50 to 400 eV. Typical curves of the ion part of the probe characteristic are presented in figure 6. It shows the contribution of the SEE in increasing of the ion current intensity of the probe. In figure 6 under each I-V characteristic is represented the energy of the mono-kinetic electron beam E_b .

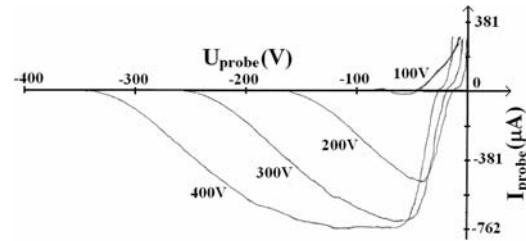


Fig.6 Ion part of the experimental plane probe I-V characteristics in the presence of SEE

In this experiment, the electrons incident on the probe with low energy could not be relieved on the current-voltage characteristics of the probe. These electrons can be classified in two groups: 1) incident electrons with energy $E_c < E_{th}$ that can not produce SEE and 2) incident electrons with energy $E_c > E_{th}$ that can produce SEE but with $0 < \gamma < 1$. They could not be observed on the experimental characteristics because they are reflected by the strongly negative electric field near the probe surface. An electrostatic mirror effect appears between the electron gun exit and the strongly negative probe surface. In the purpose of exceeding this experimental inconvenient, modification of the electron gun design is envisaged to obtain a better collimated primary electron beam.

4. Conclusions

The phenomena of secondary electron emission at the probe surface were studied by simulation, analytical theory and experiment.

Experimental results are in good agreement with the one obtained by numerical simulation. The electrons that reach the probe with low energy ($E_c < 50$ eV) do not produce secondary electron emission (the region BC in figure 4). They are not observed on the experimental characteristics due to their reflection on the strongly negative electric field near the probe.

Probe diagnostics methods can be applied to determine some proprieties of the solid materials from which probe are made of.

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*Corresponding author: marius_solomon@plasma.uaic.ro