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Test results of a spherical Langmuir probe with retarding grids

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***Abstract*— This paper deals with the analysis of the test data of a new type of sensor which combines the functions of a Langmuir probe, a retarding potential analyzer and an EUV spectrometer. The instrument concept and the test data are presented, described and analyzed. Evidence is shown of the effect of the grids on the instrument signal which is not only due to the grid electrostatic potential as expected but is also due to significant particle collection by the grids. The main conclusion is that the signal seems to differ significantly from that of standard Langmuir probes or retarding grid analyzers and new current models would have to be developed in order to be able to exploit the measurements of this new instrument for plasma density estimates.**

Keywords—plasma measurements, space plasma sensors, Langmuir probe, retarding grids

I. INTRODUCTION

Space plasma measurements are required by solar system scientific missions to understand the dynamics and the evolution of solar system bodies and their environments. Space plasmas also affect the operation of basic spacecraft systems such as electrical systems. In fact, when a spacecraft is immersed in a plasma, it is exposed to a large flux of electrons and ions, which can lead to voltage elevation and electrostatic discharges with subsequent damage. Space plasma measurements are therefore also required for specifying and monitoring the environment of application satellites. Measurement of plasmas in space can be performed via wave measurements or charged particle flux measurements. Flux measurements are usually performed by measuring the electrical current collected on an exposed electrode, this is the Langmuir probe technique, or by counting particle impacts on a sensitive device such as a micro-channel plate, usually after selecting particles in energy and/or direction via electrostatic (retarding) grids or channeling guides.
In this paper test results performed in a plasma chamber of an innovative type of sensor which combines a spherical Langmuir probe with retarding grids are presented.

II. DESCRIPTION OF THE SYSTEM

The Spherical EUV Plasma Sensor, SEPS, is potentially an innovative instrument in terms of space diagnostic technology as it combines the characteristics of a Langmuir probe with a retarding potential analyzer and an EUV spectrometer. The concept has been proposed by a team at Fraunhofer-Institut für Physikalische Messtechnik, IPM, Freiburg who developed a prototype in 2009 [1-2]. A sketch of SEPS is shown in Figure 1.

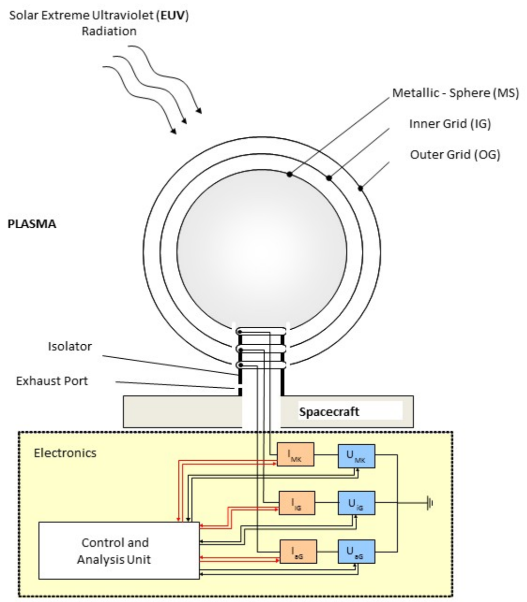

Figure 1: SEPS design. Each sphere is linked to its own electrometer and hence its own electronic circuit in charge of the control of the instrument and data processing.

SEPS is composed of three isolated concentric spherical conductors. The core metallic sphere, MS, is approximately 60mm in diameter; the inner grid, IG, is a thin and transparent double grid of respectively 67 and 72 mm diameter; while the outer grid, OG, is a spherical grid of 80 mm diameter. The meshing of the grids is made with a laser that cuts small regular triangular holes into an Aluminium shell.

The bias voltage control and measurement of low currents down to 100pA is taken care of by an electronic system developed by Astrium Gmbh.

Operation modes

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Several mode of operation are possible based on the setting different electrostatic potentials to the various elements. Typical measurement mode configurations are listed in Table 1. These modes are summarized below.

In the Langmuir probe mode, the three spheres have the same potential which can be varied between -70 and +70 V.

In the shielded Langmuir probe mode, the potential of the core sphere only is varied between -70 and +70 V while the inner and outer grids are maintained at 0V.

In retarding potential analyzer (RPA) mode, the core sphere is at ±20 V and the outer grid at 0 V. The retarding grid is the inner grid whose potential can vary from -70 to +70 V. The core sphere is at +50 V in electron measurement mode and -50 Volts in the ion measurement mode.

In EUV spectrometer mode the outer grid is at +50 Volts to repel ions and the inner grid is at -50 Volts. The selection of photo-electron energy is performed by varying the inner sphere potential from -70 to +70 Volts.

In calibration mode, the core sphere is maintained at 0 Volt, the outer grid at + 50 volts and the inner grid is at -50 volts. In the absence of EUV source this mode should provide zero current.

	$U_{outer\ grid}$	$U_{inner\ grid}$	U_{sphere}
Langmuir Mode	SWEEP +8V < U < -8V $U_o = U_i = U_{sphere}$	SWEEP +8V < U < -8V $U_o = U_i = U_{sphere}$	SWEEP +8V < U < -8V $U_o = U_i = U_{sphere}$
Shielded Langmuir Mode	Fixed Value U=0V	Fixed Value U=0V	SWEEP +20V < U < -70V
Plasma Shielded Langmuir Mode	Fixed Value U = Plasma-potential	Fixed Value U = Plasma-potential	SWEEP +20V < U < -70V
RPA Electron Mode	Fixed Value U=0V	SWEEP +40V > U > -70V	Fixed Value U = 20V
RPA Plasma-electron Mode	Fixed Value U = Plasma-potential	SWEEP +10V > U > -70V	Fixed Value U = 20V
RPA Ion Mode	Fixed Value U = 0V	SWEEP -30V < U < +70V	Fixed Value U = -20V
RPA Plasma Ion Mode	Fixed Value U = Plasma-potential	SWEEP -30V < U < +70V	Fixed Value U = -20V
EUV Mode	Fixed Value U = 50V	Fixed Value U = -50V	SWEEP -70V < U < +70V
Calibration Mode **(Current = 0)**	Fixed Value U = +70V	Fixed Value U = -70V	Fixed Value U = 0V

Table 1:Voltage settings for the SEPS measurement modes.

III. TEST MEASUREMENTS IN A PLASMA CHAMBER

Plasma test measurements were performed in a plasma chamber at the European Science and Technology Centre (ESTEC) [3-4]. The chamber is a 1 meter diameter and three meter long cylinder. It is equipped with a vacuum pump, generating a 10-4 Pa vacuum, and a Kaufman ion Argon source. Ions can be accelerated by a voltage difference of 0 to 15 V and electrons are generated by a heated filament. Typically, plasma density ranges from 109 to 1010 cm-3 and the temperature is about 0.1 eV.

The position of the SEPS instrument in the plasma chamber is shown in Figure 2. Also visible in the figure is a wire Langmuir probe with diameter 0.53 mm and length 23.9 mm. This probe is used to characterize the plasma density and temperature in the vicinity of the SEPS instrument through a least square fit of its current-potential relation according to the cylindrical Langmuir probe formula [7-8].

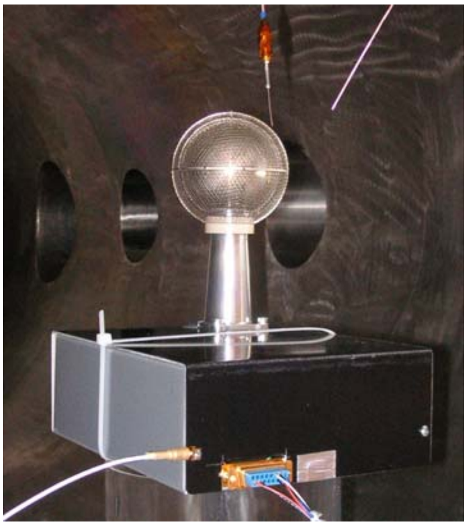

Figure 2: SEPS and the wire Langmuir probe in a plasma chamber at ESTEC.

EUV Mode

A dedicated EUV measurement test campaign was performed at a synchrotron facility and has been reported elsewhere [5]. However, EUV measurements were also performed at ESTEC using the plasma itself as an EUV source through recombination of ions on the plasma chamber surface or in volume. An example of such measurements in EUV mode is shown in Figure 3 below.

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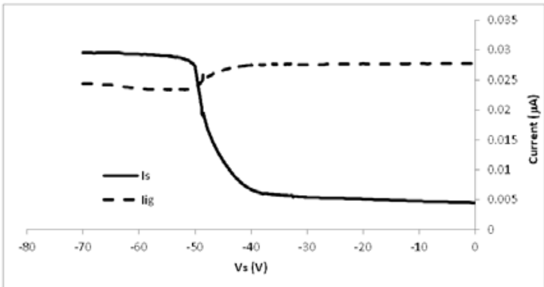

Figure 3: Current measured on the core sphere (solid line) and the inner grid (dashed line) as a function of the core sphere potential in EUV measurement mode.

It can be observed that for very negative potential of the core sphere, the current is highest and almost constant up to -50 Volts. This is because all the photo-emitted electrons can escape. For potential values more positive than -50 Volts, some of the photo-electrons are repelled by the potential of the inner grid which is at a potential of -50 Volts. Beyond -35Volts most of the electrons are repelled. This reflects that the spectrum of EUV extends to about 15 eV which is the energy of the primary ions.

RPA Electron Mode

An example of test data in RPA Electron Mode is shown in Figure 4 below. The total current collected by the core sphere drops to zero for very negative potential because all electrons have been stopped from reaching it. The current starts to increase at about -1.5 V and then increases very rapidly up to a few Volts, reaches a maximum at about 15 Volts and decreases again. This decrease beyond 15 Volts is suspected to be due to the collection of particles by the inner grid which dominates at high potential, therefore preventing a large amount of electrons from reaching the sphere. The slope of the logarithm of the current to the core sphere as a function of the potential between -1.5 V and + 1V is initially of 0.3 but varies by over an order of magnitude within a few Volts, leading to a rather high uncertainty for the temperature measurement.

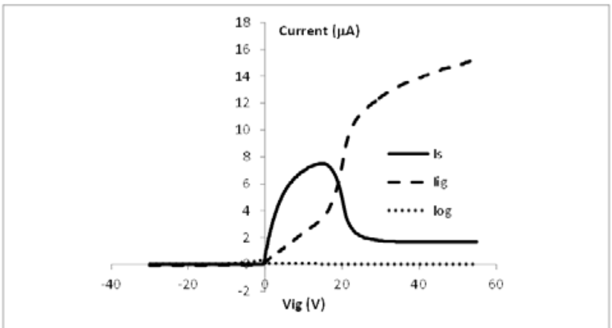

Figure 4: Current measured in RPA electron mode on the core sphere (Is), the inner grid (dashed line), and the outer grid (dotted line) as a function of the potential of the inner grid.

RPA Ion Mode

An example of test data in RPA Ion Mode is shown in Figure 5 and 6 below. The total current collected by the core sphere for very negative potential is the ion saturation current (see closer look in Figure 6) because electrons are prevented from reaching the core sphere which is biased at -20 V. The current decreases nearly linearly up to 20 V without noticeable change of slope. It is not understood yet why no slope change is observed at +15 V which is the directed energy of the ions. This may be because the ions arrive at a range of angles to the normal.

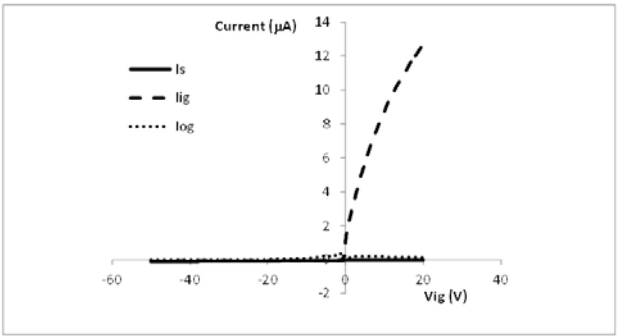

Figure 5: Current measured in RPA ion mode on the core sphere (Is), the inner grid (dashed line), and the outer grid (dotted line) as a function of the potential of the inner grid.

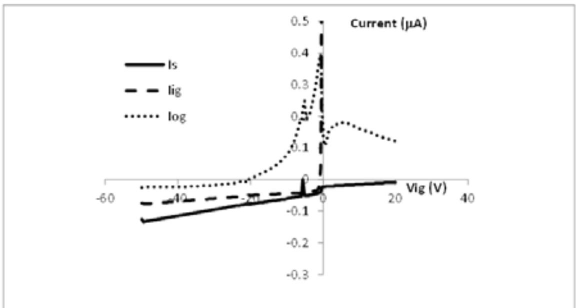

Figure 6: Same as Figure 5 on a narrower scale of current to better visualize the ion current.

Shielded Langmuir Mode

An example of measurements made in Shielded Langmuir mode is shown in Figure 7. It can be seen that the current on the outer grid depends only slightly on the potential of the core sphere as expected. This should in principle correspond to the thermal current impacting the grid. The current to the core sphere seems to behave like a standard Langmuir probe with a region saturated by ions at very negative potentials and a region saturated by electrons at very positive potential. The

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slope in the region -1 V to + 2V varies over an order of magnitude leading to a rather high uncertainty for the temperature measurement. The current to the inner grid appears to vary with the potential of the core sphere. This could be explained by the fact that when the potential of the core sphere is moderately low many particles have a trajectory that takes them only partly into the region between the inner grid and the core sphere and so they are collected by the inner grid. When the potential of the core sphere is significantly positive many of these particles can be collected by the core sphere. No saturation of the current on the core sphere is observed.

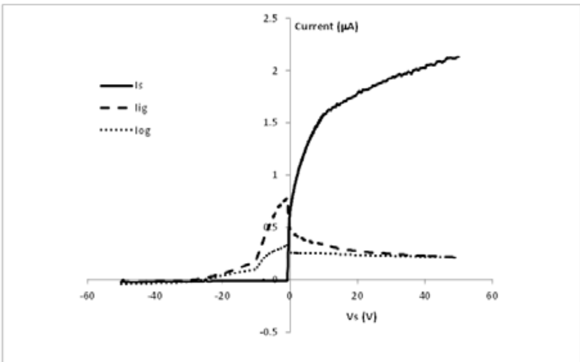

Figure 7: Current measured in Shielded Langmuir mode on the core sphere (solid line), the inner grid (dashed line), and the outer grid (dotted line) as a function of the potential of the core sphere.

IV. CONCLUSION

Plasma test measurements of SEPS have been performed in a plasma chamber at ESTEC. The analysis of the measurements shows strong effects of current collection on the grid which is of the same order of magnitude as the current collected by the core sphere. Such effects make quantitative interpretation of the signal in Langmuir probe modes difficult. Quantitative interpretation of the signal seems still possible in EUV mode and in RPA Electron mode because these rely on the identification of significant curve changes at specific energies. The next step is to develop a model for the signal in the different measurement modes. This model will have to take into account the collection of the current by the grids.

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References

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