

RF potential oscillations in a magnetized capacitive discharge

E. Faudot¹, S. Devaux¹, J. Moritz¹, S. Heuraux¹, M. Usoltseva^{2,3}, A. Nikiforov², K. Crombe^{2,4}, R. D’Inca³, J. Jacquot³

¹ Institut Jean Lamour UMR 7198 CNRS-Université de Lorraine, Nancy, France

² Department of Applied Physics, Ghent University, Belgium

³ Max-Planck-Institut für Plasmaphysik, Garching, Germany

⁴ LPP-ERM-KMS, TEC partner, Brussels, Belgium

Abstract : Radiofrequency (RF) oscillations of the electric potential in a magnetized plasma can be the source of bad measurements with Langmuir probes or can enhance instabilities and turbulent transport across the magnetic field lines. Low RF oscillations lead to a quiet plasma ideal for comparison with steady state models, while high RF oscillations are much more relevant to study plasmas at the edge of tokamaks, especially in the vicinity of Ion Cyclotron RF (ICRF) antennas. Our plasma device, Aline, is a linear magnetized chamber equipped with a RF capacitive cathode designed to study RF sheath and potential biasing of the plasma close to a RF source. The RF system can be driven in 2 modes: without DC current by adding a capacitor between the RF amplifier and the cathode or with DC current. Plasma and floating potentials have been measured by a RF compensated Langmuir probe mounted on a 3D manipulator, providing maps of plasma characteristics in the machine. Potential maps have been obtained for the two RF modes and compared to an equivalent electric model taking into account the RF sheath physics. The main result is that plasma potential oscillations are very small (1-2 V) with the capacitor. Without the capacitor, the near field RF coupling is similar to the case of ICRF antennas, but potential oscillations in the plasma still remain small. This is due to the saturation of the DC current on the RF surface, which is generally much smaller than the grounded wall of the device. The DC biasing is also shifted toward the positive values, which in turn induces strong convective cells. These cells can be analysed thanks to the electric potential maps.

Introduction

The measurement of potential oscillations in a radio-frequency (RF) plasma discharge is key point to understand the noisy IV characteristics that could be measured in the SOL of tokamaks or in the core of helicon plasmas. It reveals the necessity to well compensate the RF oscillations disturbing the Langmuir probe measurements. In addition, the amplitude of DC and AC component of the rf potential in the plasma depends on the way the rf power is coupled to the plasma. A DC coupling induces a DC positive self-biasing of the plasma while the DC potential of the RF electrode remains at 0 volt. On the contrary a capacitive coupling imposes a negative self-biasing of the RF electrode while the DC plasma potential remains a little bit higher than the floating potential [1]. The problematic of the DC self-biasing of the plasma is front of a RF biased surface appears in the vicinity of ICRH antenna in Tokamaks [2]. The problematic of AC plasma potential is of importance in driving instabilities and turbulences in the edges of tokamaks and also to Langmuir probe measurements in such disturbed plasmas.

This work focuses on floating potential measurement, not in the vicinity of a ICRH antenna [3] but in a rf Argon discharge [4] contained in a cylindrical chamber (1m long 30 cm wide in diameter [5]. Here measurements are made in a magnetized chamber at different magnetic field values, and 3 dimensions (3D) maps of these floating potential will be presented so that it is possible to measure the typical scale length of parallel and perpendicular AC and DC potential gradients, useful to deduce the typical perpendicular and parallel conductivities of the plasma around a RF biased surface.

The floating potential probe

The measurement probe is the reference probe of a RF self-compensated probe [6,7] in which the compensation composed of several inductors has been removed to be able to compare the IV characteristics to the direct floating potential measured in real time. An oscilloscope probe is connected at the back of the Langmuir probe body to a small wire (1m long) itself connected to the reference probe. To allow the oscilloscope to “see” a potential as close as possible to the floating potential at the entrance of the sheath on the reference probe it is necessary to take into account the impedance of the wire between reference probe and the oscilloscope probe as well as the sheath impedance. The evaluation of these impedances reveals that the potential seen by the oscilloscope can be as twice lower than the potential at the entrance of the sheath leading to an underestimate of the AC component. This point has to be improved for further measurements but despite this fact the relative values of the AC component can even be interpreted in the 3D maps.

Concerning the DC potential, its value is accurate considering the much higher resistance of the oscilloscope (1Mohms) compared to the one of the wire (several ohms) and the sheath. The probe tip is independent of the reference probe and can be biased to plot the IV characteristic permitting to deduce the floating potential and the ion density. In our plasma the ion neutral collision frequency (10^5 Hz) is higher than the ion cyclotron frequency (10^4 Hz) so that ions are not magnetized and the collecting ion current law on the negative side of the characteristics remains valid to deduce the ion density (10^{16} m⁻³). The working gas pressure is 1.3 Pa, ions are cold and $T_e=2$ eV. The magnetic field direction is along z axis, axial direction in the cylindrical chamber.

The probe is mounted on a 3D manipulator translated by a step motor allowing a displacement range along z axis of 50 cm, 10 cm along x axis, and 10 cm along y axis.

Floating potential profiles

First we present a floating potential profile along y, perpendicular to the magnetic field and the electrode main surface (fig. 1) between $y=40$ mm and -40 mm and making vary the magnetic field from 0 to 100 mT. DC and AC components are plotted as a function of the position and the magnetic field strength in the figure 2 and 3.

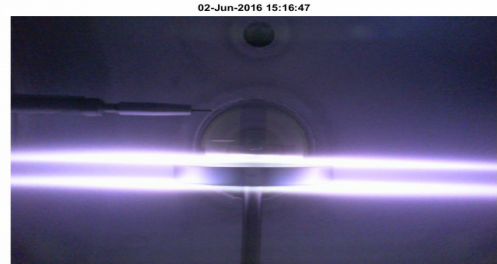


Illustration 1: RF cathode and Langmuir probe

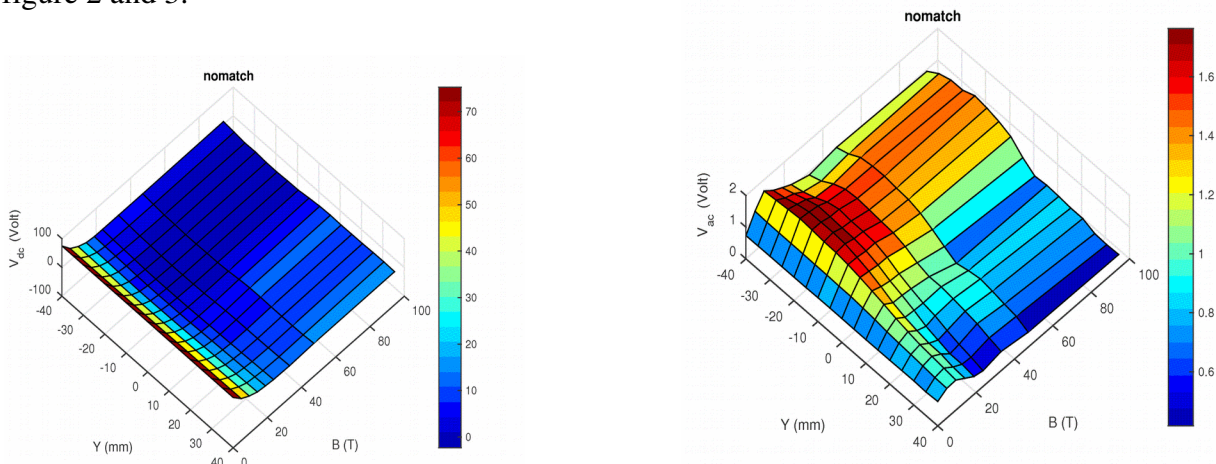


Illustration 3: DC floating potential as a function of y and the magnetic field

Illustration 2: AC floating potential as a function of y and the magnetic field

Only the map without matching box (DC coupling) are presented in this short paper. And it appears that the magnetic field strength make strongly decrease the positive DC self biasing of the plasma as we had a capacitive coupling. The higher the magnetic field and the lower the DC current on the surface quasi parallel to the surface, as if the sheath around the cathode could be modelled with just a capacitor instead of a capacitor in parallel with a non linear resistor. This also explain why the coupling is much better with a magnetic field (at least 50 % of the power is coupled instead of only 10 % without magnetic field). The AC map shows the highest values of the AC potential for magnetic field higher than 15 mT and for y position magnetically connected to the cathode (-15 mm > y > -25 mm).

Necessity of the compensation

Because AC amplitude are higher close or connected to the antenna, it can disturb the IV characteristics measured by the probe tip without its compensation. This is actually observed in figure 4 again without matching (the effect is more important than with matching because of the positive biasing, higher oscillations can be seen). The region with the highest potential gap between the direct floating DC potential and the one deduced from the IV char of the uncompensated RF probe, is a region where the IV characteristic are strongly reshaped leading to a negative shift of the floating potential. On the contrary, far from the cathode, and due to the strong asymmetry of the discharge, the amplitude of the AC potential falls down to values lower than 1 volt, which makes the compensation unnecessary. In fact, the higher is the asymmetry of the discharge and the sooner the RF currents saturates making decrease the amplitude of the oscillations [8].

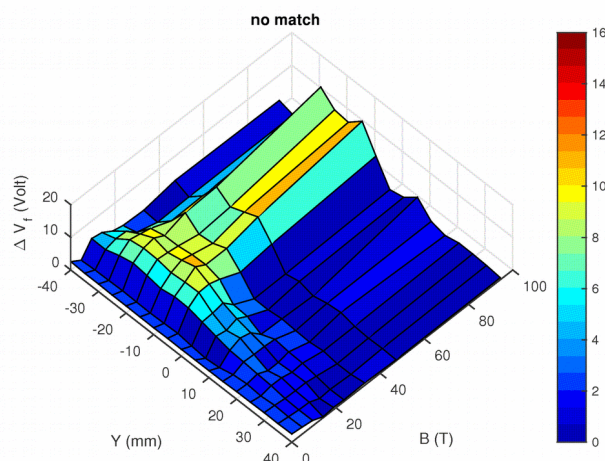


Illustration 4: Potential gap between direct DC floating potential and the one from uncompensated IV char.

3D DC potential maps

Another very interesting result is the drawing of 3D floating potential map to study the typical parallel and perpendicular decay length of the AC and DC component all around the RF cathode.

These maps has been built with 153 points of measurements and next interpolated.

The 2 maps presented in figure 5 and 6 has been performed without matching, explaining why the DC potentials are so high around the RF cathode. The region magnetically connected to the cathode is less biased and the parallel decay length is hard to evaluate here but on the order of one meter (2 V/10 cm) considering a decay factor of 2. The perpendicular decay length is on the order of 8 cm (10 V/4 cm) at 25 mT.

The same decay length can be deduced from the AC map : 0,8 V/14 cm for parallel decay length of 20 cm and 1.4V/4 cm for the perpendicular decay length (4 cm).

These 3D maps make also appear an asymmetry in (X,Y) plane of the potential, which seems to come from the convective fluxes flowing around the biased plasma structure, which changes the density and then the amount of perpendicular current.

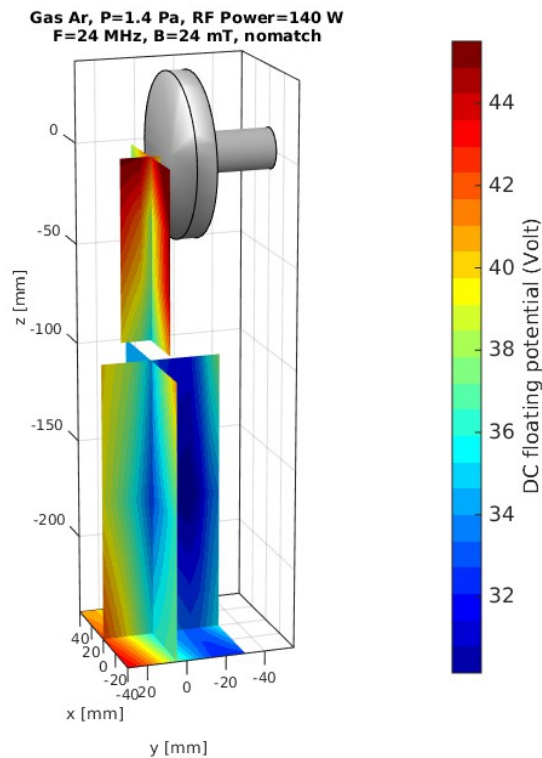


Illustration 5: 3D DC floating potential map

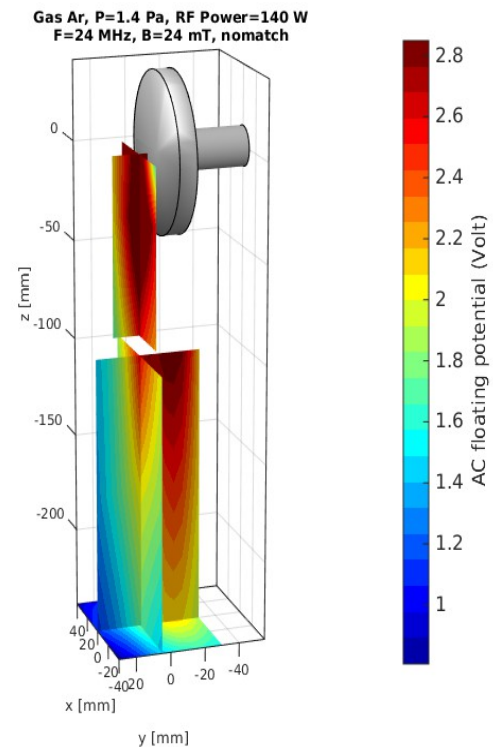


Illustration 6: 3D AC floating potential map

Conclusion

A reference probe has been used to probe in real time the floating potential in the vicinity of a RF electrode which was either directly connected to the RF amplifier (DC coupling, no matching) or connected via a matching box (capacitive discharges). The DC results confirm the self biasing dependence on the way of coupling, high positive biasing in the plasma without matching and negative DC biasing of the cathode with matching. The coupling efficiency is better with matching but the DC coupling can be used to bias a plasma flux tube, induce convection or even to investigate transport barrier. The AC measurements need to be improved because they are underestimated due to the measurement circuit impedance. Nevertheless the profiles allow to determine the perpendicular decay length as a function of the magnetic field. It seems that this length saturates to 40 mm even with a strong magnetic field (100 mT). This saturation value may depend on the asymmetry between parallel and perpendicular models. In such a plasma ions are not well magnetized due to high collision frequency with neutrals. This study focuses also on the necessity to use the RF compensation close to the RF electrode as soon as the RF voltage is higher than the electron temperature (2 eV here). And finally the 3D potential map makes appear the typical parallel and perpendicular decay length and some asymmetries in the plane perpendicular to the magnetic field due to convection.

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