Experimental Study of Cold Plasmas Considering Finite Ion temperature

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This work verifies experimentally the theoretical radial model, developed by the authors, when the positive ion temperature, T_i, is not negligible small compared to the electron one, T_e. An experimental device controlled by a Virtual Instrument (VI) performed in LabView®, has been developed. The theoretical model is a generalization of the one developed by Allen, Boyd and Reynolds (ABR theory), and due to the positive ion thermal motion, the ion current collected by the probe is increased with respect to the case of cold ions. So, we can state that the orbital models underestimate the positive ion current collected by the probe. The measurements have been performed in the ion saturation zone of the *I-V* characteristic, where the perturbation originated by the probe in the plasma is small. A very good agreement between the theoretical and the experimental ion to current characteristics has been found.

1. Introduction

The influence of T_i in the plasma sheath surrounding a conductive probe immersed in the plasma has been theoretically analyzed by using a radial model developed by the authors [1]. Nevertheless, experimental measurements to confirm the theory are demanded. The aim of this work is to propose an experimental method to verify the influence of T_i. This method is based on the measurement of the *I-V* characteristic of a cylindrical Langmuir probe immersed in the plasma. The positive ion saturation zone of the *I-V* characteristic ($V \ll V_{plasma}$) is used. This zone is a distinguished one because the charge drained from the plasma is very small, diminishing the perturbation due to the presence of the probe. Moreover, the Sonin plot [2] uses data obtained from our theoretical model of the sheath considering T_i [1]. The good agreement obtained ensures the goodness of our model.

We have developed a Virtual Instrument (VI) [3,4] in the LabView® programming environment to verify the theoretical radial model considering the influence of the positive ion thermal motion.

2. Experimental setup

The experimental device, in which the program has been tested is shown in Fig. 1. This is very adequate for this study because the plasma generated by it is very stable and the electron temperature is low [5], $T_e(\mathrm{K})\in[1000,3000]$; T_i is usually considered close to the room temperature, 400 K. The discharge device consists of a large Pyrex cylinder with two electrodes connected to a very stable high voltage power supply which generates the discharge in a low pressure Argon gas.

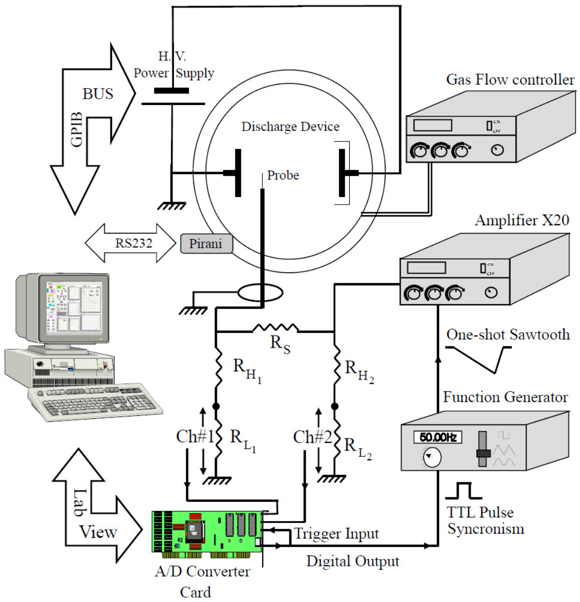

Figure 1. Experimental setup.

The *I-V* characteristic of a cylindrical Langmuir probe is measured by using an analog to digital (A/D) converter card, with several differential A/D channels, 16 bits resolution, $5\cdot10^5$ samples per second simultaneously and multiple digital input/output. Two voltage dividers are used to adapt the probe voltage to the A/D card input ranges. A LabView® program controls the whole experiment.

3. Results

In this work we have compared the theoretical results with experimental data obtained in an Argon plasma generated by a DC discharge. To compare the experimental data and the theoretical results, it is necessary to measure the plasma parameters. These parameters can be determined from the electron energy distribution function (EEDF). Since the theoretical model assumes a Maxwellian energy distribution function for the electrons, the comparison will be valid only if the EEDF is really Maxwellian. This fact is also verified in the experiment. Figure 2 shows that there is a clear agreement between the theoretical and the experimental *I-V* characteristic.

The positive ion temperature is only slightly higher than the temperature of the neutral atoms, so that the experimental $\beta=T_i/T_e$ value is between 0.09 and 0.34. Figure 3 shows the Sonin plot for both the theoretical and the experimental ion current intensity. The ion current represented in this plot has been obtained from the experimental *I-V* characteristic of the probe for a biasing potential y_p=-25KT_e. The measurements shown in Figure 3 correspond to the ion saturation zone, where most of the intensity collected by the probe, is due to the positive ions. This zone has the advantage that the perturbation originated by the probe in the plasma is small.

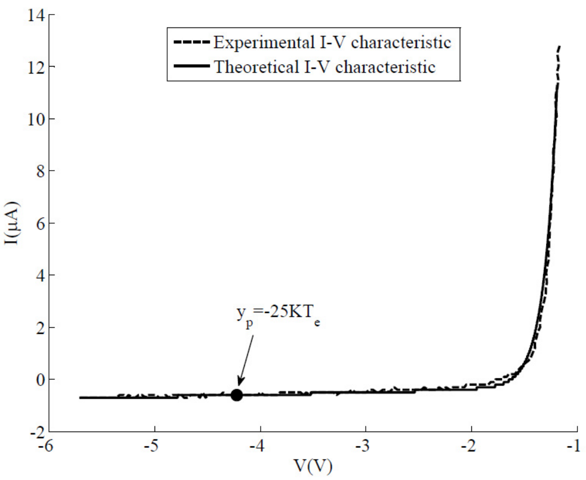

Figure 2. *I-V* characteristic; the solid line indicates the theoretical data, the dashed line are the experimental data and the point indicates the y_p =-25kT_e case. *P*=5.4 Pa and I_d=2.8 mA.

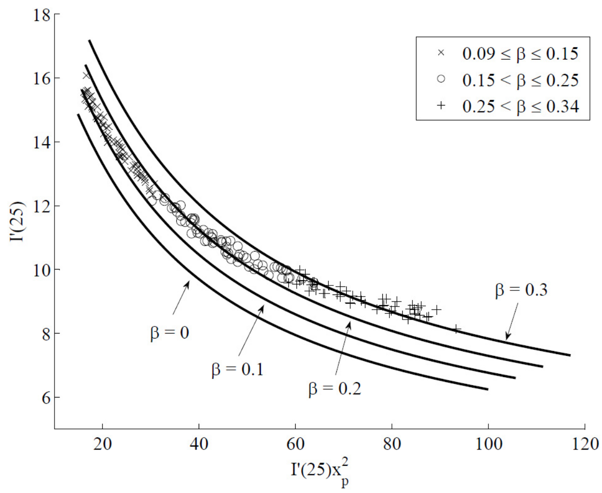

Figure 3. Theoretical Sonin plot (solid lines). The experimental data are represented by symbols (blades, circles and crosses).

Figure 3 shows the results of the radial models and the experimental values measured in our experimental device. The experimental values fit quite well to the curves for which the positive ion temperature is taken into account [7]. It also shows how the ion current collected by the probe is always higher than the one obtained from the radial model for cold ions [6,8]. The figure shows the theoretical results for β=0 (ABR), 0.1, 0.2 and 0.3.

4. Conclusions

The theoretical radial model, proposed by the authors, has been verified experimentally. We have generalized the ABR theory that considers a radial motion of the positive ions towards the probe. Our model includes the positive ion thermal motion and provides an ion current of a probe immersed in the plasma higher than the one provided by the ABR model, since the positive ions have more energy to reach the probe. The experimental ion current is also higher than the one provided by the ABR model and therefore the models which consider an orbital motion of the positive ions around the probe, underestimated the real current collected by the probe. In fact, the ion current measured in our experimental device fits quite well to the one provided by the radial models in which the positive ion thermal motion is taken into account.

Finally, the theoretical model and the experimental device provide a very accurate diagnostic method of plasmas with finite positive ion temperature.

5. Acknowledgments

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6. References

[1] R. Morales Crespo, J. I. Fernández Palop, M. A. Hernández and J. Ballesteros (2004) J. Appl. Phys. 95, 2982.

[2] J. Ballesteros, J. I. Fernández Palop, M. A. Hernández and R. Morales Crespo (2006) Appl. Phys. Lett. 89, 101501.

[3] J. Ballesteros, J. I. Fernández Palop, M. A. Hernández, R. Morales Crespo and S. Borrego del Pino (2004) Re. Sci. Instrum., 75, 90.

[4] J. Ballesteros, J. I. Fernández Palop, M. A. Hernández, R. Morales Crespo and S. Borrego del Pino (2006) Escampig XVIII, Lecce (Italy).

[5] J. I. Fernández Palop, J. Ballesteros, V. Colomer and M. A. Hernández (1995) Rev. Sci. Instrum., 66, 4625.

[6] J. E. Allen, R. L. F. Boyd and P. Reynolds (1957) Proc. Phys. Soc., 70, 297.

[7] J. G. Laframboise (1966) UTIAS Report No. 100, University of Toronto.

[8] F. F. Chen (1965) J. Nucl. Energy, Part C 7, 47.