Experimental study of the transition of the ion current to a cylindrical Langmuir probe from the orbital to the radial theory

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This work deals with the experimental comparison, between Argon and Helium plasmas, of the ion current collected by a cylindrical Langmuir probe immersed in a plasma considering the influence of the positive ion thermal motion. In the Argon plasma, the behaviour of the positive ion current collected by the probe is described by a theoretical radial model. In the case of the Helium plasma, the positive ion current collected by the probe shows a transitory behaviour from orbital-motion limited (OML) to radial (ABR). This fact is justified since the atomic mass of Helium is ten times lower than the one of Argon.

Introduction

There are two well accepted theories for the positive ion current collected by a negatively biased Langmuir probe: the orbital-motion limited theory (OML) and the radial-motion theory for T_i=0 (T_i being the positive ion temperature) developed by Allen, Boyd and Reynolds for spherical probes [1] and extended by Chen for cylindrical ones (ABR) [2]. The authors have developed an extension of the ABR theory taking into account a finite positive ion temperature [3], which is assumed to be similar to room temperature. The OML theory was extended by Bernstein and Rabinowitz for ions having a finite but uniform total energy and by Laframboise for ions following a Maxwellian distribution function [4]. In this way, the analysis of Langmuir probe characteristics contains a paradox in that it is unknown *a priori* which of both theories is applicable before it is applied. The usual way of determining whether the OML or the ABR probe theory is applicable, is comparing the experimental values with the theoretical curves on a Sonin plot.

The aim of this work is to show an experimental study of the ion current to a cylindrical Langmuir probe for Argon plasmas, which shows an ABR behavior considering the positive ion temperature, and for Helium plasmas which shows a transition in its behavior from OML to ABR. The comparison is performed by using the theoretical Sonin plot obtained from our model [5], and the model of Laframboise obtained from the fitting formula developed by Peterson and Talbot considering T_i [5]. This comparison is quite critical, since, on the one hand, a small variation in the positive ion current implies a large variation in the Sonin plot; on the other hand, as Figure 1 shows, a small variation in the positive ion temperature also corresponds to a large variation in the Sonin plot.

Results and conclusions

We have measured the *I-V* characteristic of a cylindrical Langmuir probe inmersed in an Argon plasma and a Helium plasma in a low pressure DC discharge [6,7]. From the measured *I-V* characteristic, several magnitudes characterizing the plasma are obtained and the corresponding Sonin plot is presented.

Figure 1 shows the Sonin plots obtained from the different theories: radial (ABR and the extension developed by the author for finite positive iones temperature), OML and Lafranboise, for some $\beta=T_i/T_e=0$ (T_e being the electron temperature) values. In Figure 1, the positive ion current collected by the probe, obtained from the experimental smoothed *I-V* characteristic, is also presented. For the Argon plasma, the experimental values fit quite well to the Sonin plots obtained from the radial model for $\beta\neq0$ [7]. On the other hand, Figure 1 shows that for the Helium plasma the situation is more complex and the positive ions current shows a behavior which goes from ABR to OML-Laframboise, depending on te plasma conditions. This is due to the fact that the atomic mass of Helium is ten times lower than the one of the Argon but both, Argon and Helium ions have similar β values. Therefore, the initial tangential component of velocity, far from the probe, is much higher for Helium than for Argon, and the Helium ions fall to the probe following an orbital motion trajectory.

Moreover, as β disminishes, that initial tangential component of velocity also disminishes and the positive ions falls to the probe following a trajectory which tends to be radial.

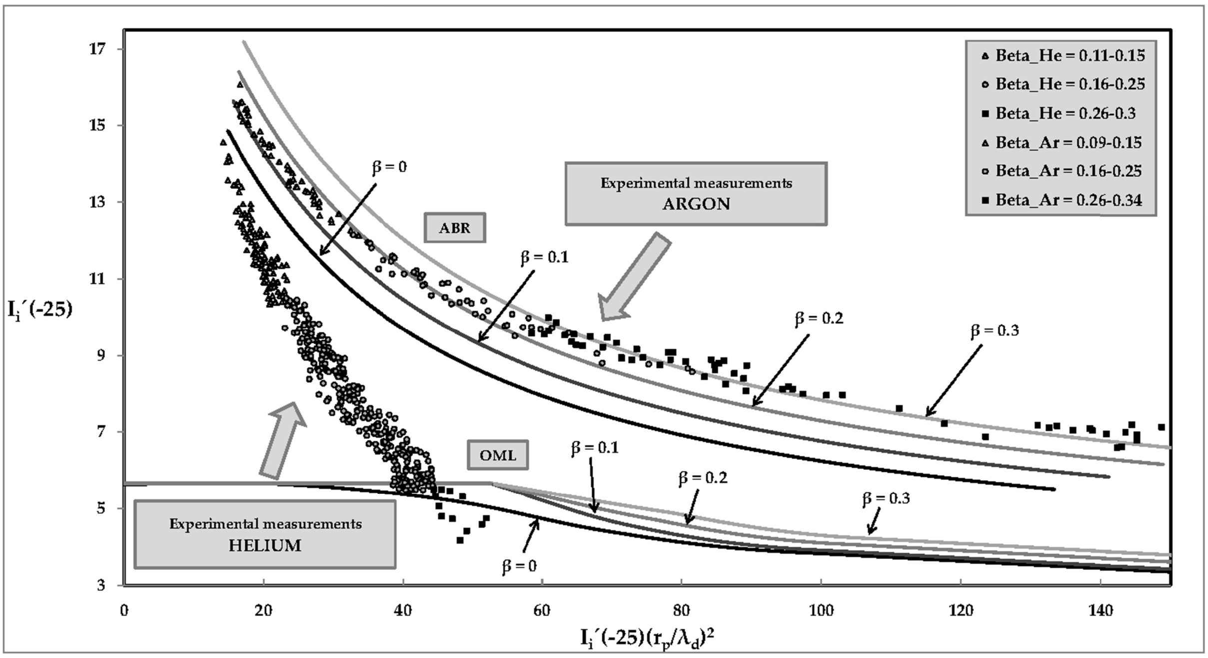

Figure 1. Theoretical Sonin plots for y_p=-25 and for several β values (solid lines), and experimental Sonin plot values (triangles, circles and squares as a function of the corresponding β value). Shown in figure for both cases, ABR (fitting functions developed by the authors) and OML (Laframboise theory and fitting formula developed by Peterson and Talbot) models.

We are working on the study of the application of several criteria that discriminate between the radial or orbital behaviour for the ions reaching the probe. The next measurements will be performed in Neon plasmas, because since the atomic mass has an intermediate value between those of Argon and Helium, we assume that we will be able to see more clearly the transition between OML and ABR. This full study will be the subject of a future article.

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