Model and PIC simulation of the ion collection by Langmuir probes

J. Held[1,3], W. Villafana[2], I. Kaganovich[2], U. Kortshagen[1]
[1] *University of Minnesota, Minneapolis, USA*
[2] *Princeton Plasma Physics Laboratory, Princeton, USA*
[3] *Eindhoven University of Technology, Eindhoven, The Netherlands*

Abstract: In this contribution, we present 2D particle-in-cell simulations of a plasma surrounding a negatively biased probe. Ion currents collected by the probe are compared to models from the literature, which are commonly used for ion-density diagnostics. We find only qualitative agreement between these models and the simulation results. We propose a new model that is more accurate than existing approaches and potentially much easier to use.

1. Introduction

Langmuir probes remain one of the most important diagnostic tools for plasma processing applications. To accurately determine the electron density, it has become customary to rely on the electron current part of the Langmuir probe characteristic. However, in plasmas that contain negative ions or charged dust particles, a separate measurement of the positive ion density is required. This can be done by analysis of the ion current collected by a negatively biased probe. However, even at low pressures of a few Pa, the ion current is affected by collisions due to the large cross section for charge exchange. Available theories for collisional or collision-enhanced ion currents onto probes are complex, not well validated, and often only suitable for a certain range of probe sheath thickness or collisionality. Thus, in this contribution, we compare available collisional probe theories for the ion collection by a probe immersed in a plasma to particle-in-cell (PIC) simulations. Using these results, we propose a simpler and more intuitive model for the ion current collected by the probe, based on the model of Gatti and Kortshagen developed for the charging of dust particles [1].

2. Methods

A particle-in-cell (PIC) simulation is utilized to study the argon plasma surrounding a probe of 100 µm diameter and 5 mm length, comparable to typical experimental conditions. The open-source EDIPIC package [2] is used to perform the simulation in a 2D cylindrical geometry (*r*-*z* plane), allowing us to capture the influence of the finite probe length. The ion current collected by the probe is investigated at different argon pressures, between 0.01 Pa and 300 Pa (10^{-4} Torr to 2.3 Torr).

3. Results and Discussion

Figure 1 shows the ion current collected by a Langmuir probe surrounded by an electropositive argon plasma at a density of $n = 2 \times 10^{15}$ m^{-3} and an electron temperature of $T_e = 3$ eV, as a function of neutral gas pressure. The ion current can be observed to increase from the collisionless case (< 0.1 Pa) to the collision-enhanced regime (1-30 Pa) and then decrease for even higher pressures. This general trend is well reproduced by the literature models (mod. Talbot & Chou [3], Zakrzewski & Kopiczynski [4]), but the quantitative agreement is poor, especially for pressures above 10 Pa, where many processing plasmas are operated.

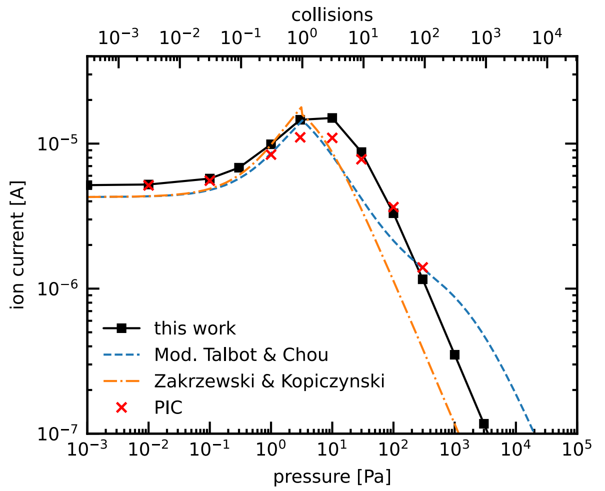

Fig. 1. Ion current collected by a Langmuir probe biased at -40 V as a function of argon pressure for a plasma at $n_e = n_i = 2 \times 10^{15}$ m^{-3} and $T_e = 3$ eV.

In this important range, our model, based on the work of Bryant [5], shows considerably better agreement. This is also true for the collisionless case (< 0.1 Pa), where the literature models neglect the current increase due to the finite length of the probe.

4. Conclusion

Our 2D PIC results show discrepancies with commonly employed models from the literature, which explains the lack of accuracy of ion density diagnostics with Langmuir probes, which is often observed. Our new model shows better agreement with the simulation results, but more work is needed to perform more rigorous validation.

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