Computational simulation of Langmuir probe characteristics

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Abstract

Langmuir probe measurements belong to the oldest and most widely spread methods of plasma diagnostics. Various probe geometries are generally used, including cylindrical, spherical and planar probes. The analysis of probe characteristics relies usually on simplified theoretical concepts, but the influence of collisions in the sheath and pre-sheath is covered by various theoretical corrections. The finite geometry of the probe is usually neglected. It has been shown experimentally (e.g. [1]), that the real geometry of the probe may influence the estimation of plasma parameters. The increasing performance of computers provides new possibilities to study these phenomena numerically. The results may enhance our understanding of the probe diagnostics and increase the accuracy of measurements.

Introduction

In our contribution we present a computational simulation of Langmuir probe characteristics in the positive column of a DC glow discharge in argon. The computer model is based on a combination of a fluid part and a particle part with an iterative coupling. Basic principles of this model were recently published in [2]. The complexity of the problem requires the fully three-dimensional approach, however, the high efficiency of the model enables us to simulate the probe characteristics considering the influence of finite dimensions and charged insulators adjoining the active part of the probe. The main physical task of our simulations was to determine, in which way the used type of the Langmuir probe and its geometry influenced the derived plasma parameters.

Results

Current-voltage characteristics of three geometrically distinct Langmuir probes were computed using the hybrid model [1]. The characteristics of cylindrical, planar and spherical probes are shown in Figure 1. The pressure was $p = 133$ Pa, the electron and ion densities were $n_e = n_i = 1 \times 10^{15}$ m^{-3}, the electron temperature was $T_e = 11600$ K and the ion temperature was $T_i = 300$ K. The dimensions of probes were following:

Cylindrical probe radius:	0.05 mm
Cylindrical probe length:	5.0 mm
Spherical probe radius:	0.5 mm
Planar probe diameter:	1.0 mm

The negatively charged dielectric holder was included in the simulation. Both electron and ion currents to the probes were computed.

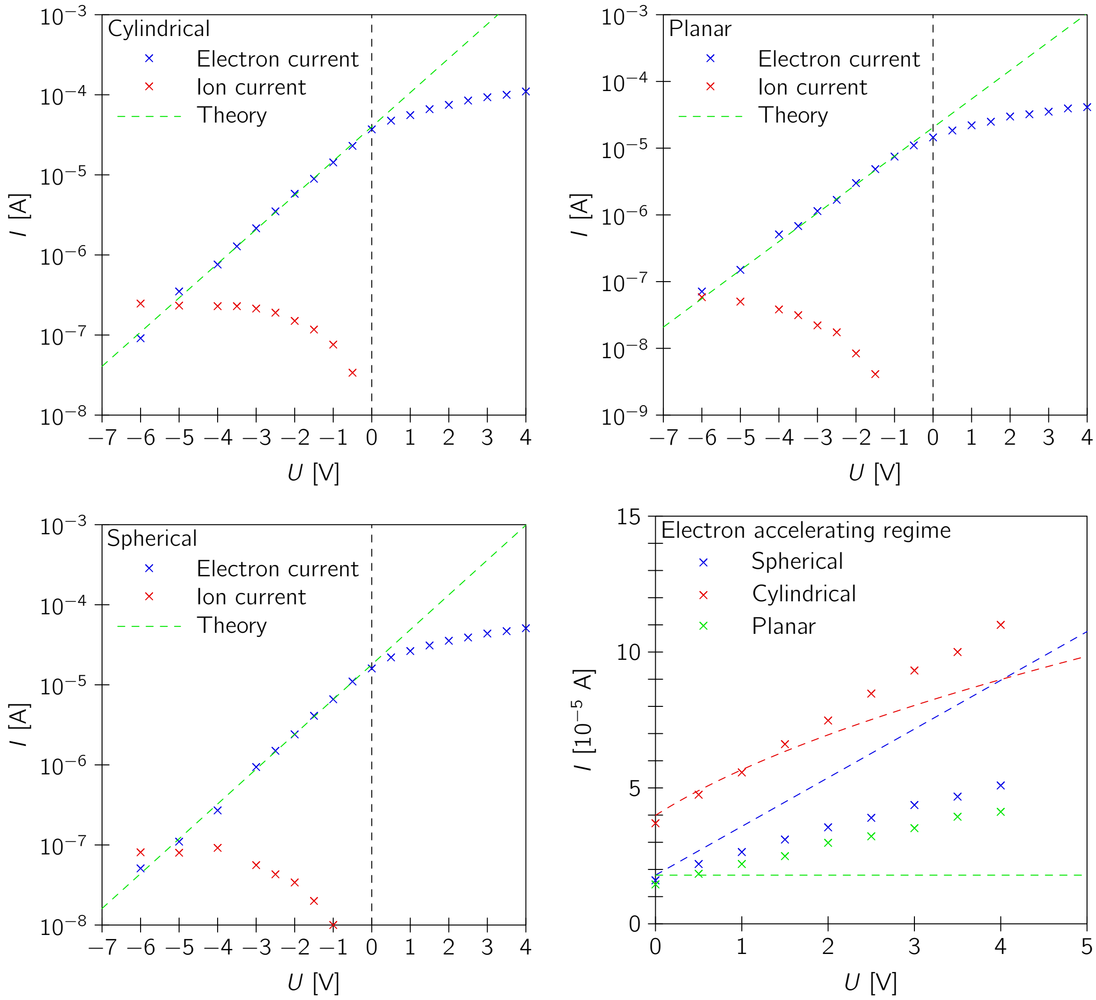

Figure 1: Electron and ion currents to the cylindrical, planar and spherical probes. The green line, which corresponds to Maxwellian EEDF, shows a good agreement of theory with results of the model in the electron retarding regime. The last figure shows the electron current in the electron accelerating regime in comparison with the OML theory.

The electron current collected by the probes in the electron retarding regime corresponds to the Maxwellian EEDF. The relative error of electron temperature and density estimations using cylindrical and spherical probes is lower than 5%. The planar probe simulation leads to less accurate results: $T_e = 13000$ K and $n_e = 8.1 \times 10^{14}$ m^{-3}.

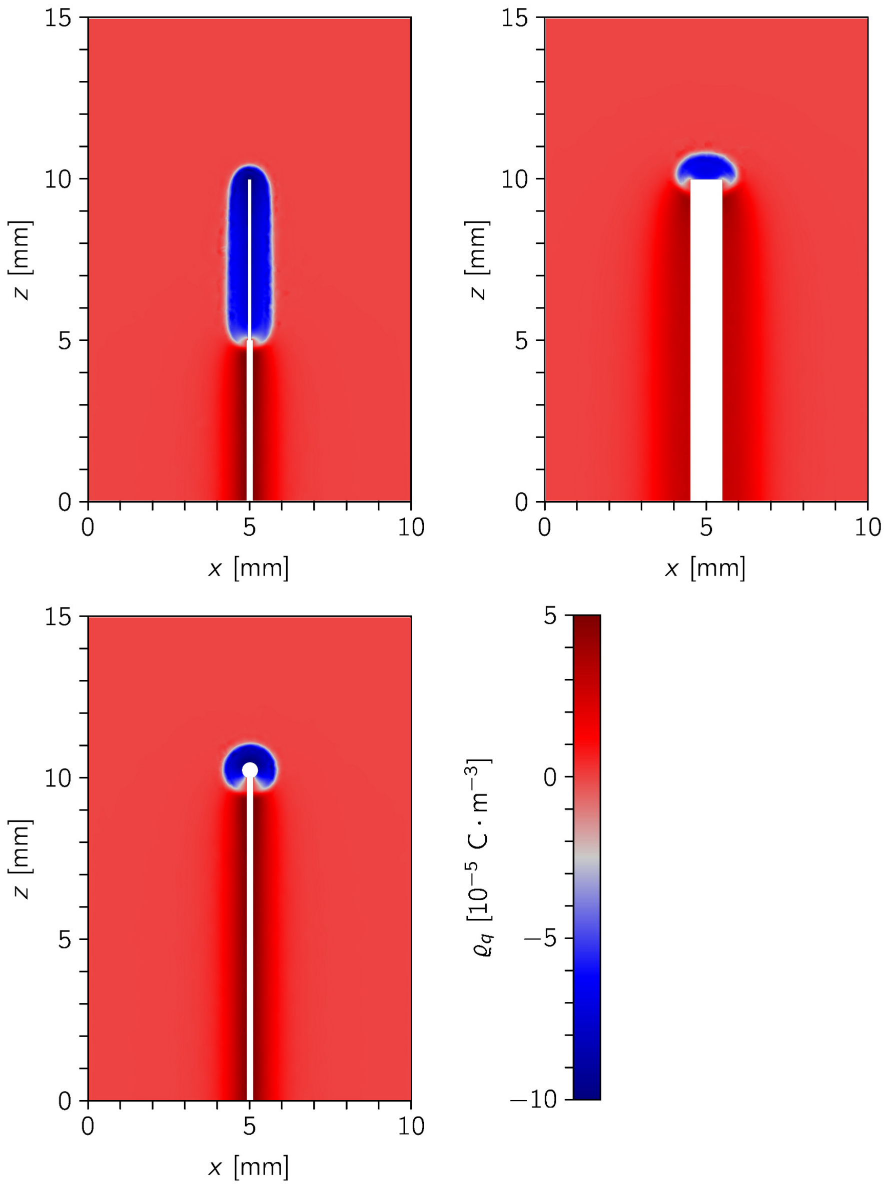

Figure 2: Space charge density in the vicinity of probes at $U = 4$ V.

In the electron accelerating regime, the discrepancy between the theory and model results is qualitatively different for all three geometries. Assuming that the sheath disappears at plasma potential $U = 0$ V, the finite dimensions are of minimal importance. With increasing voltage bias on the probe, the formation of the sheath becomes more influenced by the finite dimensions and by the presence of the dielectric holder. The discussion is based on Figure 2.

The tip of the cylindrical probe extends the sheath, while the holder limits the sheath at the opposite end. As these effects partly compensate each other, the cylindrical probe gives the best results of the three geometries.

In the case of the planar probe, the area of the sheath surface is not at all constant, as is expected by the theory, but resembles a hemisphere. Therefore the electron current increases with the bias. The size of the planar probe was intentionally very small in order to show this effect. In practical applications, the planar probe is larger and this effect is of minor importance.

The electron current collected by the spherical probe is significantly diminished by the presence of the holder, however, the rest of the sheath is spherical and the characteristic remains linear.

Conclusion

The model results of electron current in retarding regime are in a good agreement with the OML theory. In this case, the finite dimensions of probes are of minor importance. The agreement in the electron accelerating regime is much worse. The electron current to the planar probe is the most distorted, because the sheath thickness is comparable with the diameter of the probe. The current to the spherical probe is lower due to the holder presence. The cylindrical probe gives the best results of the three geometries.

The influence of the dielectric holder increases with the probe bias, because the holder remains negatively charged approximately to the floating potential regardless of the probe bias.

The efficiency of the 3D hybrid model allowed us to use a personal computer. The computation of one point of the characteristics took approximately 2 hours (12 threads on Intel Core i7 980X at 3.33 GHz).

Acknowledgements

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