Interaction of sheaths in multicomponent plasma via computer modelling

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Introduction

Particle models are well established modelling techniques commonly used in plasma physics [1]. They usually combine molecular dynamics and Monte Carlo method and can be used e.g. to better understand plasma-solid interaction. Theoretical studies of sheath creation have been already done but in conditions of multicomponent plasma these theories become quite complicated [2] and computer modelling approach is needed, especially in complex geometries.

We used 2D particle model to explore sheath structures in plasma consisting of electrons (e^-), positive argon ions (Ar^+) and negative atomic oxygen ions (O^-). Firstly, we focused on sheath in the vicinity of the cylindrical probe itself. Consequently, interaction of two sheaths in electronegative plasma was examined. The latter was based on our previous work [3] focused on interaction of sheaths in electropositive plasma and question: how much the presence of small cylindrical probe influences the sheath around the big one.

2D particle model

Our 2D particle computer model was based on Particle-in-cell method with Cloud-in-cell algorithm for collection of charge density on a rectangular mesh (typically 400×400 nodes). The motion of charged particles was resolved by velocity Verlet algorithm. Scattering processes of charged particles with neutrals were treated by modified null collision method [4]. Rectangular computational domain of dimensions 4×4 cm was surrounded by sources of particles with Maxwellian velocity distribution.

Following computations were done at 133 Pa pressure with number density of charged particles $1.59 \cdot 10^{15}$ m^{-3}. Temperature of e^- in source of particles was set to 23,600 K, temperature of Ar^+ and O^- ions to 300 K. Cross sections of Ar^+, resp. e^- scattering processes were considered according to [5], resp. [6]. Constant cross section ($4.3 \cdot 10^{-19}$m^2) of O^- elastic collisions was defined.

Electronegative plasma

A little bit artificial mixture of e^-, Ar^+ and O^- was created to determine effects of presence of heavier negative particles on sheath structure around positively biased cylindrical probe. Computations were done for three different electronegativities of modeled plasma.

According to Figure 1 shielding of the biased probe is mostly ensured by electrons in the case of 50% electronegativity. Different profiles of number density of negatively charged particles can be also seen for 10% and 90% electronegativity - electrons are still present in the sheath for the latter case. With increasing electronegativity the area where quasineutrality is broken enlarges and potential decreases over greater distance, Figure 2. These observations can be explained by different mean free paths of electrons and O^- ions. Consequently, electrons behave according to Boltzmann relation for number density and get to the close vicinity of the biased probe, while O^- ions behave according to drift-diffusion aproximation and stay further.

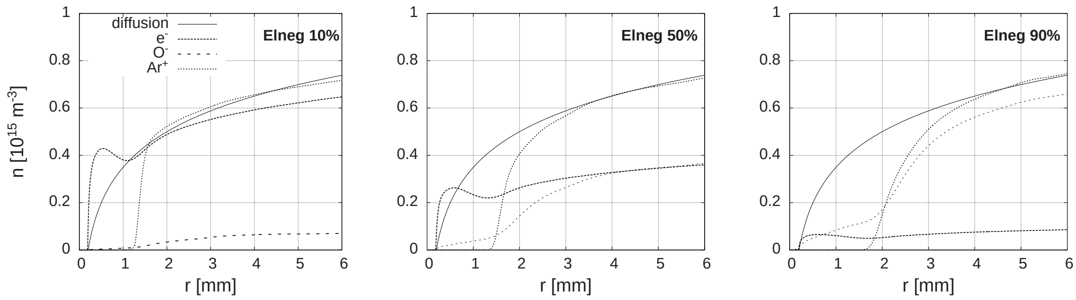

Figure 1: Density of charged particles in the vicinity of +10 V biased cylindrical probe for various values of plasma electronegativity.

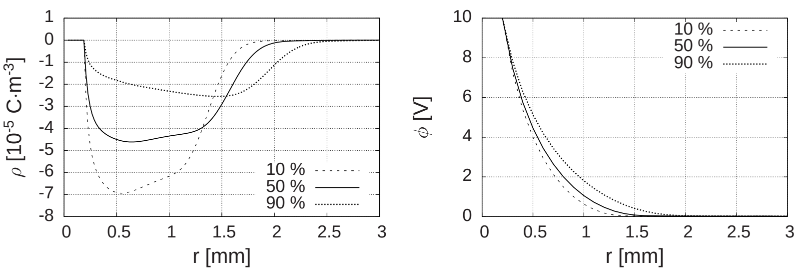

Figure 2: Charge density and potential distribution in the vicinity of +10 V biased cylindrical probe for various values of plasma electronegativity.

Interaction of sheaths

The situation when sheath of small probe immersed in electronegative plasma interacts with sheath of the greater probe was also investigated. Figures 3 and 4 show interaction of sheaths of small probe with radius 0.2 mm biased on -10 V and big probe with radius 1 mm biased on +10 V for two different mutual distances of probe centres ($1{\cdot}10^{-2}$ m and $2.5{\cdot}10^{-3}$ m) and two magnitudes of electronegativity. Results are presented in terms of electric field intensity and charge density.

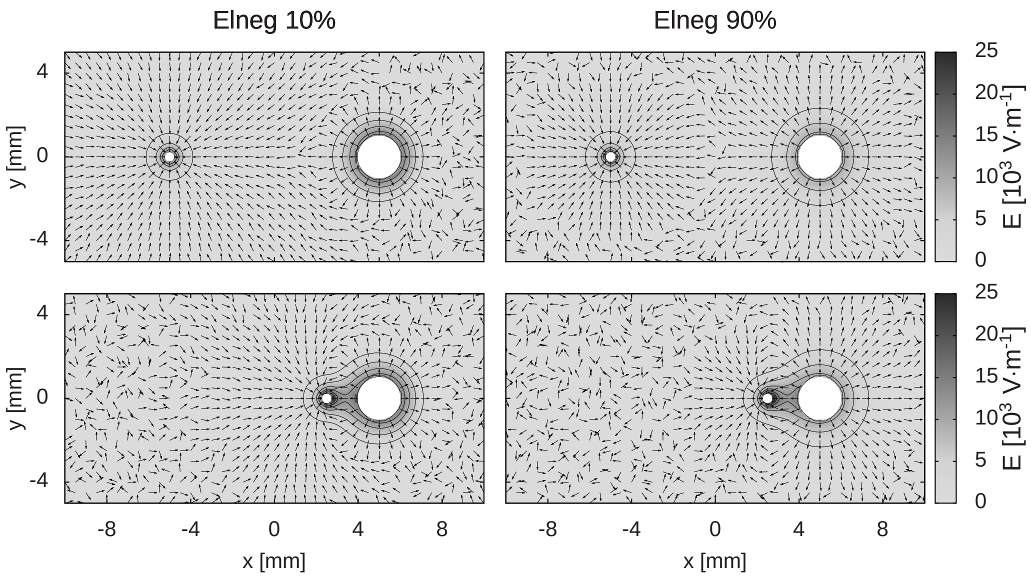

Figure 3: Electric intensity in the vicinity of two interacting cylindrical probes – voltage bias of the small probe -10 V, bias of the big probe +10 V.

Charge density in the vicinity of the big probe is significantly influenced by existence of presheath around small probe. Non-zero electric field in presheath of the small probe acts on the electrons around the big probe and push them away especially from the direction where the small probe is located. Consequently, flux of negative charge on the big probe decreases when the small probe gets closer, Figure 5. This effect can surely influence measurements of IV characteristics by the big probe. With increasing electronegativity presheath around small probe becomes smaller since less electrons are present and thermal velocity of Ar^+ is comparable with thermal velocity of O^-.

Conclusion

Size of sheath structure around solids immersed in plasma significantly depends on its electronegativity. With increasing electronegativity sheath becomes greater, presheath smaller. These changes have got effect on mutual interaction of plasma sheaths. In our contribution, it was documented by spatial distribution of charged density and electric field around interacting probes and flux of negatively charged particles on the big probe.

Acknowledgement

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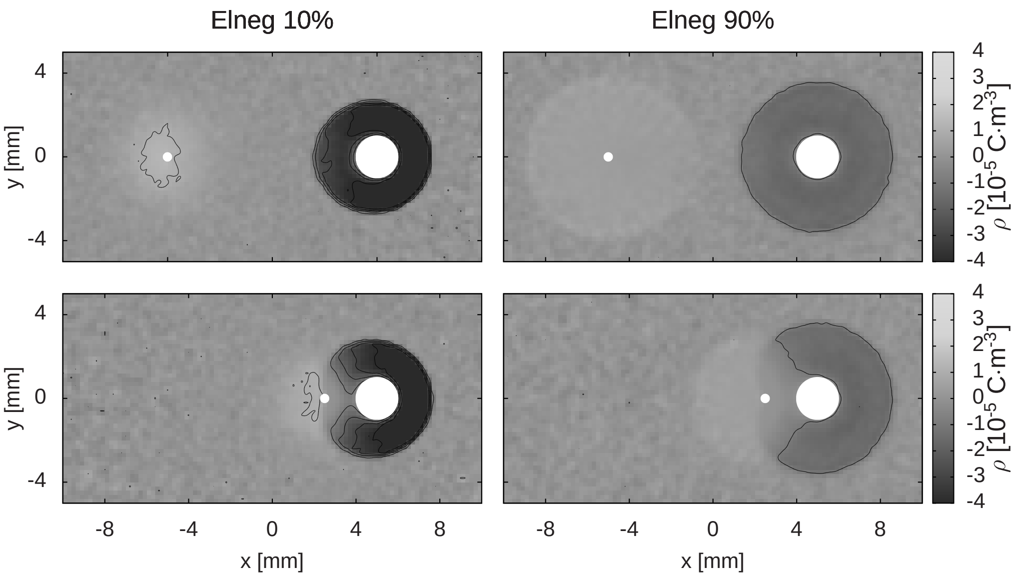

Figure 4: Charge density in the vicinity of two interacting cylindrical probes – voltage bias of the small probe -10 V, bias of the big probe +10 V.

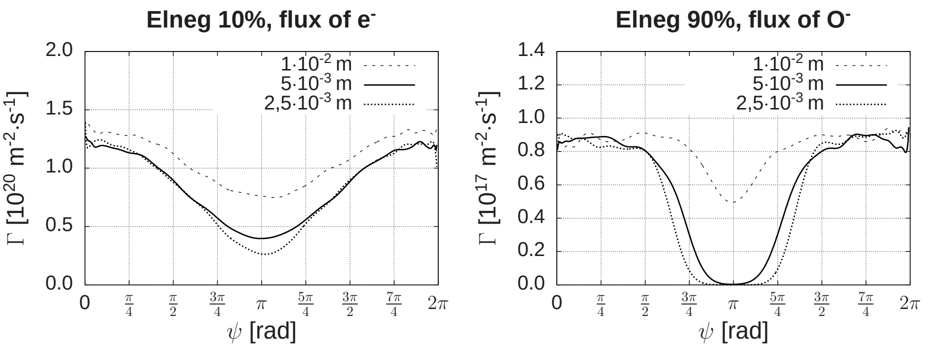

Figure 5: Angular distribution of fluxes of negatively charged particles on the big probe.

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