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2D fluid-plasma model of a tandem-type plasma source

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Abstract. A two-dimensional fluid-plasma model developed for describing the spatial distribution of the characteristics of plasma sources with complicated configurations is employed for analysis of the operation of a tandem plasma source with respect to the influence of the position of its driver.

1. Introduction

The two-chamber plasma sources are well-known as remote plasma sources [1, 2] or as tandem plasma sources [3, 4], in plasma processing technologies and as negative hydrogen ion beam sources for additional heating of tokamak plasmas, in particular in ITER. In both cases the source consists of a driver region where the radio frequency power is applied and of an expanding plasma region. Obviously, the description of the operation of sources with such a complicated configuration requires the development of – at least – two dimensional (2D) models [1, 2, 5-9] which should outline new channels in the gas-discharge physics theory directed towards description of plasma existence in regions without external power deposition.

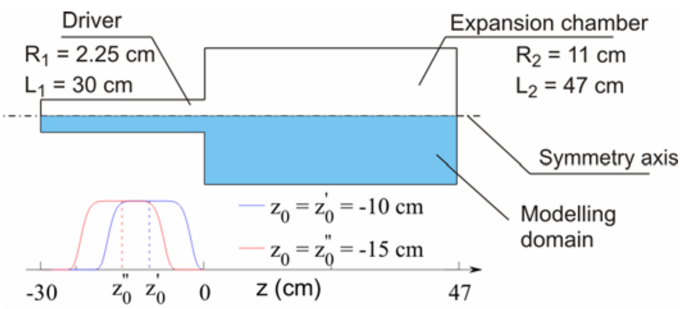

Figure 1. Configuration of the source. The location of two positions ($z_0 = z_0'$ and $z_0 = z_0''$) of the centre of the power deposition region is shown. The dimensions of the source are given and the modelling domain is marked.

A 2D fluid-plasma model developed recently [10] is employed here in the analysis of the operation of a tandem plasma source (figure 1). The discharge vessel consists of two chambers. The driver, i.e., the region of the external power deposition, is located in a smaller-radius (R_1) chamber with length of L_1, while a larger-radius ($R_2 > R_1$) chamber of length L_2 provides the volume for plasma expansion from the driver. In the technological applications of such sources, the plasma processing takes place in the second chamber. This motivates studies on the mechanisms ensuring plasma existence in expanding plasma regions and on the plasma behaviour there.

The results presented here show that changing the position of the driver affects strongly the distribution of the plasma parameters and the charged-particle and electron-energy fluxes in the source. The regime of the discharge maintenance is with a net dc current in the discharge, unlike the well-known ambipolar diffusion regime characterized by equality of the ion and electron fluxes. This is confirmed by the results for the charged particle fluxes usually not discussed in previous studies on two-chamber sources.

2. Basis of the model

The fluid-plasma description presented here is within the drift-diffusion approximation. The discharge is in an argon gas. The set of equations numerically solved includes the continuity equations of electrons and ions, the electron energy balance equation and the Poisson equation:

$$\operatorname{div}\vec{\Gamma}_{\mathrm{e,i}} = \frac{\delta n_{\mathrm{e,i}}}{\delta t}, \tag{1}$$

$$\operatorname{div}\vec{J} = P_{\mathrm{ext}} - e\vec{\Gamma}_{\mathrm{e}}\cdot\vec{E} + P_{\mathrm{coll}}, \tag{2}$$

$$\Delta\Phi = \frac{e}{\varepsilon_0}\left(n_{\mathrm{e}} - n_{\mathrm{i}}\right). \tag{3}$$

In (1)-(3), $n_{\mathrm{e,i}}$ are the concentrations of electrons (e) and ions (i), $\vec{\Gamma}_{\mathrm{e}}$ and $\vec{\Gamma}_{\mathrm{i}}$ are the electron an ion fluxes, including drift- and diffusion- fluxes as well as the electron thermal diffusion flux, $\delta n_{\mathrm{e,i}}/\delta t$ is the charged particle production via direct and step ionization, $\vec{E}$ is the dc field in the discharge (Φ is its potential), $\vec{J}$ is the electron energy flux, including both the conductive and convective fluxes, P_{coll} summarizes the electron energy losses in collisions and e and ε_0 are, respectively, the elementary charge and the vacuum permittivity. The balance equation of the excited atoms completes the initial set of equations. The deposition of the external power applied for the discharge maintenance is shaped by a super-Gaussian axial (z) profile $P_{\mathrm{ext}} = P_0 \exp\left\{-(1/2)\left[(z-z_0)/\sigma\right]^{2m}\right\}$, which provides a good approximation of the axial changes of the power input in inductive discharges with cylindrical coils. The power deposition P_{ext} occurs in the smaller-radius chamber (figure 1), centered at $z = z_0$; σ characterizes its width.

The boundary conditions for the fluxes normal to the walls are those [5] usually used for metal walls. Conditions for symmetry at $r = 0$ are also employed.

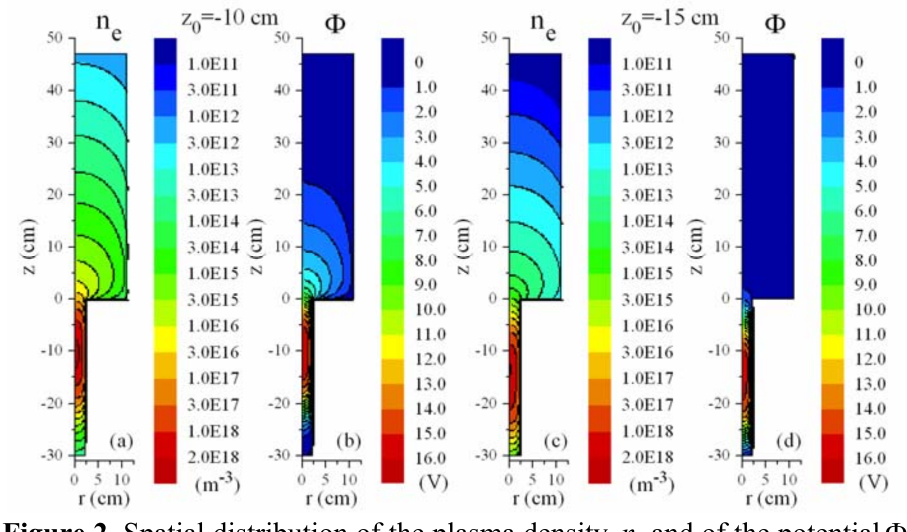

Figure 2. Spatial distribution of the plasma density n_{e} and of the potential Φ of the dc field in the discharge for $z_0 = -10$ cm and $z_0 = -15$ cm.

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3. Results and discussions

The results presented here are for discharge maintenance in the source shown in figure 1, at a gas pressure of 50 mTorr and different axial positions of the centre (z_0) of the power deposition P_{ext} . The total power applied and the width of its axial profile are the same: 100 W and $\sigma = 7.2$ cm.

The plasma density n_{e} and the potential Φ of the dc field in the discharge (figure 2) decrease both in the radial and axial directions. Shifting the position of the applied power P_{ext} away from the transition $z = 0$ between the two chambers moves the regions of high plasma density and high plasma potential deeper inside the first chamber.

The plasma existence in the regions without power deposition is due to charged-particle and electron-energy fluxes from the driver (figures 3 and 4). Although not influencing the directions of the fluxes, changing the position of the driver has a strong impact on the magnitude of the fluxes entering the second chamber.

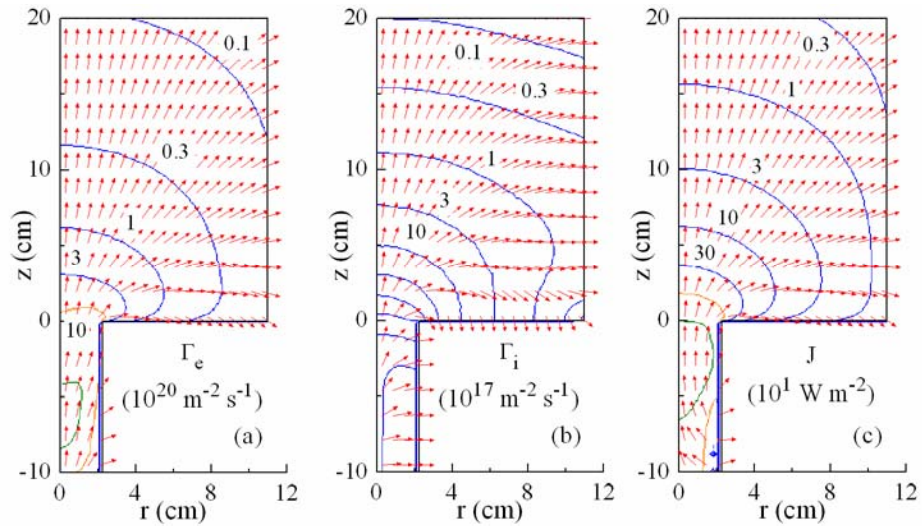

Figure 3. Electron (a) and ion (b) fluxes and the electron energy flux (c) in the case of $z_0 = -10$ cm. All the contours are in the (1-3-10)-sequence.

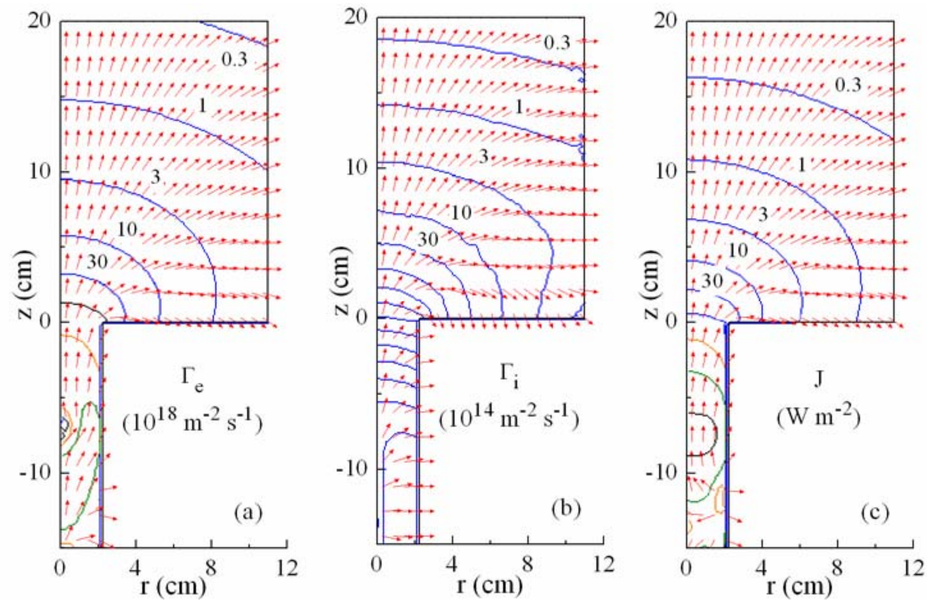

Figure 4. The same as in figure 3 but for $z_0 = -15$ cm.

Shifting the driver away from $z = 0$ (figure 5(a)) enlarges the region with a steeper axial gradient of n_e, due to bigger radial losses of charged particles in small-radius chambers. Consequently, the plasma density in the second chamber decreases. The dc field in the second chamber is also extremely low (figures 2(d) and 5(c)) when the driver is shifted away from $z = 0$. Since the electron energy flux $\vec{J}$ in the expanding plasma region is lost for maintaining the dc field there [10], described by the second term in the right-hand side of (2), the electron temperature (figure 5(b)) is higher in the second chamber when the driver is away from it.

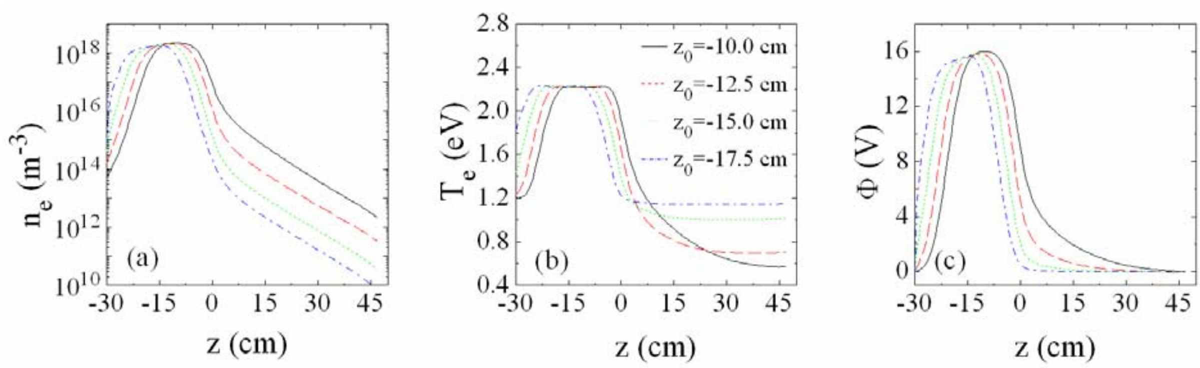

Figure 5. Axial distribution at the discharge axis ($r = 0$) of the plasma density n_e (a), of the electron temperature T_e (b) and of the plasma potential Φ (c).

Figures 3 and 4 clearly show a strong difference in the electron and ion fluxes, both in their directions and magnitudes, i.e. the discharge maintenance (a high-frequency discharge) is under the conditions of a net current in the discharge short-circuited through the walls. This is due to the metal walls of the source and its different size in the transverse and longitudinal directions which leads to establishment of a dc electric field in the discharge, different from the ambipolar field.

4. Conclusion

The results presented in the study show that the position of the driver has a strong impact on the parameters of the plasma expanding in the second – large-volume – chamber of the tandem sources.

Acknowledgements
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