Particle and Energy Fluxes in a Two-Chamber Plasma Source

Stanimir Kolev, Antonia Shivarova, Khristo Tarnev, and Tsanko Tsankov

***Abstract*—A regime of discharge maintenance with a net dc current flowing through the plasma is established in the gas-pressure range that is usually governed by ambipolar diffusion. The conclusion is based on results from a 2-D fluid-plasma model developed for describing discharge maintenance in a two-chamber plasma source with metal walls.**

***Index Terms*—Charged particle fluxes, electron energy flux, high-frequency discharges, remote plasma sources, tandem plasma sources.**

THE USE of gas discharges in plasma processing technologies and as particle sources is the motivation for the increasing interest in the modeling of plasma sources with complicated geometry. The two-chamber plasma source is such a complex source known as a remote-plasma source [1] in the technological applications of discharges operating in different gases and as a tandem plasma source [2] of negative hydrogen ions developed regarding the neutral beam injectors of big fusion machines like ITER. The construction of a source which combines a driver with an expanding plasma volume should drive the importance of the charged-particle and electron-energy fluxes stressed on here.

The results in Fig. 1 are for the magnitude and the directions of the charged-particle and electron-energy fluxes obtained from a 2-D fluid-plasma model within a drift-diffusion approximation including thermal diffusion. The discharge vessel (Fig. 1) consists of two metal chambers of different sizes: a small-radius chamber where the driver is located (RF power deposition in the region $z = (-2.5 \div -17.5)$ cm) and a big-radius chamber with plasma expanding from the driver. The design of the source—with metal walls of the entire source—is that of the inductively driven (by external coils) plasma sources, with a Faraday shield inside the driver region, which are used both in plasma processing technologies [3] and as negative ion sources [4]. The discharge is in an argon gas at pressure $p =$ 50 mTorr. The model is based on the continuity equations for electrons, ions, and excited atoms, the electron energy balance equation, and the Poisson equation [5]. The charged particle production is via direct and step ionization. The electron energy balance involves both the conductive and convective fluxes, electron energy losses for the maintenance of the dc electric field in the discharge, and losses in collisions. The boundary conditions are for symmetry on the axis, particle and energy fluxes on the walls determined by thermal and drift motion, and zero dc potential on the metal walls.

Stressing on plasma maintenance in the second chamber, the discussions on Fig. 1 are concentrated on the region extended in the axial direction from $z = -10$ cm, where the center of the driver is located, toward $z = 47$ cm (the back wall of the second chamber). The charged particle fluxes in Fig. 1(a) and (b) show plasma expansion from the driver. Fig. 1(c) shows the difference $\vec{\Gamma} = \vec{\Gamma}_e - \vec{\Gamma}_i$ of the electron and ion fluxes. An axial electron flux [Fig. 1(a)] that is larger than the axial ion flux [Fig. 1(b)] determines [Fig. 1(c)] an axial Γ_z-flux ($\Gamma_z = \Gamma_{ez} - \Gamma_{iz}$) directed from the driver toward the second chamber of the discharge vessel. The charged particles are lost by their radial fluxes at the side walls of the discharge chambers and by axial fluxes to the front ($z = 0$ cm) and back walls of the second chamber.

In the driver region, the radial flux of the ions is larger than that of the electrons, as Fig. 1(a) and (b) show. A difference in the electron and ion fluxes means the establishment of a discharge regime that is different from the ambipolar diffusion regime and, thus, the creation of a dc electric field in the discharge which deviates from the ambipolar field. Although the potential difference between a given point in the plasma and the metal walls is the same, due to the different radial and axial dimensions of the source, the radial dc electric field is, in general, larger than the axial one. The dc field is accelerating for the ions and retarding for the electrons. As a result, the ions predominantly move in the radial direction in the driver [Fig. 1(b)]. The strong radial dc field prevents the movement of the electrons in the radial direction, and they leave the driver mainly parallel to the axis [Fig. 1(a)]. Thus, a net dc current flows through the discharge (an RF discharge) from the walls of the second chamber toward the driver where it is directed to the side walls of the first chamber [Fig. 1(c)]. This current is due to combined effects of the metal walls of the discharge vessel and its different dimensions in the radial and axial directions. The plasma produced by the applied RF power appears as a dc voltage supply with its own electromotive force and internal resistance and "battery" terminals short-circuited by the grounded metal walls of the source. Such a situation reminds us of Simon diffusion [6], which is well known in the literature, however, for discharges in

---

Manuscript received November 28, 2007; revised February 28, 2008. This work was supported by the Program of the Bulgarian Association EURATOM/INRNE (task 2).

S. Kolev, A. Shivarova, and T. Tsankov are with the Faculty of Physics, Sofia University, 1164 Sofia, Bulgaria (e-mail: ashiva@phys.uni-sofia.bg).

K. Tarnev is with the Department of Applied Physics, Technical University of Sofia, 1000 Sofia, Bulgaria.

Digital Object Identifier 10.1109/TPS.2008.922438

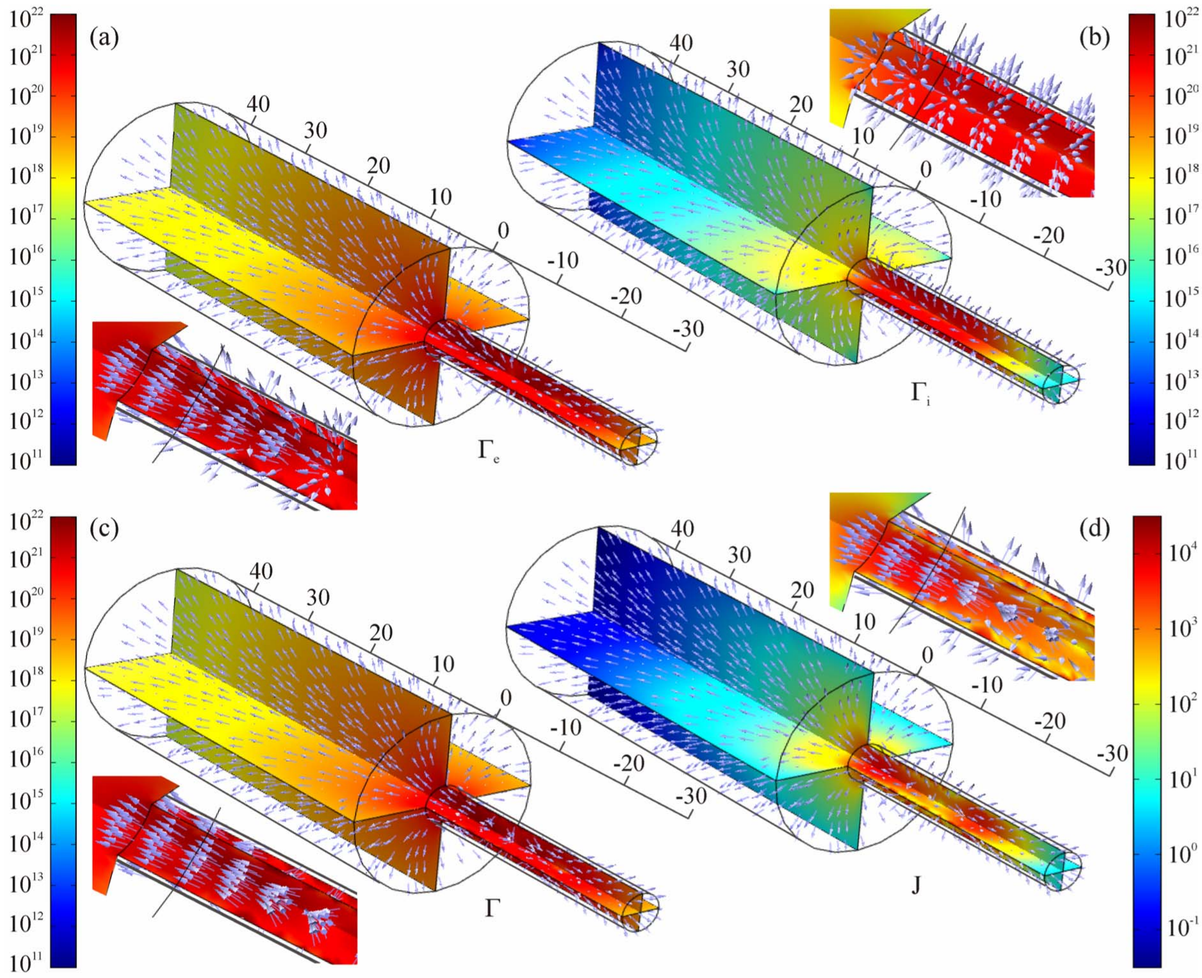

Fig. 1. Computationally generated images presenting the magnitude and the directions of the (a) electron and (b) ion fluxes in particles per meter square per second, (c) their difference, the flux $\vec{\Gamma} = \vec{\Gamma}_e - \vec{\Gamma}_i$ in particles per meter square per second, and (d) the electron-energy flux in watts per meter square. The presentation by arrows is a normalized one to the local value of the corresponding flux. The part $(-15 \text{ cm} \leq z \leq 0 \text{ cm})$ of the driver presented separately is another view to it, which is from a different angle. Size of the discharge vessel: Radii $R_1 = 2.25$ cm and $R_2 = 11$ cm of the first and second chambers of the vessel, respectively, and length as given on the figure.

an external magnetic field. Although $\vec{\Gamma}_e \neq \vec{\Gamma}_i$, $\text{div}\vec{\Gamma}_e = \text{div}\vec{\Gamma}_i$ is fulfilled.

An axial electron energy flux [Fig. 1(d)] created in the driver is the power input in the expanding plasma region. The detailed analysis [5] of the contributors to the electron energy balance shows that this power input goes for compensating losses for the maintenance of the dc electric field there.

In conclusion, in the gas-pressure range that is usually considered to be governed by ambipolar diffusion, a gas discharge regime with a net dc current through the plasma is found out in discharges with unmagnetized plasma production. Discharge vessels with metal walls and different dimensions in the radial and axial directions provide the conditions for its establishment.

REFERENCES

[1] M. J. Kushner, "Pulsed plasma-pulsed injection sources for remote plasma activated chemical vapor deposition," *J. Appl. Phys.*, vol. 73, no. 8, pp. 4098–4100, Apr. 1993.

[2] M. Bacal, "Volume production of hydrogen negative ions," *Nucl. Instrum. Methods Phys. Res. B, Beam Interact. Mater. At.*, vol. 37/38, pp. 28–32, Feb. 1989.

[3] W. Kulisch, P. Colpo, F. Rossi, D. V. Shtansky, and E. A. Levashov, "Characterization of a hybrid PVD/PACVD system for the deposition of TiC/CaO nanocomposite films by OES and probe measurements," *Surf. Coat. Technol.*, vol. 188/189, pp. 714–720, Nov./Dec. 2004.

[4] U. Fantz *et al.*, "Negative ion RF sources for ITER NBI: Status of the development and recent achievements," *Plasma Phys. Control. Fusion*, vol. 49, no. 12B, pp. B563–B580, Dec. 2007.

[5] S. Kolev, A. Shivarova, K. Tarnev, and T. Tsankov, "Two-dimensional fluid model of a two-chamber plasma source," *Plasma Sources Sci. Technol.*, 2007. submitted for publication.

[6] V. E. Golant, A. P. Zhilinskiy, and A. J. Sakharov, *Fundamentals of Plasma Physics*. Moscow, Russia: Atomizdat, 1997. Russian.