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Research Article

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News Distributions in Cartesian geometry of Subnormal Glow discharge

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Abstract This paper presents news distributions in Cartesian geometry of subnormal glow discharge; such are the longitudinal currents densities of electron and ion, the longitudinal electron energy flux as well as both ionization and energy sources terms. The macroscopic model used for this investigation is the fluid two orders, counting continuity and momentums transfers' equations of electron and ion and electron's energy equation, the set of equations are coupled with Poisson's equation in a self-coherent way. The test of validity of the model is carried out in this paper.

Keywords Boltzmann's equation; Poisson's equation; Subnormal Glow Discharge; Electron Temperature

1. Introduction

The ability of glow discharges to provide electric-energies of charged-particles at low gas pressure has made it very attractive for plasma processing [1-9]. For this reason, DC glow discharges are widely used in the microelectronics industry, for the deposition and etching of thin solid films. The understanding of charged-particle transport in the sheaths is of paramount importance for a better control and optimization of industrial reactors. In spite of the widespread use of DC discharges in microelectronic manufacturing, our understanding of the physical mechanisms of the discharge is still incomplete.

On the other hand, due to the recent development of very efficient plasma diagnostic techniques such as LOG (laser opt galvanic) and LIF (laser-induced fluorescence) it is now possible to obtain complete space-time mappings of the electric field and energies electron's in the discharge, and it seems very useful to develop self-coherent numerical models [10-14] in connection with the experimental approach.

A complete model of DC discharge used in plasma process reactors must account for the coupled interactions between charged–particle kinetics, neutral-particle kinetics and energies electron's, and electric field; this is indeed a very formidable task and no complete self-coherent model has yet been developed [15,16].

The outline of the manuscript is as follows. The model is briefly introduced in section II and the initial boundary conditions, as well as numerical technique are described in this section. The results obtained are shown, discussed and validated in section III. Finally, concluding remarks are presented in section IV.

2. Fluid Model Two Orders

Fluid model two orders [12, 13] designed for subnormal glow discharge in monatomic argon gas. Including the continuity and momentum transfer equations for electron and ion and an electron energy equation, these set of equations are coupled with Poisson's equation in a self-coherent way; for take into count the space charged of gas discharge and then calculate the electric field.

Continuity equations for electron and ion:

$$\frac{\partial n_e}{\partial t} + \nabla \mathbf{\Phi_e} = S \qquad (1)$$

$$\frac{\partial n_i}{\partial t}+\nabla\boldsymbol{\Phi}_{\mathbf{i}}=S \tag{2}$$

Where n_e , n_i , $\boldsymbol{\Phi}_{\mathbf{e}}$, and $\boldsymbol{\Phi}_{\mathbf{i}}$ are the electron and ion densities, the electron and ion fluxes, respectively. S represents the net source term.

Momentum transfer equations for the electrons and positive ions are:

$$\boldsymbol{\Phi}_{\mathbf{e}}=-\mu_e n_e \mathbf{E}-D_e\nabla n_e \tag{3}$$

$$\boldsymbol{\Phi}_{\mathbf{i}}=\mu_i n_i \mathbf{E}-D_i\nabla n_i \tag{4}$$

$$S=K_i N n_e \exp(-E_i/K_B T_e) \tag{5}$$

where, μ_e , μ_i ,D_e , D_i , K_i , E_i , T_e , N and $K_B=1.38062 \times 10^{-23}$ (J/K) are the electron mobility, ion mobility, electron diffusivity, ion diffusivity, ionization rate prefactor, ionization rate activation energy, electron temperature, gas density and the Boltzmann's constant, respectively. E represents the electric field.

The relation between the electric field and the space charge in the inter-electrode space is given by Poisson's equation:

$$\nabla E=\frac{|e|}{\varepsilon_0}\left(n_i-n_e\right) \tag{6}$$

Where, $\varepsilon_0=8.85\times 10^{-14}$ $CV^{-1}\,cm^{-1}$ and $e= 1.6\times 10^{-19}$ C are the permittivity of free space and particle charge, respectively.

The electric field **E** is related to the potential by the following relation:

$$E=-\nabla V \tag{7}$$

The equations for the electron energies are [12, 13]:

$$\frac{\partial n_e\varepsilon_e}{\partial t}+\frac{5}{3}\nabla\boldsymbol{\Phi}_{\boldsymbol{\varepsilon}}=S_\varepsilon \tag{8}$$

$$\boldsymbol{\Phi}_{\boldsymbol{\varepsilon}}=-\mu_e n_e \varepsilon_e \mathbf{E}-D_e\nabla n_e\varepsilon_e \tag{9}$$

$$S_\varepsilon=-e\phi_{e_L}E_L-e\phi_{e_T}E_T-K_i N n_e \exp(-E_i/K_B T_e)H_i \tag{10}$$

with ε_e , $\boldsymbol{\Phi}_{\boldsymbol{\varepsilon}}$, H_i the electron energy, electron energy flux and the energy loss per ionizing collision, respectively.

And:

- ϕ_{e_L} is the longitudinal electron flux along the X axis
- ϕ_{e_T} is the transversal electron flux along the Y axis

$$E_L=-\frac{\partial V}{\partial x}\ ;\ E_T=-\frac{\partial V}{\partial y}$$

- E_L is the longitudinal electric field along the X axis
- E_T is the transversal electric field along the Y axis

The transport coefficients for an argon gas have been taken from LIN et al. [17-19]. A parallel plate configuration is considered. The inter-electrodes spacing is L=3.525 (cm). The electrode radius is R=5.08 (cm). Neutral species density is $N=2.83 \times 10^{16}$ (cm^{-3}); gas temperature is 323 (K); both electron and ion diffusivity are $D_e=10^6$ (cm^2s^{-1}), $D_i=10^2$ (cm^2s^{-1}), respectively; both electron and ion mobility are $\mu_e=2 \times 10^5$ ($cm^2v^{-1}s^{-1}$) and $\mu_i=2 \times 10^3$ ($cm^2v^{-1}s^{-1}$); ionization rate prefactor is $K_i=2.5 \times 10^{-6}$ (cm^3s^{-1}); ionization rate activation energy is $E_i=24$ (eV) and ionization enthalpy loss is H_i =15.578 (eV).

A. Initial and boundary conditions

The boundary conditions are required at each electrode and the initial conditions in order to complete the problem. The potential at the anode (x=0, y) is fixed to be zero (Volt) and at the cathode (x=L, y) equal to -77.4 (Volts). The secondary electron emission coefficient at the cathode is taken to be 0.046. The electron temperature at the cathode is 0.5 (eV).

The initial distributions of the electron and ion densities are set as a Gaussian form [20] given by the following relation:

$$n_e = n_i = 10^7 + 10^9 (1 - x/L)^2 (x/L)^2 + (1 - y/2R)^2 (y/2R)^2 \qquad \text{cm}^{-3} \tag{16}$$

The initial distribution of the electron temperature is chosen to be 1 eV.

The boundary conditions are set as follows:

- The electron density is equal to zero at the anode
- The electron and ion densities are taken as zero at the dielectric walls
- The electric potential is in accordance with the Neumann condition $(\frac{\partial V}{\partial y} = 0)$ at the dielectric walls

The effect of the secondary electron emission coefficient γ enters through the pertaining boundary conditions

$$\phi_e\left(\frac{X}{L} = 1, y\right) = -\gamma \phi_i \left(\frac{X}{L} = 1, y\right) \tag{17}$$

With:

L is the inter-electrode spacing

B. Numerical technique

The spatial discretization scheme used for the transport equations is the SCHARFETTER-GUMMEL [21] exponential scheme. This discretization is carried out in the Cartesian geometry. The transport equations of charged particles (electrons and ions) and Poisson's equation of them are solved using an implicit technique with a typical integration time step of the order of 10^{-9} s. Then, the resolutions of the equations set are solved by Thomas algorithm combined with the iterative relaxation method.

Results and Discussion

In this section, the results are given for the DC subnormal glow discharge in low pressure argon gas between plane-parallel electrodes. Two-dimensional distributions of the longitudinal electron energy flux and both ionization and energy sources terms as well as the longitudinal current densities are presented to illustrate the discharge behavior.

Figure 1 represents the 2D spatial distributions and the contour plots of the longitudinal electron energy flux ($\Phi_{e\varepsilon x}$) in the stationary state. I observe that the $\Phi_{e\varepsilon x}$ is important in the cathodic region and is negligible at both cathode and anode surfaces, because that the limit conditions of electron energy at the cathode that is presence so that the electron density at the anode. I notice that the electron temperature influence directly on the $\Phi_{e\varepsilon x}$. Consequently, one says that the electron energy is more important than the electric field on the longitudinal electron energy flux thermal behavior.

Figure 2 illustrates the 2D spatial distributions and the contour plots of the ionization source term in the stationary state. It depends exponentially of electron temperature but varies linearly with electron density. The ionization source term is characterized in the discharge by one peak value; S=3.73241 X 10^{12} ($\text{cm}^{-3}\text{s}^{-1}$) for X/L=0.7071 at the symmetric axis of the electrodes. The electron temperature influences directly on the ionization source term in both regions; the cathode sheath, and dielectric walls because of the electron density that is less significant.

Figure 3 represents the 2D spatial distributions and the contour plots of the energy source term in the stationary state. It is composed of three terms in the 2D geometry. Two terms are due to the heating, the first one of these two terms is generated by longitudinal electric field with longitudinal electron flux, and the second one is generated by transversal electric field with transversal electron flux. The third term is due to the cooling effect of electron species, it is generated by ionization process.

It was noticed that the energy source term has a symmetric value because of the physical phenomena’s equilibrium which is in progress (cooling and heating). The heating effect due to the transversal electric field is perceptible on the dielectric walls.

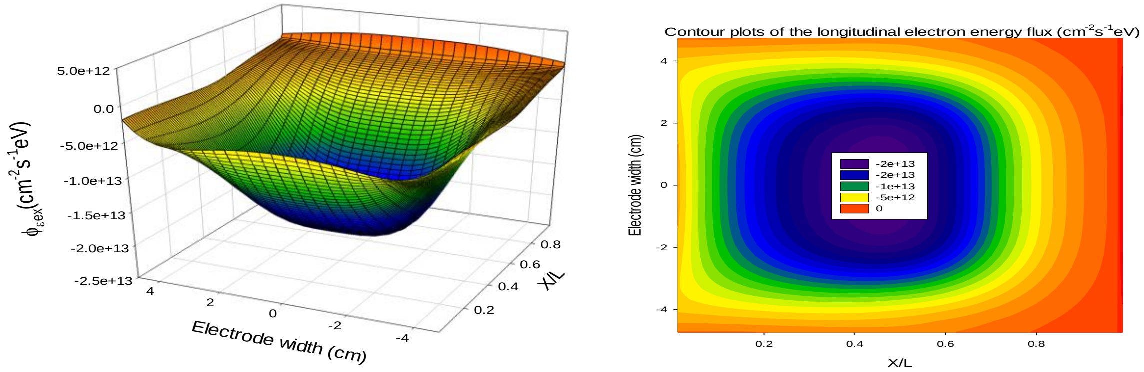

Figure 1: Presentation in 2D and in contour plots of the longitudinal electron energy flux in the stationary state

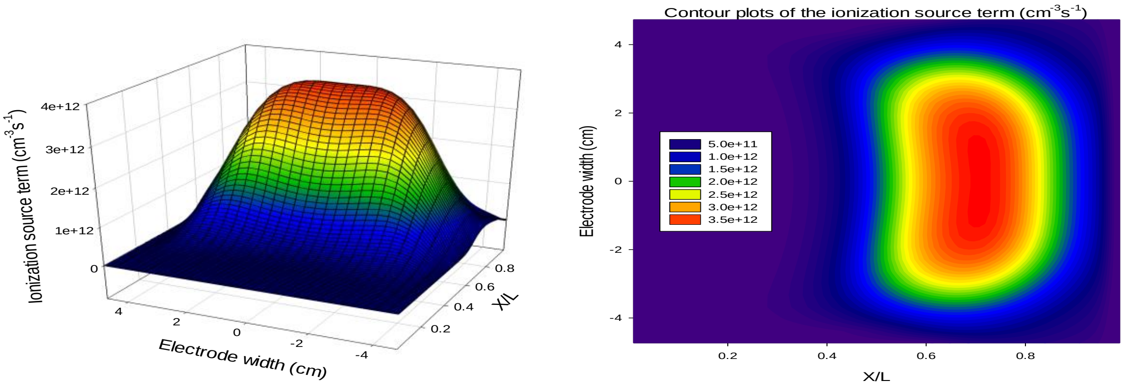

Figure 2: Presentation in 2D and in contour plots of the ionization source term in the stationary state

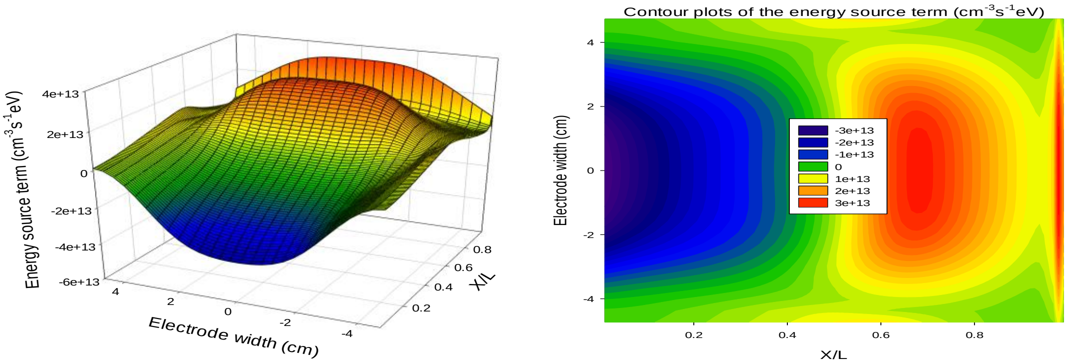

Figure 3: Presentation in 2D and in contour plots of the energy source term in the stationary state

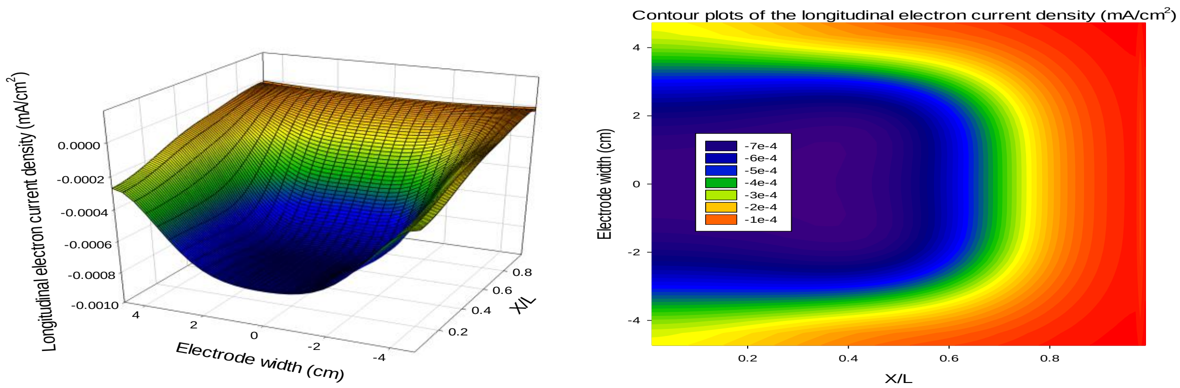

Figure 4: Presentation in 2D and in contour plots of the longitudinal current density of electron in the stationary state

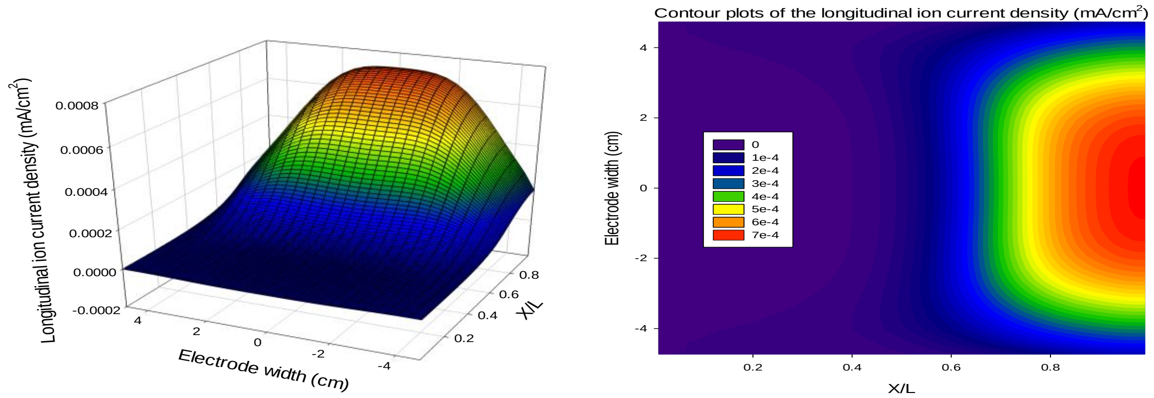

Figure 5: Presentation in 2D and in contour plots of the longitudinal current density of ion in the stationary state

Figures 4 and 5 represent the 2D spatial distributions and the contour plots of the longitudinal current densities of electron and ion in the stationary state of the subnormal glow discharge, respectively.

It was observed that the distributions of the longitudinal current densities of electron, ion are more important at the symmetry axis of the electrodes (corresponding for y=0 (cm) of the electrode width). It was noticed, that the current densities of electron and ion decrease linear towards dielectric walls because of the boundary conditions that are imposed. The electron current density (see Figure 4) in the anodic region is larger than the current density in the cathode region; it is of order -7 x 10^{-4} mAcm^{-2} in the anodic region at the symmetric axis of the electrodes. The longitudinal electron current density cannot be null in the cathode sheath because of the secondary electron emission coefficient process that is presence, which has caused by bombardment positive ions cathode surface from the ionized gas.

It was also noticed that the longitudinal ion current density (see Figure 5) in the cathode region is larger than the current density in the anodic region due to the propagation of ions positive towards electrode cathode. It is about 7 x 10^{-4} mAcm^{-2} in the cathode region at the symmetric axis of the electrodes.

I observe there are accumulations of charged particle species of both ions in the anodic sheath region and of electrons in the cathode sheath. I notice that the longitudinal electron current density in the anodic sheath has the same value just like ion species in the cathode sheath, which has an almost symmetric behavior between the current densities of ion and electron species.

A. Validity of the model

It was investigated, this discharge of the same conditions of both charged particles transports and geometry parameters as LIN et al. [17] To validate my results; I compared those issues on the symmetric axis of the electrodes with have been given by Lin et al [17] in the Figure 6.

It was observed that the longitudinal current densities of electron and ion are in good agreement with those obtained by Lin et al [17-19].

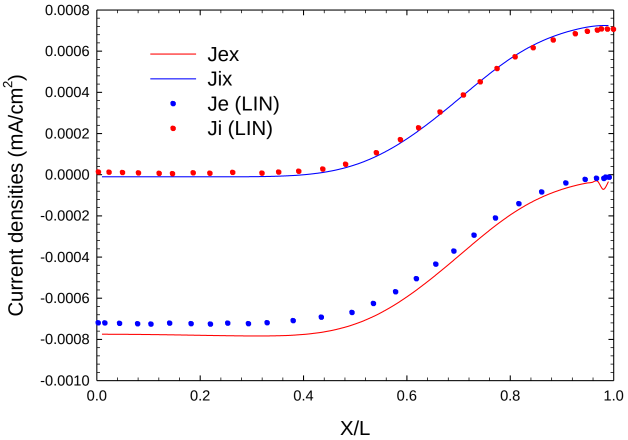

Figure 6: Comparison between the spatial distributions of the longitudinal current densities of electron, ion and total in the stationary state on the symmetric axis of the electrodes and that given by Lin et al.

Conclusion

In this article, a two-dimensional spatial distributions of the longitudinal electron energy flux and both ionization and energy sources terms as well as the longitudinal current densities of electron and ion have been presented in the stationary state of a DC subnormal glow discharge. Monatomic argon gas in low pressure has been utilized in this study. The discharge is maintained by a secondary electron emission coefficient at the cathode. The model used in this work is based on the first three moments of the Boltzmann's equation and the Poison's equation. The simulation results obtained were validated by using a comparative study with those of Lin et al [17-19].

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