EFFECT OF THE ORDER FLUID MODEL ON A GLOW DISCHARGE SUSTAINED BY A EXTERNAL SOURCE OF IONISATION

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Abstract: *In this article, a DC glow discharge maintained by an external source of electrons and ions uniform production is studied.*
The fluid model presented in this work, is based on the use of the moments of Boltzmann equations, where the number of moments used indicates the model order. The basic system of first order fluid model equations is closed by the local electric field approximation and second order fluid model equation is closed by the local electron energy approximation. These equations are coupled to the Poisson's equation self-consistently.
The simulation of the glow discharge is performed using a 1D and 2D fluid mode code. The electric properties at stationary state of the glow discharge in argon are presented in this paper, the obtained results are very sensitive to both the net source term value which is characterized by various mode of the glow discharge (abnormal, normal, subnormal mode), and also to the order choice of the fluid model and the related assumptions used to described the electronic fluid evolution and to quantify the gas expansion and the temperature increase during the discharge phase.

Keywords*: Subnormal – Normal – Abnormal mode, Glow discharge, Boltzmann equation, source term, the charged particles density, Poisson equation, finite difference.*

1. Introduction

Lightning, northern lights... all these natural phenomena have aroused the curiosity of the scientific community. The spread efforts are considerable and the advancements of electrical discharges study have resulted in a great number of applications [1-5], both in technology, such as optoelectronics and microelectronics field, the deposit of thin films, the purity analysis and the surface treatment of heat sensitive materials, or in the medical field and the field of environmental protection.

The economic and environmental repercussions are extremely important, for this reason the electric discharge was studied experimentally and theoretically.

The transient character and the small dimensions make some micro-discharges parameters, like charged and radical densities, electron energy or electric field strength, difficult to be accessible to measurements, so given the complexity of the phenomena governing the glow discharges or corona discharges, simulation remains an indispensable mean for predicting the electric discharge behavior for its parameters variation and can help us to choose the best operating conditions.

Glow discharges maintained by secondary emission of electrons at the cathode, have been the subject of several studies, according to the parameters and the mode of the electric discharge [6-9]. In this type of self-sustained electric discharge, the maximum of the charged species density in the plasma region depends of secondary electron emission coefficient. Our work involves the study of glow discharges maintained by an external source, the charged species density depends of the net source term of electrons and ions production. Several modes of the glow discharge can be observed: normal, abnormal or subnormal mode, according the net source term value.

Ideally, the particle transport, in an electrical discharge, is described by the hydrodynamics electric model (also called the macroscopic fluid model) based on using Boltzmann transport equations which are the continuity equations of charged particles and momentum transfer equation. To take account of the large space charge electric field filling up the gaseous medium, the transport equations must be coupled with the Poisson equation, for this reason, the proposed models are self-consistent models.

The fluid model is based on the use of the moments of Boltzmann equations, where the number k of moments used indicates the (k-1) model order.

Nevertheless, hydrodynamics simulations of the electric discharge have shown that the obtained results are very sensitive to both the numerical techniques employed and also to the order number choice of the hydrodynamics model used to described the electronic fluid evolution. The present paper is particularly devoted to the comparison of two hydrodynamics models and the analysis of the validity of the associated classical approximation (the local electric field approximation, the local electron energy approximation).

In fact, during the discharge phase, the electronic fluid can be modelize with either the first or the second order fluid model, while the first order model is sufficient to follow the heavier ionic fluid evolution. However, even if the second order model results, taking into account the electron fluid dynamics, are more accurate, its solution is more complex especially due to the lack of basic data.

The main objective of the present work is to develop a more rigorous second order fluid model applicable to multidimensional space, coupled with electronic kinetics, by adding the Einstein relation, to show the influence of the first and second order hydrodynamics electric model on glow discharges maintained by an external source.

We present the equations of first and second order fluid model, the analysis of order fluid model influence and the ionisation net source term effect on the essential electrical characteristics of the glow discharge.

2. Presentation of the fluid model

2.1. First order fluid model

The basic equations of first order fluid model [10, 11] are the equations of continuity and momentum conservation equation for each charged species coupled to the Poisson's equation for the space charge electric field calculation. In this model, the momentum conservation equation is simplified into the classical drift–diffusion approximation in order to calculate the mean velocity of the charged particles. The obtained system of fluid equations is then closed by the local electric field approximation which assumes that the transport and reaction coefficients of charged particles depend only on the local reduced electric field *E/N* (where *E* is the total electric field and *N* the gas density). These equations have enabled us to study experimentally and theoretically, the distributions of the potential and electric field and the density of the charged particles in the glow discharge sustained by an external source [10- 14].

To address the problem of this glow discharge type, we used certain assumptions applied to our model: The discharge is weakly ionised so that the discharge physics problem can be decoupled from the transport of neutral gas. In addition electron-electron collision is negligible. This assumption is usually satisfied for the discharge used in electronics-materials processing since the charged particle-to-neutrals ratio is usually below 10^{-4}. The particle loss through gas convective motion is negligible and the electrons emission at the cathode is negligible because the electric discharge is sufficiently sustained by uniform source of charged particles. With these assumptions, a simple model comprising only electrons and positive ions Ar^{+} (case of argon) in a two-dimensional geometry can be represented by following equations:

$$\frac{\partial\, n_e(E/N)}{\partial\, t} + \nabla\Phi_e(E/N) = S_e(E/N) \qquad (1)$$

$$\frac{\partial\, n_+(E/N)}{\partial\, t} + \nabla\Phi_+(E/N) = S_+(E/N) \qquad (2)$$

$$\Phi_e = -n_e\mu_e E - D_e\nabla(n_e(E/N)) \qquad (3)$$

$$\Phi_+ = n_+\mu_+ E - D_+\nabla\left(n_+(E/N)\right) \qquad (4)$$

$$S_e(E/N) = S_+(E/N) = S' + n_e\,\alpha(E/N)\,\mu_e\,E - \gamma\, n_e\, n_+ \qquad (5)$$

$$\alpha/N = 4.910^{-17}\exp(-1.4810^{-15}N/E)\ (\mathrm{cm}^2) \qquad (6)$$

Where, n_e, n_+, Φ_e, Φ_+, D_e, D_+, μ_e , μ_+ are the electron and ion densities, the electron and ion fluxes, electron and ion diffusivity, electron and ion mobility respectively. *S* represents the source term where the parameter α is the first Townsend ionization coefficient [10, 11, 16,17], γ is the recombination coefficient of the ions and *S*' is the net constant source term of electrons and ions production, it is considered uniform through-out the inter-electrodes region and being independent of the applied electric field.

2.2. Second order fluid model

The previous first order model is generally well adapted in order to follow the ionic fluid evolution during the discharge phase. However, due to the very high electron mobility in comparison to the ion one, the first order model can be considered no more valid especially in the glow discharge near the cathode sheath where the electronic energy is high.

To improve study, we used the first three moments of Boltzmann transport equations which are the continuity equations of charged particles and momentum transfer equation and the electronic energy conservation equation. The momentum conservation equation can be also simplified into the classical drift–diffusion approximation, when it is assumed that the time scale of a significant variation of the mean electron momentum is very short in comparison with the one needed to follow the micro-discharge dynamics. Thereby, the electron velocity flux can be obtained at each time step, from a local stationary energy approximation. This local balance assumption is used to close the system of Boltzmann equations [18]. In this physical model, we included Einstein's relation of electron diffusivity depends of electronic temperature to describe the kinetics of the electron particles as follow:

$$\frac{\partial n_e(\varepsilon_e)}{\partial t} + \nabla_r \Phi_e(\varepsilon_e) = S_e(\varepsilon_e) \qquad (7)$$

$$\frac{\partial n_e(\varepsilon_e)\varepsilon_e}{\partial t} + \frac{5}{3}\nabla_r \Phi_\varepsilon(\varepsilon_e) = S_\varepsilon(\varepsilon_e) \qquad (8)$$

$$\Phi_e = -n_e \mu_e E - \nabla(n_e D_e(\varepsilon_e)) \qquad (9)$$

$$\Phi_\varepsilon = -n_e \varepsilon_e \mu_e E - \nabla(n_e \varepsilon_e D_e(\varepsilon_e)) \qquad (10)$$

$$S_e(\varepsilon_e) = S_+(\varepsilon_e) = S' + K_i N n_e \exp(-E_i/K_B T_e) - \gamma n_e n_+ \qquad (11)$$

$$S_\varepsilon(\varepsilon_e) = -S'\varepsilon_e - e\Phi_e E - n_e K_i N H_i \exp(-E_i/K_B T_e) + E_i \gamma n_e n_+ \qquad (12)$$

The electronic diffusion coefficient is related to the electronic temperature as following relation:

$$D_e = (\mu_e / \mathrm{e}) \mathrm{k_B} T_e \qquad (13)$$

Where, K_i, E_i, H_i, ε_e, K_B, e, are respectively, the ionization pre-exponential factor, the ionization activation energy, the energy loss in ionizing collision, electronic energy, Boltzmann constant and e is elementary charge. The relation between the electric potential and the space charge in the inter-electrode space is given by Poisson's equation:

$$\Delta V = -\frac{|e|}{\varepsilon_0}(n_+ - n_e) \qquad (14)$$

Where, ε_0 is the vacuum permittivity.

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

$$E = -\nabla V \qquad (15)$$

3. Numerical fluid model

Overall, the transport equations (1), (2), (7), (8) have the same form, these equations to solve and the Poisson's equation (14), have following form in 2D Cartesian geometry:

$$\frac{\partial n(x,y,t)}{\partial t} + K\frac{\partial \Phi(x,y,t)}{\partial x} + K\frac{\partial \Phi(x,y,t)}{\partial y} = S \qquad (16)$$

$$\frac{\delta^2 V(x)}{\delta x^2} + \frac{\delta^2 V(x,y)}{\delta y^2} = -\frac{e}{\varepsilon_0}(n_+ - n_e) \qquad (17)$$

The transport equations are discretized by an implicit finite differences method using an exponential numerical scheme, this numeral method was adopted by SCHARFETTER and GUMMEL to describe the electron transport in semiconductors [19]. We use centered finite differences to solve the Poisson's equation.

The effectiveness of this scheme lies in its ability to handle both situations where particle diffusion is dominant. It can be used for continuous or variable discharge power. This method can be extended to multi-dimensional case in Cartesian geometry and cylindrical or in different electropositive and electronegative gases for the study of subnormal, normal and abnormal discharges mode DC schemes, it is stable and requires a relatively long computation time.

The discretized [10, 11, 15] form of transport equation (16) is:

$$n_{i-1,j}^{k+1}\left[K\frac{D_{i-1,j}^{k}\exp T_2}{\Delta x^2\left(1-\exp T_2\right)}T_2\right] +$$

$$n_{i,j}^{k+1}\left[\frac{1}{\Delta t} - \frac{KD_{i,j}^{k}\exp T_1}{\Delta x^2\left(1-\exp T_1\right)}T_1 - \frac{KD_{i,j}^{k}\ T_2}{\Delta x^2\left(1-\exp T_2\right)} - \frac{KD_{i,j}^{k}\exp T_3}{\Delta y^2(1-\exp T_3)}T_3 - \frac{KD_{i,j}^{k}T_4}{\Delta y^2(1-\exp T_4)}\right] +$$

$$n_{i+1,j}^{k+1}\left[\frac{KD_{i+1,j}^{k}T_1}{\Delta x^2(1-\exp T_1)}\right] + n_{i,j-1}^{k+1}\left[\frac{KD_{i,j-1}^{k}\exp T_4}{\Delta y^2\left(1-\exp T_4\right)}\right]T_4 +$$

$$n_{i,j+1}^{k+1}\left[\frac{KD_{i,j+1}^{k}T_3}{\Delta y^2(1-\exp T_3)}\right] = \frac{n_{i,j}^{k}}{\Delta t} + S_{i,j}^{k}\,. \qquad (18)$$

The discretized form of Poisson equation (eq.17) is:

$$\frac{V_{i-1,j}+V_{i+1,j}}{\Delta x^2}+\frac{V_{i,j+1}+V_{i,j+1}}{\Delta y^2}-2V_{i,j}\left(\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}\right)=$$

$$-\frac{e}{\varepsilon_0}(n_{+i,j}-n_{ei,j}) \qquad (19)$$

Where T_1 is defined by:

$$T_1=-s\frac{\mu}{D^k_{i+1/2,j}}(V^k_{i+1,j}-V^k_{i,j}) \qquad (20)$$

$$T_2=-s\frac{\mu}{D^k_{i-1/2,j}}(V^k_{i,j}-V^k_{i-1,j}) \qquad (21)$$

$$T_3=-s\frac{\mu}{D^k_{i,j+1/2}}(V^k_{i,j+1}-V^k_{i,j}) \qquad (22)$$

$$T_4=-s\frac{\mu}{D^k_{i,j-1/2}}(V^k_{i,j}-V^k_{i,j-1}) \qquad (23)$$

$s=+1$ for positive ion particle and $s=-1$ for electron.

For the study of the second order fluid model, the ionic and electronic mobility, as well as the ionic diffusion coefficient are required as function of electronic energy. In the present calculations, we have neglected their variation, having little fluctuation in a certain interval of variation of the electron energy [20]. So the coefficients ND_+ and μ_+N μ_eN are taken as constant for the two models.

Electronic diffusion coefficient depends of electronic temperature as Einstein relation (9). In the model of order one, the electronic diffusion coefficient was set constant [10, 11, 14, 16, 17], because its variation is relatively low in a certain range of variation of the reduced electric field (*E/N*) [20].

The recombination coefficient γ is also set constant, the use of the following expression (eq. 24) depending on the electron mean energy [21] gave excessive results of particles densities and electronic energy spatial distribution.

$$\gamma = 7.6\ 10^{-8} / \left(\bar{\varepsilon}\right)^{067} \qquad (24)$$

For the first order fluid model, the reaction coefficients of charged particles depend on the local reduced electric field *E/N* (eq.6) and for the second fluid model they depend on electron mean energy (eq. 11, 12), we can add excitation processes with following expression:

$$S_e(\varepsilon_e)=S_e(\varepsilon_e)+\ K_{ex}Nn_e\ \exp(-E_{ex}/k_BT_e) \qquad (25)$$

$$S_\varepsilon(\varepsilon_e)=S_\varepsilon(\varepsilon_e)-\ K_{ex}Nn_e\ H_{ex}\exp(-E_{ex}/k_BT_e) \qquad (26)$$

Where, K_{ex}, E_{ex}, H_{ex} are respectively, the excitation pre-exponential factor, the excitation activation energy and the energy loss in excitation collision,

The set of equations (18) and (19) can be solved by the Thomas algorithm combined with the iterative relaxation method [22]. The fluid equations are solved using an implicit integration scheme with a typical integration time step of the order of 10^{-9}s. The calculation run time takes more than 18 hours to reach the converged solution for one set of discharge conditions.

A similar study has been developed by B. Kraloua [23], for the study of a self-sustained glow discharge by secondary electron emission at the cathode; using the second order fluid model and constant electron diffusivity, the transport equations of the fluid models obtained were resolved by N-BEE Time Splitting method. The 1D results are similar to those obtained by the finite differences method [10, 16].

4. Results and discussion

The electrical discharge modelling has been carried out in the case of some electrical discharges type in gases which are produced when a spatially uniform source of ionisation fills the medium between two plane-parallel conducting electrodes. It is assumed that the electrodes are perfect absorbers of electrons or ions with no electron and ion emission due to thermionic, photoelectric, or other secondary processes. Space-charge effects in these discharges are significant, particularly in the electrode-sheath regions and controllable, for this reason we have taken back the study of this electric discharge type and its possible different modes.

Wardiaw and Cohen [24] have studied properties of similar discharges in photo ionization chambers. Analytic properties were derived for various asymptotic limits of the strength of the ionisation source and the applied electric field.

Examples of discharges that are discussed and were experimentally verified, in the present paper are: (1) γ-ray irradiated discharges, where photo ionization of the gas is produced by rays, (2) plasmas produced by neutron irradiation, where volume ionization of the gas is produced by fission fragments generated by neutron-induced disintegration or a suitable target within the discharge tube, and (3) laser glow discharges, where volume ionization is produced by a high-energy electron beam which enters the discharge tube through a thin metal window, but which does not contribute directly to the discharge current.

4.1 The effect of fluid model order

The transport equations set of first fluid model and second fluid model, allow both to study the evolution of the ion and electron density, the potential and electric field in the discharge tube. In this section, we present the 1D case study to better estimate the influence of the local field approximations and local energy approximations uses; we will deduct the effect of the fluid model order on the distribution of these electrical quantities. For this, we use the similar parameters [10, 11, 15, 16, 25] and similar boundary conditions in [10, 15, 26] carried out in the case of a two parallel-plane electrodes configuration.

The discharge is assumed to be uniform and infinite in the z direction perpendicular to the (x, y) plane. Only the stationary-state glow discharge will be considered in this following. The inter-electrodes distance and their width are set to 0.3 cm, the applied voltage is set constant value of 100 V at the anode, and the net source term is equal to $S' = 8.6\ 10^{16}\ cm^{-3}s^{-1}$.

The results showing the influence of the fluid model order on electric potential and electric field are not very significant, we judged useful to note electronic density distribution, where we can observe in figure (1) a light difference between the two curves (same variation has been observed for ionic density distribution). At the stationary state of the glow discharge, the curves show clearly, the presence of three distinct areas: the cathode sheath, the positive column and the anodic area: it's the normal mode of the glow discharge.

Fig 1: Electronic density spatial distribution: (—) first fluid model and (----) second fluid model.

The results show that, in our simulation conditions the first order model overestimate the positive column and reduce the cathodic and anodic sheaths. In the second fluid model case, we note a graduated increase of particle density in the two sheaths, due to the increasing of electric field in this area and electronic mean energy approximation.

To go deeper in our research, we performed the study of second fluid model with the same constant electronic diffusivity of first fluid model, the results obtained are similar of those show in figure (1). So, we can deduce that the difference observed between the two curves in figure (1), is due essentially to electron diffusivity depending of electron mean energy, and this effect is negligible on reaction coefficients. We can also note that, the effect of electronic diffusivity is preponderant relatively to the effect of reaction coefficients on the model order. This is due to the important net source term value (S'), which product an important charged particle concentration, comparing to those create by ionization processes.

We reduced the net source term effect by using different simulation condition: $S' = 3.6\ 10^{14} cm^{-3}s^{-1}$:

Fig 2: Electronic density spatial distribution: (—) first fluid model and (----) second fluid model.

Also, the electric potential and electric field curves are almost confused the effect of local field approximation or local electron mean energy is nearly the same on this electric distributions. On the other hand, the maximum reached for the particles density is higher in second order fluid model case ($1.1\ 10^{10} cm^{-3}$) comparing to the first order fluid model ($9.\ 10^{9} cm^{-3}$), particularly in the positive column. This increase of particle concentration is due to ionization process increasing with the high electronic energy acquired in the cathodic sheath.

4.2. The effect of the ionisation source

In the steady state, the voltage curve as a function of the current between two plane-parallel electrodes of electric discharge tube, (V (i)), has been the subject of several studies and it is representative of the electrical behavior of a gas discharge [27]. It can be split up into several segments corresponding to different electric discharge types and different luminescent intensity of the gas. The Townsend discharge current increasing, by reducing the introduced resistance or increasing the electromotive force, induce a voltage decreasing from a certain value of current and the dark discharge quickly turns to a glow discharge, characterized by three different areas: the subnormal glow discharge (negative slope), the normal glow discharge (flat portion) and the abnormal glow discharge (positive slope), where the excitation and ionization and charge recombination processes occur differently. In discharge tubes of great lengths at low pressure, these regions can be observed directly in the luminescence intensity difference of the gas.

The previous results of numerical model are used to describe the well-know properties of the glow discharges and its different modes (subnormal, normal and abnormal modes) according to the

uniform particle source term.
An effect study of the constant ionization source on micro-discharge proprieties, using the first order fluid model has already been realized [10]. We will extend the study to the second order fluid model, using more realistic conditions.The essential electrical characteristics simulation in 2D Cartesian geometry allows to attend the glow discharge evolution from every angle of the gas tube.
The numerical study results, according to the net source term value, are presented in this section.

A. Subnormal glow discharge

The order model effect has been bench, the simulation results showed the low effect on electrical potential and electrical field due, relatively, to the high net source term value.
For a uniform source term: S'= 8.0×10^{13} ($cm^{-3}s^{-1}$); solutions appropriate to a γ rays ionization chamber, the first order fluid model [10] results showed the absence of the positive column in space inter-electrodes, the sheath thickness is great, and there is no plasma region. There is imbalance between the maxima of ionic and electronic density; the electron density is lower than the positive-ion density. The surface occupied by the ions and the electrons is different. The electrons are in the vicinity of the anode with a symmetrical space distribution around the axis of the discharge. On the other hand, the distribution of the ionic density is quasi isotropic in the inter-electrodes space except near of the anode sheath, where the net space charge density is not nil. Thus the longitudinal electric field is intense in the anodic region: This is one of the characteristics appropriate to the subnormal glow discharge.
For the second order fluid model, the resolution of the third momentum of Boltzmann equation and Einstein relation (eqs. 8, 13) allowed to deduce the spatial distribution of electron energy and performing our work.

Fig 3: Electronic energy spatial distribution in subnormal regime

In figure 3, we notice that electron energy in the cathodic sheath increase slowly with electric potential. This energy accelerates the electrons movement towards the anodic region where they get more energy due to the geometric electric field presence, there is no positive column.

This situation indicates to us that the ionic and the electronic densities did not modify the uniform geometrical field yet and we note that there is a beginning of a pseudo positive column formation which can extend gradually towards cathode with the increase of the source term. This is one of the characteristics appropriate to the Townsend's discharge.
Bouchikhi [29] and Yihung [9] also got a subnormal mode of a glow discharge self-sustained by secondary emission of electron at the cathode; the electron diffusivity was set constant.

B. Normal glow discharge

The source term increasing influence considerably; the glow discharge mode and decreases the order effect on simulation results.
The normal mode of the glow discharge was obtained by modifying the source term. The uniform source term produced by the ionization due to fission fragments is set: S'=3.6×10^{16} ($cm^{-3}s^{-1}$). This discharge corresponds to the experimental conditions of Leffert and Al for argon [12] and simulation condition used in [10, 11, 15, 16].
In the first order fluid model studies [10], the distributions of the electric potential, and electric field, and charged species densities show clearly, the presence of three distinct areas: the cathode sheath, the positive column and the anodic area. The first area is characterized by a negligible electronic density compared to the ionic density. This density gradient in this area is due to the fact that the electrons move much more quickly than the ions in the presence of a potential gradient, what involves the depopulation of this area by the electrons. The positive column area is characterized by a constant electronic and ionic densities which are and quasi equal (2×10^{11} $cm^{-3}s^{-1}$): the plasma is formed. Consequently, the space charge is negligible. In the anodic region, the ionic density is relatively significant compared to the electronic density because of the constant source term.
To perform our work we add the electronic spatial distribution in stationary state.

Fig 4: Electronic energy spatial distribution in normal regime.

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The electronic temperature increases with the electric potential increasing and presents a maximal value (Fig. 4) at the cathodic sheath proximity where a high

electric field is dominant. The behaviour of the electrons temperature increase follows the increase of both longitudinal and transversal electric field in 2D curve. This acquired energy accelerates the electrons toward the positive column, where they effect ionisation collisions with neutral, and it’s be translated by a cooling of electron, so in the positive column the electronic temperature variation is quasi linear, the electrons continue their displacement toward the anode region, where temperature diminution is fierce dues to electron displacement inverse of the electric field sense.
Bouchikhi [30] obtained a normal mode of a glow discharge self-sustained by secondary emission of electron at the cathode, using Einstein’s relation of electron diffusivity.

C. Abnormal glow discharge

The application of the second order fluid model allowed us to infer the evolution of the spatial electronic temperature. We used the same conditions as the first fluid model [10] to simulate the abnormal mode of the glow discharge, we increased the source term: $S'=3.6\times10^{17}$ ($cm^{-3}s^{-1}$) and the applied voltage to 120V. This increase involves a growth of the positive column surface and leads automatically the contraction of the cathode and anode sheaths for both of electron and ionic densities.

Fig **5:** Spatial distribution of electronic energy in abnormal regime.

The figure (5) shows clearly the reduction of the cathode and anode sheath and the positive column expansion.
The potential gradient in the cathode sheath becomes increasingly significant with the increase of the source term due to positive ions presence in this area, this increase the electron energy. In the positive column, the longitudinal electric field is null due to neutrality between charged species. In the anodic sheath, we note also, a less important variation of the electronic energy due to the less variation of the potential gradient comparatively to cathodic sheath. The positive column expansion is due primarily to the source term increasing, comparatively to the ionisation processes. In this mode, the sheath thickness is equal to 0.05mm while it is around 0.25mm in normal mode.
Anyway, except the exaggerated surface of the positive column due to the increase of the net source term, it is noticed that the behaviour of the electronic energy in the abnormal mode is similar to the normal mode of the glow discharge. The term source has a normal behaviour; this parameter correctly reacts to the potential gradient presence. The term source is relatively high, in the cathodic and anodic sheaths because of the ionisation term contribution due to electric field value. In positive column the net source term effect is negligible.

5. Conclusion

A discharge physics model with a predictive capability is essential for an investigation of the discharge chemistry related to the electronics materials processing applications. In this paper, we presented a multi-space numerical code using the fluid model and applied to glow discharge sustained by a constant source of electron and ion production.
The electric properties such as electric potential and field and electronic and ionic densities can be deduce by the first order fluid model, using the equations of continuity and momentum conservation equation simplified into the classical drift–diffusion approximation. The obtained system of fluid equations is then closed by the local electric field approximation. For the second order fluid model, the use of three moments of Boltzmann equation, can also describe this electric properties evolution in a glow discharge. This study has been accomplished by adding the electron mean energy conservation equation and using the electron mean energy approximation.
For this glow discharge type, the effect study of model order show an increasing of charged particle densities with order model increasing and a real estimation of cathodic and anodic width.
Also, the study effect of the net source term shows different mode of the glow discharge. In the subnormal mode, the contribution of ionization collisionnel term is negligible comparatively to the net source term, thus le electric field is relatively weak to change the initial profile of geometric electric field and it’s imply by the absence of positive column. The increasing of net source term modifies the glow discharge mode to normal mode. The ionization collision term increase and the three characteristic areas of the normal glow discharge appear: cathodic sheath, positive column and anodic sheath. An important increasing of net source term, increase the column positive width, so reduce the

sheaths, it's the abnormal mode of the glow discharge.

To validate our numerical mode of resolution, we carried out a study of the electric discharge in the argon, using the first order fluid model in 2D, based on resolution of the first two moments of the Boltzmann equation and considering the local field approach, within the same conditions as those of Hamid [11] where electron diffusivity is constant. We have also compared 1D second order fluid model results and 2D results obtained on symmetric axe, in the medium of the electrodes [15, 16]. We note that the 2D steady state spatial distributions of symmetric axe for the normal mode of the glow discharge are in very good agreement with the 1D results.

The maximum in the positive-ion density in the cathode sheath that is predicted in the present work for high current densities is qualitatively similar to predictions of Ward [28] made for discharge sustained by photoelectric emission from the cathode. For industrial flue gas flow, the efficiency, of the high densities and the large positive column width of this glow discharge type, is to sow energetic electrons and charged species in the whole flue gas volume with a long lifetime to react selectively with the pollutant molecules.

The effect study of the order fluid model on the flue gas streamer dynamics was developed by Eichwald [31], the use of the complete electron momentum conservation equation allow to better quantify the radical formation in a micro-discharge applied to pollution control. The tests have been carried out in the case of a wire-to-plane corona reactor filled with a typical flue gas (76% N_2, 12% CO_2, 6%O_2, 6% H_2O) at atmospheric pressure and ambient temperature.

Further works are in progress where we develop a numerical code considering the three moments of Boltzmann equations, and the electron energy dependence of electron mobility in 2D and 3D dimensions. The electronic fluid equations are obtained from the more accurate second order model which involves the complete momentum and energy conservation equations without simplified equation of the classical drift–diffusion.

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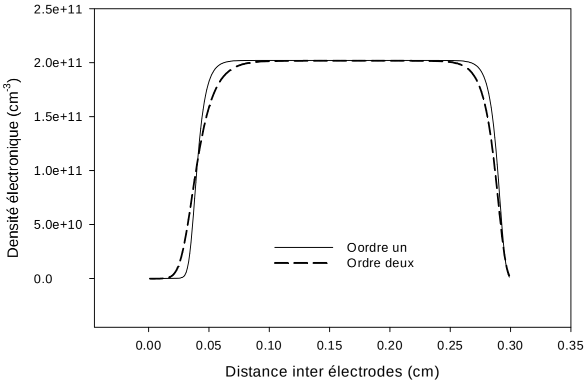


Fig 1

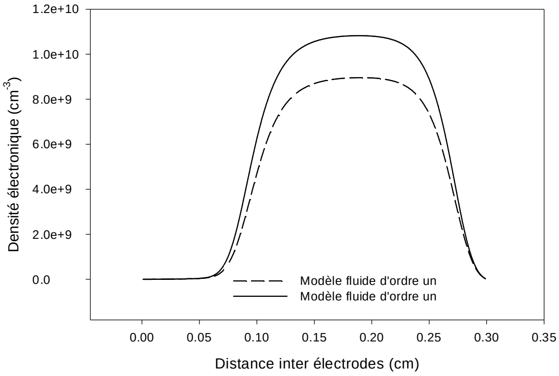
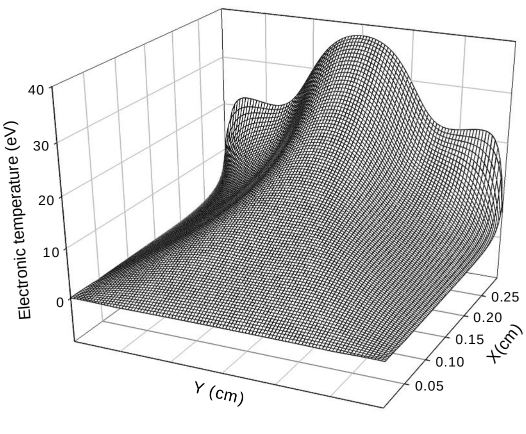


Fig 2



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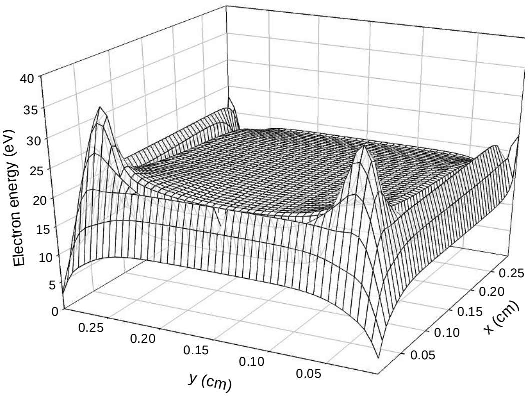

Fig 4

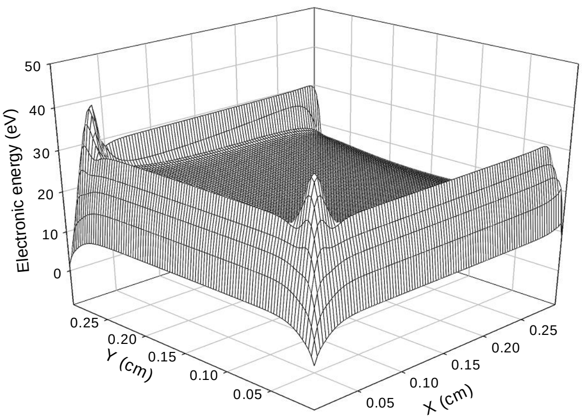

Fig **5**