A modeling of atmospheric DBD parameters effect on plasma elctrical characteristics

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Abstract—**Dielectric Barrier Discharges (DBD) plasma at atmospheric pressure (APP) are characterized by the presence of at least one dielectric layer between metal electrodes in discharge space. A numerical simulation using one dimentional fluid model is performed precisely at various discharge conditions in helium plasma to calculate electrical characteristics such gas voltage and discharge current.**

The presente model solves the continuity equations for charged species and the electron energy balance equation, coupled with Poisson's equation, by the finite element method; using COMSOL Multiphysics software.
a parallel plate dielectric barrier discharge (DBD) scheme is considered and a peak-to- peak voltage of 1kV, a low frequency power source of 200 Hz, a disharge gap of 3 mm and a dielectric constant of 10 are applied as input parameters.

Effect of applied voltage, driven frequency and secondary emission of electrons is studied. The obtained results are given in terms of temporal variations of descharge current.

Keywords-Atmospheric pressure; plasma DBD; numerical simulation; COMSOL Multipysics; Fluid model; Electrical characteristics;

I. INTRODUCTION

In recent years,dielectric barrier discharge (DBD) at atmospheric pressure has attracted much attention because of its advantages for industrial applications such as ozone formation [1,2], thin-film deposition, pollution control, modification of Polymers, plasma-chemical vapor deposition excitation of CO_2 lasers, excimer lamps, plasma-display panels [3-6] **,** sterilization of biological samples [7-10]. In the past decades, remarkable studies on atmospheric pressure discharges (APD) have been done experimentally and numerically in different gases, particularly in pure helium or helium with small addition of N_2, O_2, Ar [11-13] or other noble gases [14-16].

A dielectric barrier discharge (DBD) plasma is a discharge phenomenon where an alternating current (Ac) voltage is applied on at least two electrodes and the electrodes are insulated by at least one dielectric material with a gap distance of some millimeters and a low frequency of few kilohertz.

In this paper, a 1-D fluid model of helium atmospheric pressure DBD plasma, mainly based on the continuity equations coupled with Poisson's equation and solved by finite element using COMSOL software, is presented. We have investigated the electrical characteristics of the discharge of the parallel-plate plasma DBD reactor using discharge parameters applied in our laboratory in sterilization by atmospheric plasma DBD to optimize work conditions. The paper is organized as follows, sections 2 gives a description of the model. In section 3, numerical results are presented and discussed and in section 4, effect of external parameters is considered.

II. NUMERICAL SIMULATION MODEL

A. Description of Modeling Geometrys

The atmospheric Dielectric Barrier Discharge (DBD) plasma reactor considered in this simulation is similar to the homemade reactor used for Escherichia coli inactivation, depicted in Fig. 1, where the dielectric glass plate is applied as sample-supporting surface [17]. The numerical model treats the case of dielectric-barrier discharges in presence of one insulating layer between metal electrodes. Discharge gap width and thickness of dielectric barrier are 3 mm and 1.3 mm, respectively. The dielectric constant of insulating barrier is assumed to be 10 in this modeling.

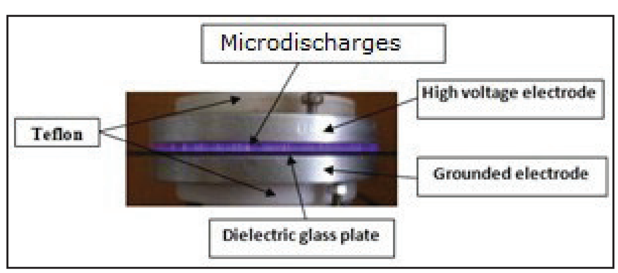


Fig 1. Schematic diagram of the 1-D DBD simulation model for a parallel-plate DBD reactor with one dielectric barrier

B. Governing Equation

The numerical model of the homogeneous barrier discharge is based on the one-dimensional continuity equations for plasma particles (electrons and ions) (1) and electron energy density (2) coupled to the Poisson's equation (3):

$$\frac{\partial n_k}{\partial t} + \nabla(\Gamma_k) = S_k \quad (1)$$

$$\Gamma_k = n_k \upsilon_k = Z.(n_k \mu_k E - \nabla n_k D_k) \quad (2)$$

$$Z = \begin{cases} -1 \text{ for } e \\ +1 \text{ for } i \end{cases}$$

$$\Delta V = \frac{q}{\varepsilon_0}(n_e - n_i) \quad (3)$$

Poisson's equation (3) is used to calculate the electric field:

$$E = -\nabla V \quad (4)$$

The energy balance is solved only for electrons:

$$\frac{\partial (n_e \varepsilon)}{\partial t} + \nabla(\Gamma_\varepsilon) + E.\Gamma_e = S_\varepsilon \quad (5)$$
$$\Gamma_\varepsilon = -n_\varepsilon \mu_\varepsilon E - \nabla n_\varepsilon D_\varepsilon)$$

Where n_K is the density and Γ_K the flux of particle k (k = e, i denotes electrons and positive ions) and S_k is the source term. μ_k, D_k and E are the charged species mobility, the diffusion coefficient and the electric field respectively. V is the electrostatic potential, q the electron charge and ε_0 is the vacuum permittivity.
Ɛ is the electron mean energy, Γ_ε is the mean energy flux, S_ε is the electron energy lost in collisions, μ_ε and D_ε are the electron mobility and diffusion coefficient for the electron flux respectively.

In this simulation we can summarize several points as follows:

- The set of reactions considered and the corresponding reaction rates are given in Table 1[18]:

Table 1: Important collision processes in Helium discharge

Réaction	*Formule*	*Type*	*Δε (eV)*
1	e+He =>e+He	Elastique	0
2	e+He =>e+Hes	Excitation	19.5
3	e+Hes =>e+He^+	Ionization	24.5

- *Surface charge accumulation :*

Elsewhere, in DBD reactors, surface charge accumulation is produced at the dielectric surface which is adjacent to the gap where the plasma forms. This phenomenon leads to the following boundary condition:

$$\begin{cases} n.(D1 - D2) = \rho \\ n.(E1.\varepsilon 1 - E2.\varepsilon 2) = \rho \end{cases} \quad (6)$$

Where E1 and E2 denote the electric field at the dielectric gas interface and ε_1 and ε_2 , the relative permittivity of gas and dielectric, respectively.

- *The boundary condition for the electron flux is:*

$$-n.\Gamma_e = \frac{1}{2} V_{e,th} n_e - \sum_p \gamma_p (\Gamma_p.n)$$
$$V_{e,th} = \sqrt{\frac{8 K_B T_e}{\pi \cdot m_e}} \quad (7)$$

Where the $V_{e,th}$ is the electron thermal velocity, K_B is the Boltzmann constant and m_e is the electron mass. The second term on the right hand side of Equation 7 is the gain of electrons due to secondary emission effects.
γ_p being the secondary emission coefficient

- *The electron energy flux is:*

$$-n.\Gamma_\varepsilon = (\frac{5}{6} V_{e,th} n_e \varepsilon) - \sum \varepsilon_p \gamma_p (\Gamma_p.n) \quad (8)$$

The second term in Equation 8 is the secondary emission energy flux, Ɛp being the mean energy of the secondary electrons.

- *Electric potential :*

Finally, the electric potential applied at driven electrode is $V = V_{rf} \sin(2\pi ft)$.

III. RESULTAS AND DISCUSSIONS

To investigate the detailed discharge characteristics of atmospheric helium DBD, a one dimensional numerical simulation is carried out for a discharge gap and thickness of barrier of 3 mm and 1.3 mm, respectively. The dielectric constant of insulating layer is assumed to be 10 for a gas temperature of 400 K. A voltage of 1kV with a frequency of about 200 Hz is applied and a secondary electron emission coefficient of = 0.01 is considered.

Fig. 2 describes the time evolution of the calculated electrical characteristics during one and a half cycles of the applied voltage. The current and gas voltage curves show a typical discharge pattern of helium APGD, which has a single current peak in every half cycle of the applied voltage [13-19]. The current peak has an amplitude and a duration of about 3.2 mA and 200µs, respectively. The gas voltage characteristic presents a rapid drop at the same moment the current peak appears and increases again after the discharge peak.

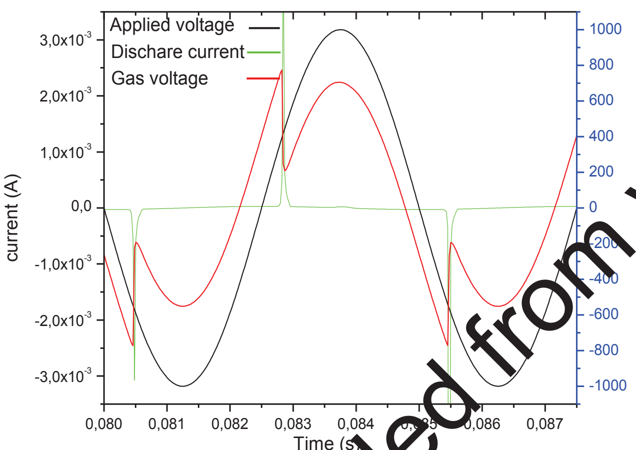


Fig. 2. Time evolution of discharge current and gas voltage during one and a half cycles of an applied filed in helium for an applied voltage of 1kV, a frequency of 200 Hz and a gap distance of 3 mm.

IV. INFLUENCE OF DBD REACTOR PARAMETERS:

The discharge characteristics of the DBD reactor depend on operation parameters of the discharge system, such as: gas gap distance, nature and thickness of insulating layer material, electrodes material and amplitude and frequency of applied voltage. In this work we present the study of effect of applied voltage, frequency and secondary electron emission coefficient.

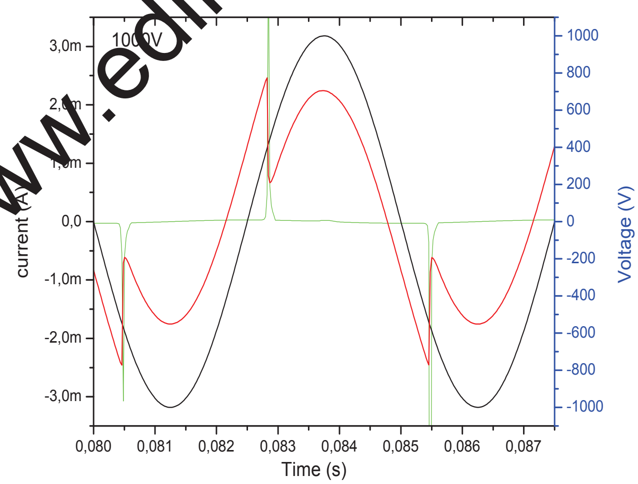
A- Influence of applied voltage

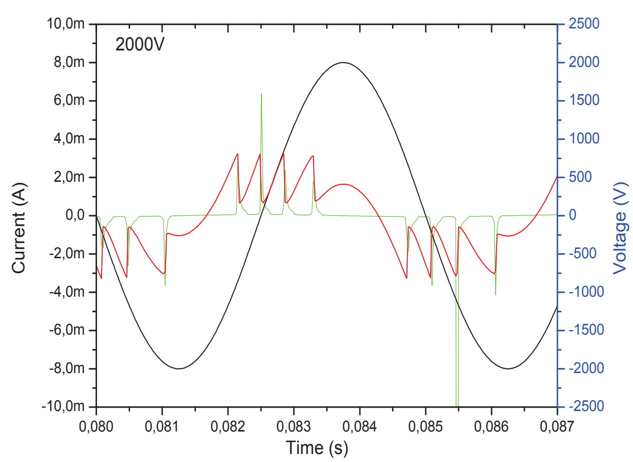
In this section, we present effect of applied voltage on the electric characteristics of helium DBD. The results are presented for value of applied voltage varying from 1 to 9kV, gas gap of 3 mm, frequency of the external voltage equal to 200 Hz and constant dielectric of the insulating layer maintained constant, equal to 10.

Figure 3 shows the temporal variation of discharge current and gas voltage for different values of applied voltage, at atmospheric pressure.

The obtained current is characterized by a large number of current discharge pulses per half cycle for different values of applied voltage. Generally, the discharge current is called micro-discharges. As the amplitude increases, the number of peaks grows and the distance between the micro-discharges becomes smaller.

This results shows when the value of the applied voltage increases the discharge tends to the filamentary mode.





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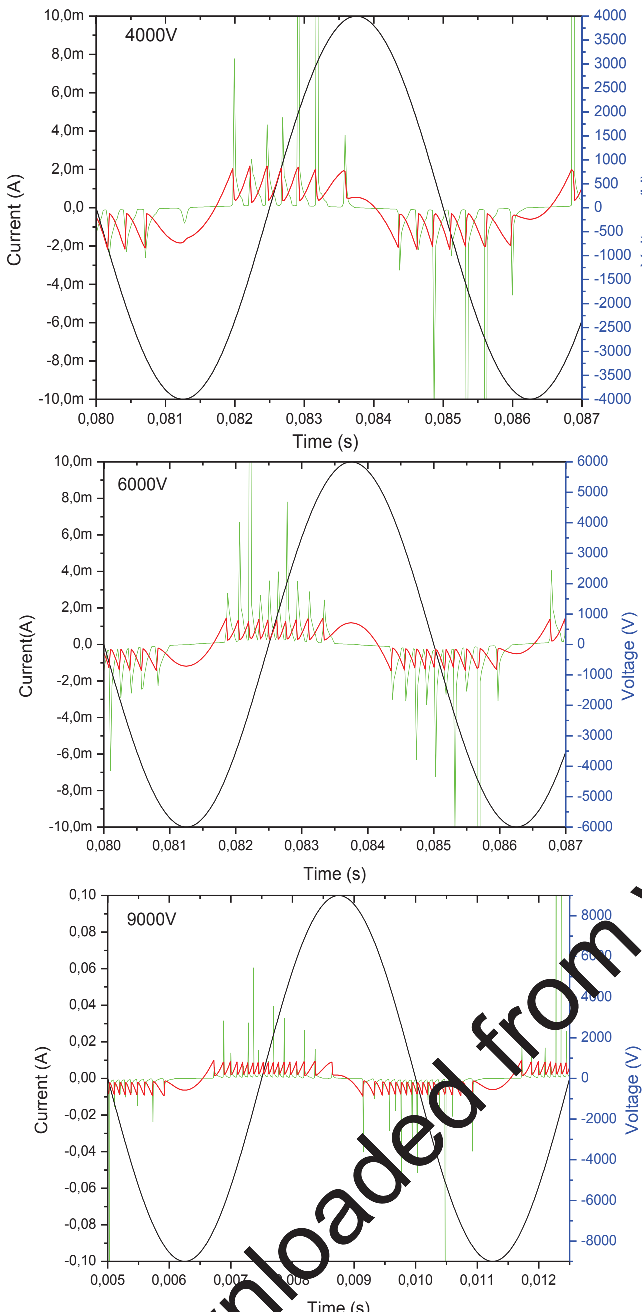


Fig.3 The characteristics of current and gas voltage waveform for applied voltage peak to peak 1k,2k,4k,6k and 9kV, a frequency of 200 Hz, a distance gap of 3mm and $\varepsilon_r = 10$.

B- *Influence of frequency*

In this part, the parameters using in this simulation are applied voltage of 1kV, gas gap distance of 3 mm and a relative permittivity of 10.

The profile of discharge current is depicted in fig 4. The maximum value, of the discharge current, increases with the amplitude of the frequency of the signal.

When the values of frequency grow a second peak of discharge current appears.

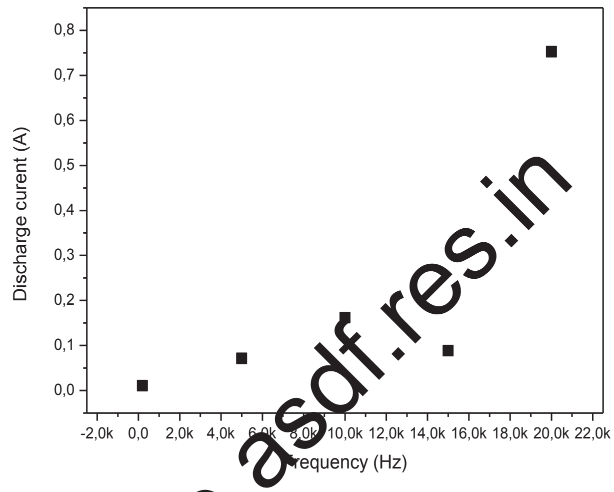


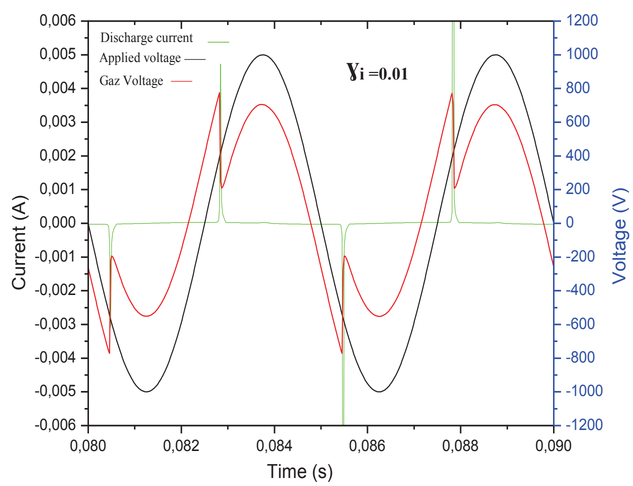
Fig. 4 Evolution of discharge current peak t with frequency for an applied voltage of 1kV, gas distance of 3 mm and Ɛr =10

C- *Influence of secondary emission of electrons*

Current discharge of helium DBD is calculated for secondary emission coefficient of 0.01 and 0.05. The result of simulation is depicted on figure 5.

The value of secondary emission coefficient of dielectric barrier material affects the plasma discharge. This effect is well illustrated by the change in waveforms of discharge current and gas voltage, as shown in fig. 5, when the secondary emission coefficient γi increases from 0.01 to 0.05. Several current peaks are observed in current waveform when γi is equal to 0.05.

Therefore, these simulation results can be used as a good guidelines for the selection of barrier material suitable for each application.



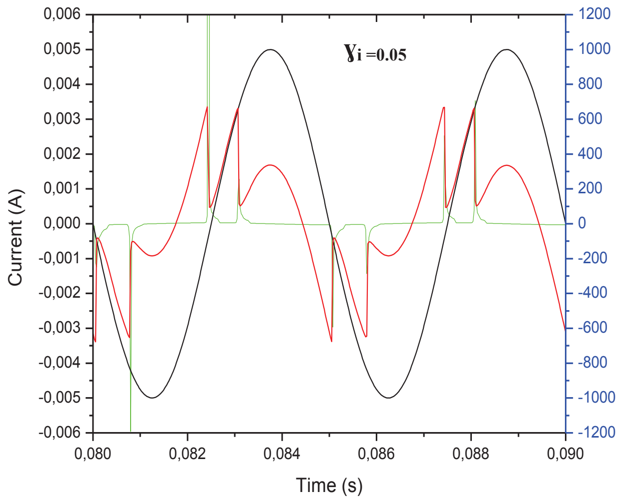


Fig.5 Calculated current and gas voltage waveform for applied voltage for 1kV, a frequency of 200 Hz, distance gap of 3mm (a) ɣi =0.01, (b) ɣi =0.05.εr is maintained at 10.

CONCLUSION

A one-dimensional fluid model of a homogeneous dielectric barrier discharge (DBD) in helium at atmospheric pressure is constructed.

The simulation is made by COMSOL Multiphysics software for a discharge driven by a low frequency of 200 Hz, an applied voltage of 1kV, a gap distance of 3 mm and a constant of dielectric barrier of 10.

The discharge behaviors are studied by varying external parameters such as the amplitude of applied voltage, the frequency and the secondary electron emission coefficient. The obtained results are given in terms of temporal variation of electrical characteristics.

The simulation results of electrical characteristics show that the variation of applied voltage amplitude and frequency value changes the form and the value of current discharge, maximum value of the discharge current increases with the amplitude of frequency of external voltage and this increase creates a second peak of discharge current. More and more current peaks are formed in each half cycle of the applied voltage along with the increase of the applied voltage and the distance between the micro-discharges becomes smaller. Therefore the value of secondary electron emission coefficient of dielectric barrier material changes the form of the discharge current and the gas voltage per half cycle.

The simulation results allow us to make a good choice of external parameters for discharge conditions suitable for the envisaged applications. The application in our case being the sterilization.

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