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# Calculation of breakdown voltage in plasma display panels

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**Abstract**

Plasma display panels play an important role in flat display panel market. The description of physical phenomena present in the alternative current plasma display panel discharges needs to know the breakdown voltage. This leads to minimize the applied voltage. The Paschen law gives the breakdown voltage for only pure gases. For this reason an analytical calculation has been done for pure gases and a xenon-neon mixture in order to estimate the breakdown voltage. This study makes it possible to see the importance of the parent gas. The results were obtained in an analytical approach to the numerical and experimental data.


*Keywords:* Plasma display panels; Breakdown voltage; Analytic; Fluid; Model

## 1. Introduction

The technology of plasma display panel (PDP) is one of the leading "emissive" technologies of flat display panel [1,2]. It is a display device which uses a gas discharge to transform an electric signal into visible image. More precisely each element of an image, or "pixel" is a site of discharge where the emission of light can be controlled electrically according to the contents video signal information. The characteristic of PDPs is their depth and weight, which makes it possible to create large surfaces. Several experimental [3,4] and theoretical [5,6]] researches are still in hand in order to understand the PDP discharge.

In this work we study a coplanar AC-PDP [7,8]. When a potential difference is applied between two electrodes, the free electrons present between them are accelerated by the electric field. Their energy can reach sufficient values to excite and ionize the atoms and molecules of the gas. These ionizations lead to an electron avalanche phenomenon. The positive ions created are accelerated by the electric field towards a cathode and can, extract new electrons. This is called: secondary emission [9]. Breakdown is produced when the system is self-sustained. The breakdown voltage is a very important parameter, which is necessary to decrease in order to allow the PDP cell addressing and reduce the electrical consumption [7]. Then, several PDP cell parameters are operated such as the product of the gas pressure $p$ and the inter-electrodes distance $d$, the gas mixture, the cell geometry; and the voltage applied to the address electrode. The curve to be determined gives the breakdown voltage according to the product of the gas pressure $p$ and the inter-electrodes distance $d$ known as the Paschen curve.

The outline of this paper is as follows: the Two-dimensional fluid (2D) and the analytical models developed in this paper are presented in Section 2. In Section 3, the salient numerical results are presented and followed by the discussion on the breakdown voltage. The conclusion of the work is summarized in Section 4.

## 2. Physical model

### 2.1. Fluid model

The physical model on which this work is based is a 2D fluid model [10,11]. It consists of the two first moment equations for electrons and ion transport coupled with Poisson's equation, in order to take into account the variations of the electric field. The continuity and the momentum transfer equations in the drift-

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diffusion approximation for the electrons and positive ions are given by the following relations:

For the electrons:

$$\frac{\partial n_e}{\partial t} + \nabla n_e \overline{v}_e = S_e \quad (1)$$

$$n_e \overline{v}_e = a n_e \mu_e E - \nabla (D_e n_e) \quad (2)$$

For the ions:

$$\frac{\partial n_p}{\partial t} + \nabla n_p \overline{v}_p = S_p \quad (3)$$

$$n_p \overline{v}_p = a n_p \mu_p E - \nabla (D_p n_p) \quad (4)$$

where $n_e$ is the electron density, $n_p$ the positive ion density. $\overline{v}_e$ and $\overline{v}_p$ are the mean velocity for electrons and ions respectively, the mobilities $\mu_e$ and $\mu_p$ are functions of the reduced electric field $E/p$. $S_e(r,t)$ and $S_p(r,t)$ represent the production rates for electrons and ions $D_e$ and $D_p$ are the diffusion coefficients for electrons and ions respectively.

The electric field is calculated by solving the Poisson's equation as follows:

$$\nabla \varepsilon_r E = \frac{|e|}{\varepsilon_0} (n_p - n_e) \quad (5)$$

where $\varepsilon$ is the dielectric permittivity.

The principle of calculation of the breakdown voltage is to determine the minimal voltage which is necessary to apply between the two electrodes, so that the mean density of charged particles present in PDP is $5.10^6$ times the initial value. In fact this criterion, although arbitrary, corresponds to determine the moment when the self-sustaining condition of the following equation is carried out:

$$M = \exp[(\alpha_{Xe} + \alpha_{Ne})d] = 1 + \frac{\alpha_{Xe} + \alpha_{Ne}}{\alpha_{Xe}\gamma_{Xe} + \alpha_{Ne}\gamma_{Ne}} \quad (6)$$

Where $\alpha_{Xe}$ and $\alpha_{Ne}$ correspond to the first Townsend coefficient for xenon and neon respectively, $M$ is the electron multiplication, $\gamma_{Xe}$ and $\gamma_{Ne}$ are the secondary emission coefficients for xenon and neon respectively.

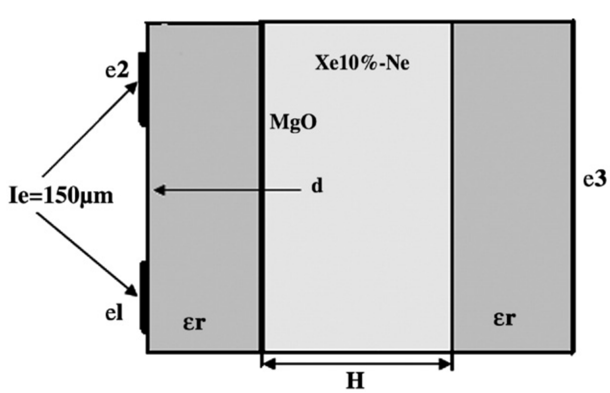


Fig. 1. Description of the cell geometry.

In the fluid model, the PDP cell can be modelled in two dimensions as shown in Fig. 1. The sustain electrodes ($e_1$ and $e_2$) have a large $L_e$ of 150 µm and are separated by a distance $d$. The permittivity of the right and left dielectrics is 10, and they are separated by a distance $H$ of 100 µm. This space is filled by a mixture 10% of xenon in neon with secondary emission coefficients equal to 0.05 and 0.5 respectively.

### 2.2. Analytical model

In this paper, we propose an analytical model in which the breakdown voltage variation is studied according to the product of the gas pressure $p$ and the inter-electrodes distance $d$.

The Paschen curve is then deduced analytically for a pure gas and for gas mixtures.

#### 2.2.1. Pure gas

We present at first the condition of self-sustaining for a pure gas which is written in the following way [12]:

$$\exp(\alpha d) = 1 + \frac{1}{\gamma} \Rightarrow \alpha d = \ln\left(1 + \frac{1}{\gamma}\right) \quad (7)$$

where $d$ is the distance between the electrodes,$\gamma$the second Townsend coefficient, and$\alpha$ the first Townsend coefficient.

We replace $\alpha$ by the flowing expression [13]:

$$\alpha = pA\exp\left(-\frac{B}{(E/p)^r}\right) \quad (8)$$

$A$ and $B$ being two positive constants determined experimentally. $E/p$ is the reduced electric field. $p$ is the pressure, and $r$ is a constant depending on the nature of gases. It equals to 0.5 for pure gases.

The Eq. (7) becomes:

$$V_b = \left| -\left[\frac{B}{\ln\left(\frac{x}{Apd}\right)}\right]^2 pd \right| \quad (9)$$

with $x = \ln\left(\frac{\gamma+1}{\gamma}\right)$

This is the final expression of Paschen.

#### 2.2.2. Mixture

In the case of a mixture of xenon in neon, the self-sustaining condition (Eq. (6)), becomes [13]:

$$\exp(\alpha_{Ne} + \alpha_{Xe})d = 1 + \frac{\alpha_{Ne} + \alpha_{Xe}}{\alpha_{Ne}\gamma_{Ne} + \alpha_{Xe}\gamma_{Xe}} \quad (10)$$

where $\alpha_{Ne}$, $\alpha_{Xe}$ and $\gamma_{Ne}$, $\gamma_{Xe}$, correspond to the first and second Townsend coefficients for neon and xenon respectively.

If we replace $\alpha$ by its expression for each gas, we find:

$$\alpha_{\mathrm{Ne}} = p_{\mathrm{Ne}} A_1 \exp\left(-\frac{B_1}{(E/p)^{0.5}}\right) \tag{11}$$

$$\alpha_{\mathrm{Xe}} = p_{\mathrm{Xe}} A_2 \exp\left(-\frac{B_2}{(E/p)^{0.5}}\right) \tag{12}$$

where $p_{\mathrm{Ne}}$ and $p_{\mathrm{Xe}}$ are the partial pressures of the neon and xenon successively. $A_1$, $B_1$ and $A_2$, $B_2$ are constants obtained in experiments for neon and xenon respectively.

Then the relation ( Eq. (10)) becomes:

$$d\left[p_{\mathrm{Ne}} A_1 \exp\left(B_1\left(\frac{p_{\mathrm{Ne}} d}{V_{\mathrm{b}}}\right)^{0.5}\right) + p_{\mathrm{Xe}} A_2 \exp\left(-B_2\left(\frac{p_{\mathrm{Xe}} d}{V_{\mathrm{b}}}\right)^{0.5}\right)\right] = \mathrm{Ln}\left[1 + \frac{p_{\mathrm{Ne}} A_1 \exp - B_1\left(\frac{p_{\mathrm{Ne}} d}{V_{\mathrm{b}}}\right)^{0.5} + p_{\mathrm{Xe}} A_2 \exp - B_2\left(\frac{p_{\mathrm{Xe}} d}{V_{\mathrm{b}}}\right)^{0.5}}{p_{\mathrm{Ne}} A_1 \gamma_{\mathrm{Ne}} \exp - B_1\left(\frac{p_{\mathrm{Ne}} d}{V_{\mathrm{b}}}\right)^{0.5} + p_{\mathrm{Xe}} A_2 \gamma_{\mathrm{Xe}} \exp - B_2\left(\frac{p_{\mathrm{Xe}} d}{V_b}\right)^{0.5}}\right] \tag{13}$$

The Eq. (13) represents the general formula of the breakdown voltage in the case of a xenon-neon mixture.

In order to determine the Paschen curve, the calculation conditions are as follows: the secondary emission coefficient of xenon and neon are equal to 0.05 and 0.5 respectively. The distance between electrodes is 100 µm. According to these conditions, we can calculate the breakdown voltage for pure gas and gas mixture.

## 3. Results and discussion

Figs. 2 and 3 present the Paschen curve for pure gases; xenon and neon. The curves indicated by solid symbols correspond to the analytical model results. The curves indicated by open symbols correspond to the fluid model results.

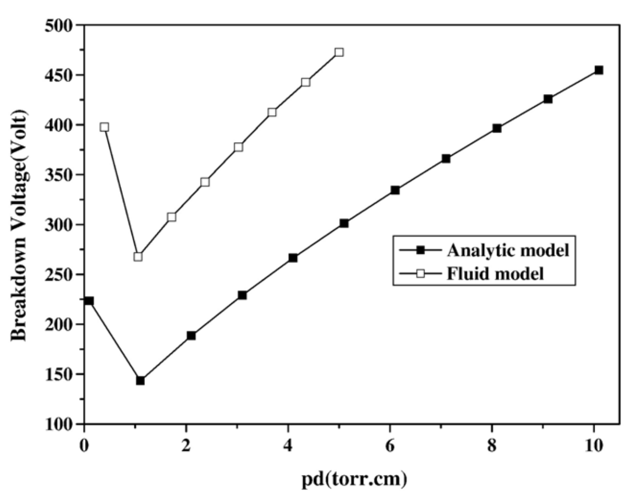


Fig. 2. Paschen curve using analytical model and 2-D fluid model for pure gases; xenon.

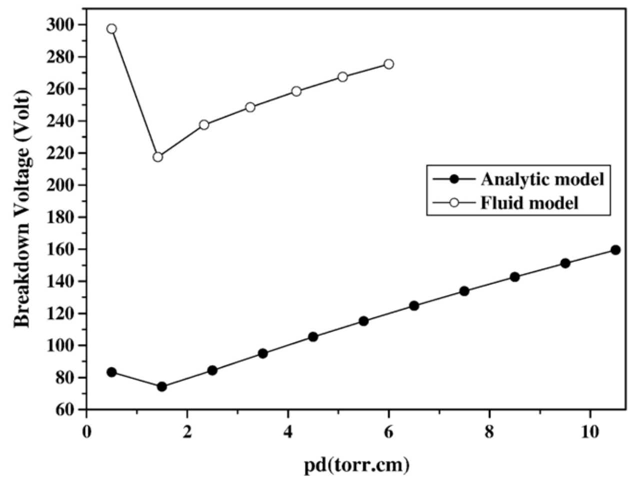


Fig. 3. Paschen curve using analytical model and 2-D fluid model for pure gases; neon.

We observe that the analytical and numerical curves exhibits the same shape nevertheless in the case of an analytical result; the minimal of the breakdown voltage is lower than for the numerical model. This is due to the fact that in the analytic model the discharge is at one dimension while the fluid model “takes into account the geometry of the cell in a two dimensional system”.

On the other hand, we note that the minimum of Paschen, $V_{\mathrm{min}}$, of neon is lower than that of xenon. It is equal to 75 V for a product of the gas pressure $p$ and the inter-electrodes distance $d$ equal to 1.5 torr cm for neon and to 144 V when P.d 1.1 torr cm for xenon. In 2D fluid calculation $V_{\mathrm{min}}$ for pure neon equals to 218 V for a product pressure-distance of 1.5 torr cm, and to 270 V for a product P.d 1 torr cm for xenon. This can be explained by the fact that the secondary emission coefficient of neon is ten times that of xenon (0.5 for neon and 0.05 for xenon) which permits to extract more electrons and then to minimize the breakdown voltage.

In Fig. 4 we present the breakdown voltage variation according to the product of the gas pressure $p$ and the inter-

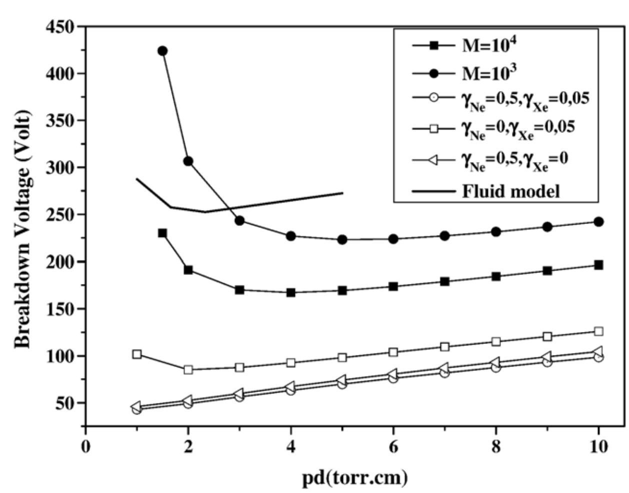


Fig. 4. Paschen curve using analytical model and 2-D fluid model for a Xe10%-Ne gas mixture.

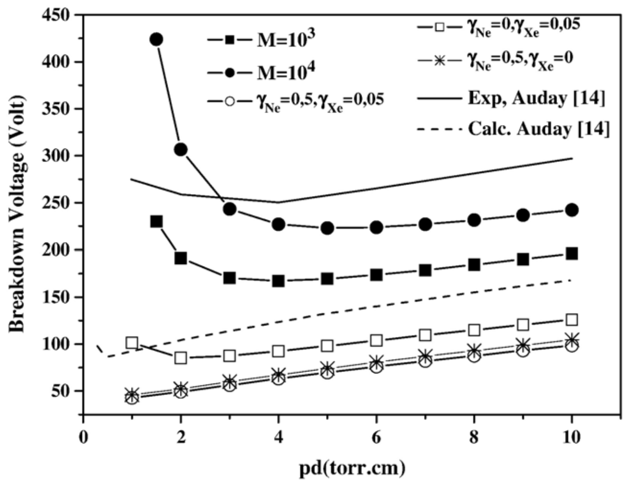


Fig. 5. Paschen curve in the case of xenon10%-neon gas mixture. Comparison between experimental and calculation results from Auday [14], and calculations from the analytical model.

electrodes distance $d$ for a mixture of 10% of xenon in neon. The fluid calculation results are displayed with a solid line. In the case of analytical results, there are two methods. In the first we use the multiplication, indicated by solid symbols. It appears that, when the multiplication is taken into account the analytical and numerical results exhibit the same trend. These results are close when the multiplication increases to a value of $10^4$. It is also noted that when the secondary emission coefficient, $\gamma$, is introduced the breakdown voltage has a value of 50-80 V at a product of the gas pressure $p$ and the inter-electrodes distance $d$ equal to 2 torr cm. This value is less than 180 V in the case of pure xenon. This is due essentially to the fact of introducing neon as a parent gas which reduces the breakdown voltage. This is the mostly important reason of using a gas mixture.

In Fig. 5 we compare our analytical results obtained by the two methods (multiplication and gamma) to experimental data, (indicated by a solid line) and calculated results (indicated by dashed line) obtained by G. Auday [14]. In its calculations, Auday uses Eq. (6) with experimental values of $\alpha$. The secondary emission coefficient of xenon and neon used in G. Auday's calculation are equal to 0.05 and 0.5 respectively.

The curves with solid symbols represent the case where the multiplication $M$ is taken into account. The curves with open symbols represent the case when the secondary emission coefficient, gamma, is taken into account. It is noted that the breakdown voltage in the case of using the multiplication is higher than in the case of using gamma. We notice also that our results approach those of the experience when we introduce the multiplication. They approach the results calculated by Auday when gamma is introduced. However the breakdown voltage of experience is higher than 10 V than that of the analytical result.

## 4. Conclusion

The present paper is a modelling of a coplanar PDP cell. For this purpose two models were used; analytical and numerical. The results exhibit the role of the parent gas in reducing the breakdown voltage. This limits the electrical consummation in plasma display panels.

Two methods were used in our analytical calculation. The comparison with the 2D fluid model shows that the analytical results approach to the numerical ones when the multiplication is taken into account. Another comparison has been done with experimental results when the secondary emission is introduced.

These comparisons ensure the validity of the analytical model for a gas mixture. However, it is noted that the breakdown voltage estimated by the analytical model is lower than that of the fluid model and/or the experience. This is due essentially to the fact that in the analytical model, the discharge is one-dimensional (called also plan–plan). This means that the Paschen law doesn't take into account the geometry where the discharge is produced. However recent technologies use several geometries which need the introduction of other parameters in breakdown voltage calculation. This leads the improvement of the Paschen law.

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