Effect of He-Xe Mixtures on Excitation Efficiency in PDP and Comparison of Ne-Xe Mixtures with Computational Method

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Abstract

Each cell in a plasma display panel (PDP) is activated by discharge of a mixture of rare gases such as He or Ne and the excitation of a main gas such as Xe. Due to the limitation in increasing Xe partial pressure, the luminous efficiency of PDP is usually lower than that of Cathode Ray Tube (CRT). In this paper we have investigated the effect of mixture composition on the micro discharge cell efficiency. We show that the excitation efficiency and luminous efficiency in He-Xe mixtures is lower than that of Ne-Xe mixtures. We find that adding a small amount of Ar in a Ne-Xe mixture increases cell efficiency, while for He-Xe mixtures cell efficiency is reduced.

1. Introduction

Production of various types of flat panel displays has been the focal point of attention, in the last decade. This fact makes it necessary to study luminous efficiency of these devices. There are many advantages of plasma display panel compared to conventional CRT and LCD displays. These include: large screen size [1], wide viewing angle, suitable for high definition television (HDTV), flat panel display, low weight and simple manufacturing process [2]. Figure (1) shows a micro cell structure in plasma display panel.

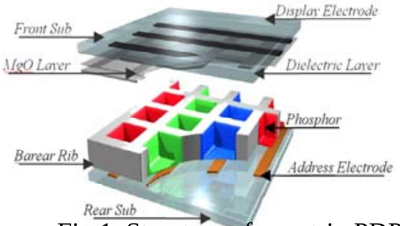

Fig.1. Structure of a matrix PDP cell

The cells consist of two glass plates, positioned at the top and the bottom of the cell [2]. An addressing electrode at the rear substrate and a display electrode at the front substrate are deposited. The cells are separated by the rib. The rib height is approximately 100 µm [3]. The space in these cells is filled with a mixture of a few rare gases such as He-Xe or Ne-Xe mixtures [4].

Applying a known voltage between address and display electrodes leads to ionization or excitation of gases, thereby a plasma discharge is created. Excited Xe atoms emit UV photon with 147 nm wavelength [3]. Upon collision of these UV photons with the phosphorous, a visible light is created. A glass dielectric layer protects the front substrate form ion and electron bombardment. This dielectric layer is covered with a protective MgO thin film about 1 µm thick. This MgO layer not only protects the dielectric layer but also reduces the breakdown voltage [4]. This latter phenomenon will be discussed later in detail. In section 2, we study the parameters which affect breakdown voltage in He-Xe and Ne-Xe mixtures. In section 3, we investigate the electric efficiency in He-Xe and Ne-Xe mixtures. In section 4, we consider the excitation efficiency and the effect of adding a small amount of Ar in He-Xe mixtures. Finally, the excitation efficiency of the He-Xe-Ar and Ne-Xe-Ar mixtures is compared.

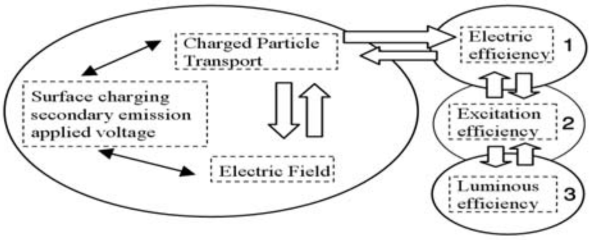

Fig.2. Schematic of a cell model

Figure (2) shows a model for a PDP matrix cell with Ne-Xe or He-Xe mixtures. This model is modified version of model produced in [5]. We study the breakdown voltage, Electric efficiency, Excitation efficiency and Luminous efficiency. This model has four parts. The central part of the model is related to the parameters associated with the breakdown voltage. We will compare the breakdown voltage between Ne-Xe and He-Xe mixtures. The simulation has been performed assuming uniform electric field between the electrodes. We used a thin film layer MgO and SIGLO series [6] for computation of the cross section. We have assumed that the UV photon produced by Xe excitation has wave length 147 nm so that $\varepsilon_{UV} \cong 8.3\, eV$ .Simulation were carried at 300° K.

In the first part of the model we simulate electric efficiency. The second part of the model is devoted to parameters defining the electric field, therefore it is dedicated to the description of UV photon and the comparisons between Ne-Xe and He-Xe excitation efficiency.

Then Luminous efficiency will be considered in the third part of the model. Finally we will discuss the result.

2. Comparison of breakdown voltage in He-Xe and Ne-Xe mixtures

2.1 Effect of MgO layer on breakdown voltage

The value of the breakdown voltage in He-Xe or Ne-Xe mixture influences excitation efficiency and luminous efficiency [7]. We investigate the effect of different parameters on the breakdown voltage.

The number of secondary electrons in micro cells depends on the kind of the thin film layer and the kind of neutral gas utilized. These two factors also affect breakdown voltage [5]. MgO thin film layer is the best known material for protecting the dielectric layer [4, 8, 9]. The life time of PDP is limited by the sputtering of MgO layer but can be larger than 10000 hours [4]. Secondary electron emission coefficient is taken to be 0.05 in the calculations for Xenon ions,0.5 for Neon and 0.3 for Helium on the MgO layer [4].

In the He-Xe mixture, the breakdown voltage is calculated from [4, 10,11]:

$$\frac{(\alpha_{Xe}+\alpha p)\gamma_{Xe}+\alpha_{He}\gamma_{He}}{\alpha_{Xe}+\alpha_{He}+\alpha p}\left[e^{(\alpha_{Xe}+\alpha_{He}+\alpha p)d}-1\right]=1 \quad (1)$$

where γ_{He} and γ_{Xe} are the secondary electron emission coefficient for He and Xe ions impingement on MgO layer respectively. The quantity $\alpha\, p$ is the effective partial first Townsend ionization coefficient per electron caused by ionization by metastable Ne or He atoms (penning ionization), $\alpha\, p$ does not affect our results [11], also d is the gap-length of the PDP cells, α_{Xe} and α_{He} are the Townsend ionization coefficients for He and Xe respectively, and are given by:

$$\alpha_{He} = \frac{\upsilon^{i}_{He}}{V_d\,(He)} \quad (2a)$$

$$\alpha_{Xe} = \frac{\upsilon^{i}_{Xe}}{V_d\,(Xe)} \quad (2b)$$

where $V_d(He)$ and $V_d(Xe)$ are the electron drift velocity, also υ^i_{Xe} and υ^i_{He} are the corresponding partial ionization frequencies and are defined by [11]:

$$\upsilon^i_{Xe} = N(Xe).V.\sigma^i_{Xe} \qquad (3)$$

$$\upsilon^i_{He} = N(He).V.\sigma^i_{He} \qquad (4)$$

where N(He) and N(Xe) are density of He and Xe atoms, respectively, V is the mean velocity of free electron for ionization of neutral atoms, and σ^i_{Xe} and σ^i_{He} are the ionization cross section for He and Xe, respectively.

The breakdown curves in Fig. (3) have been obtained using (1), but for Ne-Xe mixtures, the parameter α_{He} and γ_{He} must be changed into α_{Ne} and γ_{Ne}, thereby α_{Ne} is the ionization coefficient, and γ_{Ne} is the secondary electron emission coefficient for neon. $\boldsymbol{\alpha_{Ne} = \upsilon^i_{Ne} / V_d(Ne)}$ and $\boldsymbol{\upsilon^i{}_{Ne}}$ is the ionization frequencies and V_d(Ne) is the electron drift velocity.

It should be noted that, the mean electron velocity which is necessary to create plasma, is approximately 3×10^8 cm/s. These electrons are energetic enough to produce plasma [4].

Figure (3) shows variations in the breakdown voltage as a function of Xe partial pressure (PXe). Plate separation d=100 μm, corresponds to the gap length of the PDP cell. Electron-atom collision cross section for Xe, He and Ne are obtained from the SIGLO series [6]. Density of Xe, He and Ne are given by ideal gas principle. The total pressure of gases is taken to be 400 Torr.

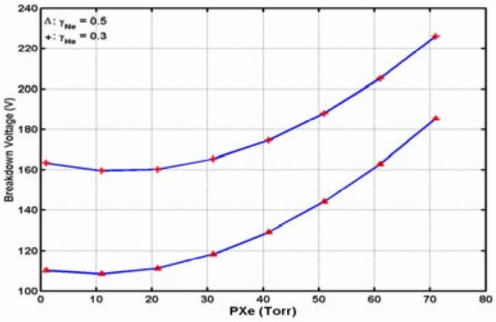

Fig.3. Breakdown voltage as a function of secondary electron emission coefficient for He ions and Ne ions on MgO layer

Figure (3) shows the breakdown voltage in He-Xe mixtures is more than that in Ne-Xe mixtures.

We will now consider the effect of gas mixture on the MgO. If electrons have enough energy, the ionization will take place. Mean free path for collisions is calculated from [11]:

$$\lambda_c = \frac{1}{N.\sigma_c} \qquad (5)$$

where N is the gas density and σ_c is collision cross section .

The ionization energy of the He is $[\in_i]He = 24.5eV$ and the Ne ionization energy is $[\in_i]Ne = 21.6eV$ [10]. Under similar conditions, the ionization frequency is much higher in the Ne-Xe mixture compared with the He-Xe mixture. Meanwhile the secondary electron emission coefficient for He ions on MgO is $\gamma_{He} = 0.3$ and for Ne is $\gamma_{Ne} = 0.5$ [4]. It is clear that the He-Xe mixture provides smaller secondary electrons in comparison with the Ne-Xe mixture. Thus, as described in (1), (4) and (5) for a certain pressure of Xe gas ,if He supporting gas is used ,breakdown voltage the cell will increase.

2.2 Effect of variation of breakdown voltage in He-Xe and Ne-Xe mixtures as a function of micro cell height

As shown in Fig. (4) Increasing the distance between substrates increases breakdown voltage in the He-Xe and Ne-Xe mixtures. This is due to the fact that, electric field reduce as distance between electrodes increases, therefore the energy and velocity of electrons, decrease, so the ionization frequency becomes smaller and we have to increase the breakdown voltage for holding plasma [11].

In Fig.(4) we consider the variations of breakdown voltage in the He-Xe and Ne-Xe mixtures as a function of variation of electrodes distance.

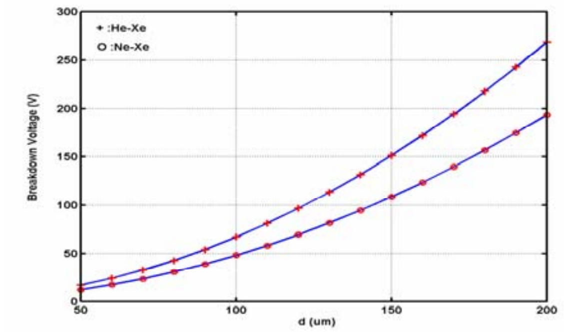

Fig. 4. Bbreakdown voltage in a He-Xe and Ne-Xe mixtures as a function of cell's hight

Assumption mode for the both He-Xe and Ne-Xe mixtures are the same and are as the follows: The total pressure is 300 Torr and Xe pressure is 30 Torr. The electron velocity is chosen such that the gas inside the cell is ionized.

General trend shown in Fig.(4) is in harmony with those obtained in [4].

2.3 Variation of breakdown voltage as a function of variation of total pressure of He-Xe and Ne-Xe mixtures

Figure (5) shows breakdown voltage for He-Xe and Ne-Xe mixtures for the total pressure 300 Torr and 500 Torr. As we expect from (4), breakdown voltage is increased by increasing the total pressure of gases, because collision frequency is increased and so mean free path and electron's velocity are decreased. This weakens the plasma, so in order to hold plasma breakdown voltage increases. Under the similar conditions, the breakdown voltage for He-Xe mixture is more than that for Ne-Xe mixture.

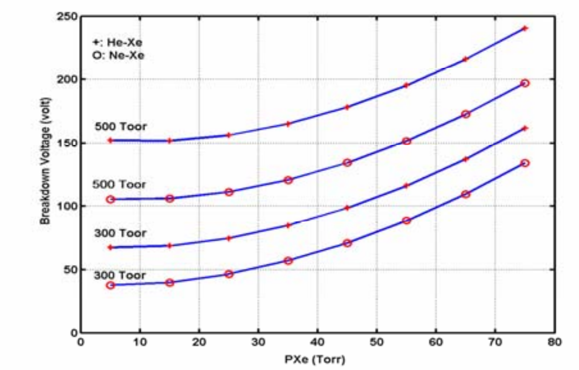

Fig.5. Breakdown voltage as a function of Xe gas pressure for different total gas pressure of the Ne-Xe and He-Xe mixtures

General trend shown in Fig.(5) is in harmony with those obtained in [10].

3. Electric efficiency

The electric efficiency is defined as [13]:

$$\eta_{elect} = \frac{total\ energy\ dissipated\ by\ electrons}{total\ energy\ dissipated\ in\ a\ discharge\ pulse} \quad (6)$$

η_{elec} can be written as [13]:

$$\eta_{elec} = \frac{1 - e^{-\alpha d}}{\alpha d} \qquad (6)$$

Where $\alpha = \alpha_{Xe} + \alpha_{He}$ for the He-Xe mixture, $\alpha = \alpha_{Xe} + \alpha_{Ne}$ for the Ne-Xe mixture and d is

Total energy dissipated by electron depends on the collision frequency of species within plasma. Figure 6(a) and 6(b) shows that increasing the total pressure increases the electric efficiency. This is due to the fact that the elastic and inelastic collisions will increase. So the total dissipated energy will increase.

As shown in figure 6(a) and 6(b) the electric efficiency of Ne-Xe mixture is more than that for He-Xe mixture.

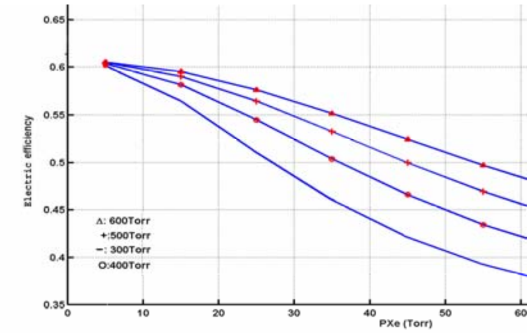

Fig.6(a). Electric efficiency in a He-Xe mixtures as a function of Xe gas pressure for different total gas pressure

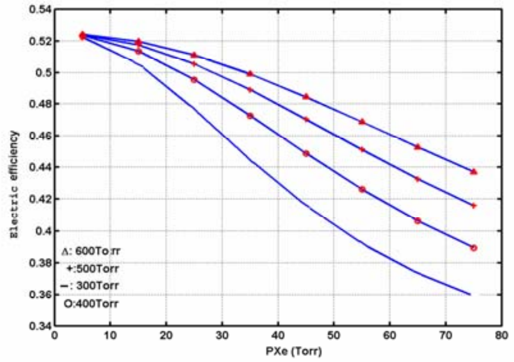

Fig.6(b). Electric efficiency in a Ne-Xe mixtures as a function of Xe gas pressure for different total gas pressure

4. Excitation efficiency

The excitation efficiency can be written as [11, 13]:

$$\eta_{exc} = \frac{\int_T dt \int_V dv \sum_{i=1}^{N_{exc}} n_e . \upsilon_{exc,i} . \varepsilon_{exc,i}}{\int_T dt \int_V dv (J_e + \sum_{i=1}^{N_{ion}} J_{ion,i}) E} \qquad (8)$$

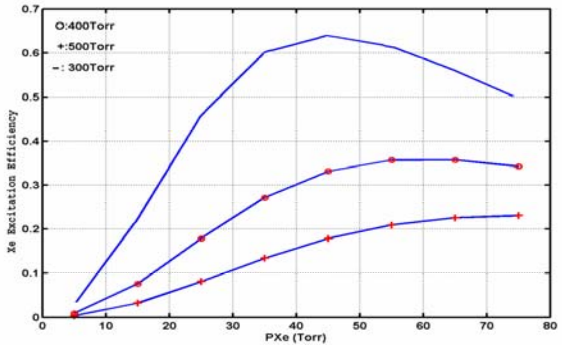

Fig.7(a). Xe Excitation efficiency in a Ne-Xe mixture as a function of Xe gas pressure for different total gas pressure

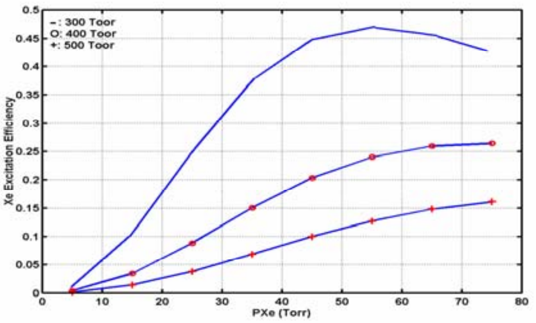

Fig.7(b). Xe Excitation efficiency in a He-Xe mixture as a function of Xe gas pressure for different total gas pressure

where n_e, is electron number density, $\upsilon_{exc,i}$, is the excitation frequency of excited state of Xe_i, $\varepsilon_{exc,i}$ is the corresponding electron energy loss, J_e is the electronic current, similarly the dissipated power per unit volume, and $J_{ion,i}$ is the current of the ion,i. Figure 7(a)and 7(b) shows variation of the excitation efficiency for He-Xe and Ne-Xe , as a function of variation of Xe gas pressure, for total pressure p=300 Torr, p=400 Torr and p=500 Torr. Equation (8) shows that electric field is inversely proportional to excitation efficiency. Therefore the excitation efficiency decreases as the total pressure increases.

4.1 Excitation efficiency of He-Xe and Ne-Xe mixtures

The required energy for the excitation and ionization of Xe is 8.3 eV and 12.1 eV, respectively [11]. Electrons with 24.5 eV energy are obtained from ionization of He., Therefore , electrons removed from He with Xe atoms can excite or ionize Xe.

$$\begin{aligned} & e + He \rightarrow He^+ + 2e \\ & e + Xe \rightarrow Xe^+ + 2e \qquad (9a) \\ & e + Xe \rightarrow Xe^* + e \end{aligned}$$

$$e + He \rightarrow He^* + e \qquad (9b)$$

where He+, He*, Xe+ and Xe* represent Helium ionization, Helium excitation, Xenon ionization and Xenon excitation. The electron removed from He uses only a small amount of its energy for the excitation or ionization of the Xe atom. In each collision, it dissipates 16.2 eV or 12.1 eV, depending on the process involved. However, energy dissipation of the electron removed from Ne, with 21.6eV ionization energy, are 13.3 eV or 9.5 eV for Xe excitation or Xe ionization, respectively. Dissipated energy in He-Xe mixtures is more than that in Ne-Xe mixtures. The Xe atom excite efficiency is plotted in Fig. 7(a,b) using Eq. (8) for He-Xe and Ne-Xe mixtures respectively. It is observed that excitation efficiency is higher in Ne-Xe mixture than that for He-Xe mixture.

4.2 Excitation efficiency of He-Xe-Ar, Ne-Xe and Ne-Xe-Ar mixtures

In an electron–atom collision, if the velocity of electron is not sufficient to ionize the gas, neutral atom may transform into a metastable state (denoted by He^{m}).

$$\mathrm{e+He} \longrightarrow \mathrm{He}^{m} + \mathrm{e}$$

This leads to energy dissipation for the electron. The Ar gas is usually used for exciting neutral Xe atom γ_{Xe}, γ_{He} and γ_{Ar} are the secondary electron emission coefficients, α_{Xe}, α_{He} and α_{Ar} are the ionization coefficients for Xe, He and Ar in He-Xe-Ar mixture, respectively, and are determined by [10] :

$$\left[\frac{\alpha_{He}\gamma_{He} + (\alpha_{Xe} + \alpha p_1)\gamma_{Xe} + (\alpha_{Ar} + \alpha p_2)\gamma_{Ar}}{\alpha_{He} + \alpha_{Xe} + \alpha p_1 + \alpha_{Ar} + \alpha p_2}\right] \cdot \left[e^{(\alpha_{He}+\alpha_{Xe}+\alpha p_1+\alpha_{Ar}+\alpha p_2)} - 1\right] = 1 \qquad (10)$$

Where $\gamma_{Ar} = 0.05$ and α_{Ar} is calculated from $\alpha_{Ar} = \upsilon_{Ar}^{i} / V_d(Ar)$, where υ_{Ar}^{i} and V_d (Ar) are ionization frequency of Ar and the electron drift velocity respectively.

Adding Ar gas to Ne-Xe or He-Xe mixtures, results does not affect the breakdown voltage profound Ar ionization (Ar^{+}) or Ar excitation (Ar°) is obtained by metastable neon atom (Ne^{m}) [10].

$$\begin{aligned} &e + Ne \rightarrow Ne^{m} + e \\ &Ne^{m} + Ar \rightarrow Ar^{*} + Ne \qquad (11a) \\ &Ar^{*} + Xe \rightarrow Xe^{*} + Ar \end{aligned}$$

$$e + Ne \rightarrow Ne^{*} + e \qquad (11b)$$

Fig.(8a) and (8b) show changes in breakdown voltage as a function of Ar partial pressure for Ne-Xe-Ar and He-Xe-Ar mixtures. Figure (9) shows that the Ar behavior for He-Xe mixture is different from that of Ne-Xe mixture. The energy of the He metastable level is $[\varepsilon_m]He \approx 20eV$ and $[\varepsilon_m]Ne \approx 16.6eV$ [10]. On the other hand the energy of the Ar excitation and Ar ionization is $[\varepsilon_{exc}]Ar \approx 11.5eV$ and $[\varepsilon_i]Ar \approx 15.8eV$ respectively[10] .So the energy difference between the (Ar°) state and He^{m} is higher than the energy difference between (Ar°) and Ne^{m}.Thus as shown in Fig.8a and 8b , the breakdown field is higher for He-Xe mixture compared with a Ne-Xe mixture. Decreasing voltage leads to higher efficiency, therefore higher excitation efficiency is obtained for Ne-Xe-Ar mixture than He-Xe-Ar mixtures.

We observe that the dissipated energy in He-Xe-Ar mixtures is higher than that in He-Xe mixtures , so the excitation efficiency for He-Xe –Ar mixture is lower than He-Xe mixture.

5. Luminous efficiency

The total visible photon energy per sustaining period T which reaches the output window of the PDP cell, given by [11]:

$$\varepsilon_{vis} = \int_T dt \int_{S_{out}} ds \ \Gamma_{Ph} \ \varepsilon_{Ph} \qquad (12)$$

where Γ_{Ph} is the number of visible photons per unit surface and per unit time and S_{out} is the area of the output window . The luminous efficiency (η) is given by [11]:

$$\eta = \frac{\varepsilon_{vis}}{\varepsilon_e + \varepsilon_i} = \frac{\int_T dt \int_{S_{out}} ds \Gamma ph \varepsilon_{ph}}{\int_T dt \int_V dv (J_e + \sum_{i=1}^{N_{ion}} J_{ion}) E} \qquad (13)$$

ε_e and ε_i are, respectively, the electrons' energy and ions' energy in plasma state.

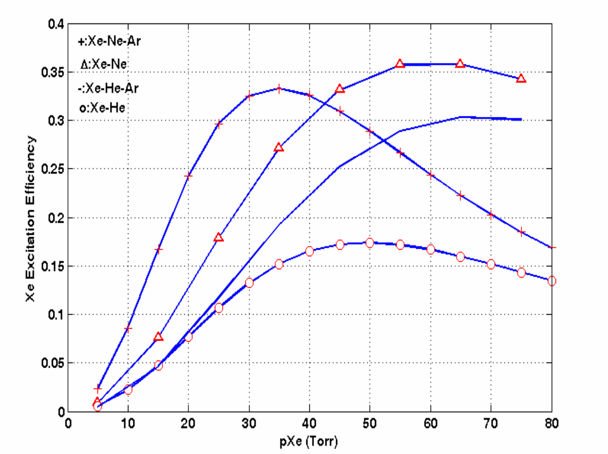

Fig. 9. Comparisons between the excitation efficiency of He-Xe , Ne-Xe , He-Xe-Ar and Ne-Xe-Ar mixtures as a function of Xe gas pressure. The total pressure is 400 Torr

Referring to Fig.(5) one finds that the breakdown voltage to initial plasma for the Ne-Xe mixture is smaller than He-Xe mixture from equation (13). We find that the luminous efficiency for Ne-Xe mixture is greater than that for He-Xe mixture.

6- Conclusion

We have studied the effect of mixture Ne-Xe, He-Xe mixtures on the breakdown voltage and on the efficiency in plasma display panel under similar condition. We have shown that the breakdown voltage in the Ne-Xe mixture is less than that in the He-Xe mixture. Efficiency is an increasing function of Xe concentration in Ne-Xe or He-Xe mixture. The Ne-Xe mixtures were found to be more efficient than the He-Xe mixtures. Addition of small amount of Ar gas increases efficiency only for the Ne-Xe-Ar mixtures.

7- References

[1] T. Kurita, M. Seki, J. Koike, Y. Takano, T. Yamamoto, H. Kokubun, K. Kobayashi, H. Murakami, ”A 42-INCH-DIAGONAL HDTV PLASMA DISPLAY”, science and Technical Research Laboratories, NHK

[2] Shinji Senda, Yoshihito Hayashi, Kazutaka Nakayama, ”APPLICATION OF PHOTO SENSITIVE PASTES FOR PDP”, 1998 IEMT/IMC Proceedings, PP. 77-81.

[3] Tsutae shinoda, Masayuki Wakitani, Toshiyuko Nanto, Noriyuki Awaji, Member, IEEE, and Shinji Kanagu, "Development of Panel Structure for a High-Resolution 21-in-Diagonal Full-Color Surface-Discharge Plasma Display Panel", IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 47, No.1, JANUARY 2000.

[4] J. P. Boeuf, C. Punset, A. Hirech, and H. Doyeux, “Physics and Modeling of Plasma Display Panels”, Thomson Tubes Electroniques, ZI Center’Alp, J. Phys, J. PHYS. IV France 7(1997).

[5] J. P. Boeuf, Th. Callegari, C. Punset, and R. Ganter, “Modeling as a Tool for Plasma Display Cell Optimization”, Workshop Digest of the 18th International Display Research Conference, Asia Display’98, pp. 209-220 (SID, 1998).

[6] http://www.sni.net/siglo/database/xsect/siglo.sec

[7] R. Ganter and M. Cappelli, “A mechanism for Anomalously high Voltages in high-Pressure dc microdischarge mixtures of He, Ne and Xe”, Thermosciences Division, Department of Mechanical Engineering, Stanford University, Stanford, Ca 94305, J. Applied Physics, October 2002.

[8] Sang Jik Kwon, Yong Jae Kim and Seong Eui Lee, "Material Properties and Plasma Display Panel Discharging Charactristics Depending on MgO Evaporation Rate", Japanese Journal of Applied Physics, Vol. 45, No. 11,2006, pp. 8709-8713

[9] Zhao Hui Li, Eou Sik Cho and Sang Jik Kwon, "Analysis of a MgO Protective Layer Deposited with Ion-Beam-Assisted Deposition in an AC PDP", Journal of the Korean Physical Society, Vol. 49, No. 6, Desember 2006, pp. 2332~2337.

[10] Georgios Veronis, Umran S. Inan, Senior Member, IEEE, and Victor P. Pasko, "Fundamental Properties of Inert Gas Mixtures for Plasma Display Panels", IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 28, No. 4, August 2000.

[11] Georgios Veronis, ”Desigen of Efficient Plasma Display Panel Cells”, Dissertation Submitted To The Department Of Electrical Engineering And The Committee On Graduate Studies Of Stanford University, For the degree of PhD, June 2002.

[12] M A Khakoo,S Trajmar,L R LeClair ,I Kanik ,G Csanak and C G Fontes,"Differential cross sections for electron impact excitation of Xe: I. Excitation of the five lowest levels; experiment and theory", J. Phys. B: At. Mol. Opt. Phys. 29 (1996)3455-3475. Printed in the UK

[13] R. Ganter, Th. Callegari, L. C. Pitchford, J. P. Boeuf, ”Efficiency of AC Plasma Display Panels”, CPAT, Universite Paul Sabatier, 118 Route de Narbonne, 31062 Tolouse cedex, France.

[14] Eun Ha Choi, Jeong Chull Ahn, Min Wug Moon, Yoon Jung, Myung Chul Choi, Yoonho Seo, Guangsup Cho, Han Sup Uhm, Kunhide Tachibana, Ki Woong Whang, and Magne Kristiansen, "Vacuum Ultraviolet Luminous Efficiency and Plasma Ion Density in Alternating Current Plasma Display Panels", Applied Physics Letters, Volume 81, number 18, 28 October 2002.