Influence of ion mobilities on discharge characteristics of AC-PDPs

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Abstract

With recent experiments to add He atoms to the Ne-Xe discharge gas mixture for high luminous efficiency PDPs, we have performed simulations on a coplanar structured AC-PDP sustained in the three species He-Ne-Xe gas mixture. We found that the correct ion mobilities are essential to get the meaningful simulation results. We determined ion mobilities in the mixture gas and presented the calculated results regarding the influence of ion mobilities on discharge characteristics.

1. Introduction

AC-PDPs are one of the most promising technologies for large-area flat panel displays. Many simulation studies [1,2] on discharge characteristics of AC-PDPs have been carried out to understand display operations and to improve luminous efficiency, without employing expensive and time-consuming experiments. However, most of simulation studies have been performed in the two species mixture gas such as He-Xe or Ne-Xe.

Recent works [3] have shown that the three species mixture gas such as He-Ne-Xe gives higher luminous efficiency and shorter address discharge time lag than the conventional Ne-Xe mixture gas. However, Rauf *et al.* [4] have reported simulation results that luminous efficiencies are lower with the increasing He contents, which is just the opposite to these experimental results. Recently, we have also performed simulations of coplanar structured AC-PDPs sustained in the three species He-Ne-Xe mixture and have obtained results which are in very good agreement with the experimental findings [5]. We have found that discharge characteristics are quite sensitive to the values of ion mobilities in the gas mixture. Thus, using correct mobility values is critical to get meaningful simulation results even though measured data on ion mobilities are very limited.

In this work, we have discussed how to determine necessary values of ion mobilities in the various discharge gas mixtures including the three species He-Ne-Xe mixture, using the available experimental values. Some representative results on the effect of ion mobilities on the discharge characteristics in AC-PDPs have also been presented.

2. Calculation methods

Experimental values of ion mobility are available only for some ion-gas pairs in the electric field of moderate strength [6]. For necessary ion mobilities whose experimental values are not available, we have assumed that the charge exchange collisions are negligible for atomic ions in the foreign gas and thus, the ion mobility is governed by the elastic collision due to the polarization force. Then, the atomic ion mobility in a foreign gas is given by [7],

$$\mu \sim \frac{1}{\sqrt{M\chi}}, \tag{1}$$

where M is the reduced mass from masses of the ion and the gas atom and χ is the polarizability of the gas atom. Now, we can determine ion mobilities experimentally unknown, using experimentally available values and the above equation (1). The obtained ion mobilities are given in Table 1.

Mobilities of ions in a mixture can be calculated using the so-called Blanc's equation. For example, the mobility of Ne^+ in the mixture of He-Ne-Xe is given by [3],

$$\frac{1}{\mu_{He-Ne-Xe}} = \frac{a}{\mu_{He}} + \frac{b}{\mu_{Ne}} + \frac{c}{\mu_{Xe}}. \tag{2}$$

Here, $\mu_{He\text{-}Ne\text{-}Xe}$ is the mobility of Ne^+ in the mixture of He-Ne-Xe, μ_{He}, μ_{Ne} and μ_{Xe} are the mobilities of Ne^+ in pure He, Ne, and Xe gas, respectively. *a, b* and *c* are the respective mixture ratios. When the electric field is strong, it is well known that the drift velocity of ions is no longer proportional to the electric field. Thus, the value of the mobility in the strong electric field is to be corrected by employing Frost's formula [7],

$$\mu = \mu_0 / (1 + A\,|E|\,/\,p)^{1/2}, \qquad (3)$$

where the low field ion mobility μ_0 and the coefficient A are given in Table 1, E is the electric field, and p is the gas pressure.

Table 1. Low field ion mobilities in unit of $cm^2/V\cdot\sec$ (at 760 Torr, 300 K). Values of the coefficient A included in Frost's formula are in parentheses for each base gas in unit of $Torr\cdot cm/V$. Values with subscript a and b are from Ref. 6 and Ref. 7, respectively, and those with subscript c are calculated using the Eq. (1).

	He^+	Ne^+	Xe^+
He (0.04)	10.8^a	16.7^a	18.1^b
Ne (0.04)	16.0^a	4.2^a	5.7^c
Xe(0.012)	3.66^c	1.72^c	0.6^a

Our two-dimensional fluid simulation code for an AC-PDP cell consists of a set of continuity equations for electrons, ions, and excited species, Poisson's equation for the electric field, and momentum transfer equations in drift diffusion approximation. In order to perform simulations for the He-Ne-Xe gas mixture, we have added necessary reaction equations for the He gas to the previous two-dimensional fluid simulation code for the conventional Ne-Xe mixture. Most of the reaction rate coefficients for He related reactions employed in this work of the He-Ne-Xe mixture are assumed to be the same as those for Ne related reactions of the Ne-Xe gas mixture used in Ref. 1. A few rate coefficients for He should be increased and were fitted in order to get more reasonable VUV emission spectra when the He content changes [5]. More details on the physical model and numerical method can be found in Ref. 5 and references therein.

Figure 1 shows the structure of a coplanar color AC-PDP, which consists of two substrates - front and back glass substrates. The geometrical parameters of a typical 42" XGA PDP were used in the simulation. The reference discharge gas mixture is the Ne-Xe10% at 500 Torr and the He atoms are added and the He concentration is varied to see the corresponding effect. In the present two-dimensional simulation, a 10-μm grid size was used in both x- and y-directions. The applied voltage pulses for the simulation are squared pulses as shown in Fig. 2. The first one or two pulses are higher than the following sequence of sustain pulses to breakdown the discharge. Notice that a half of the sustain voltage is applied to the address electrode so that it can simulate a floated address electrode, which is the condition used in the usual measurement of a test panel.

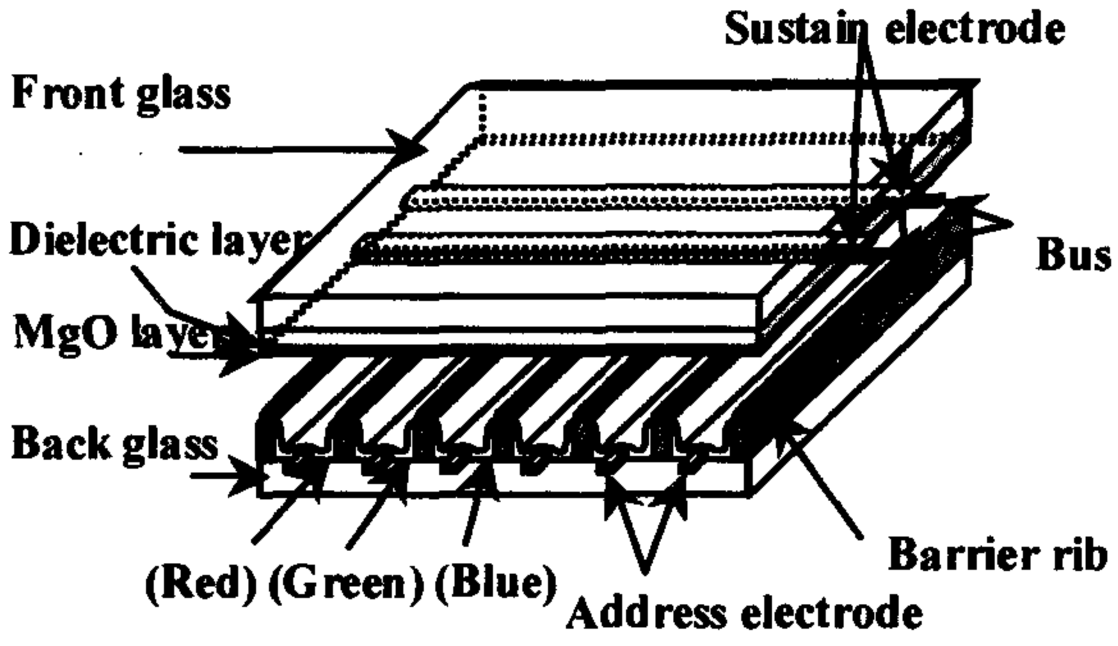

Figure 1. Schematic diagram of a coplanar color AC-PDP structure.

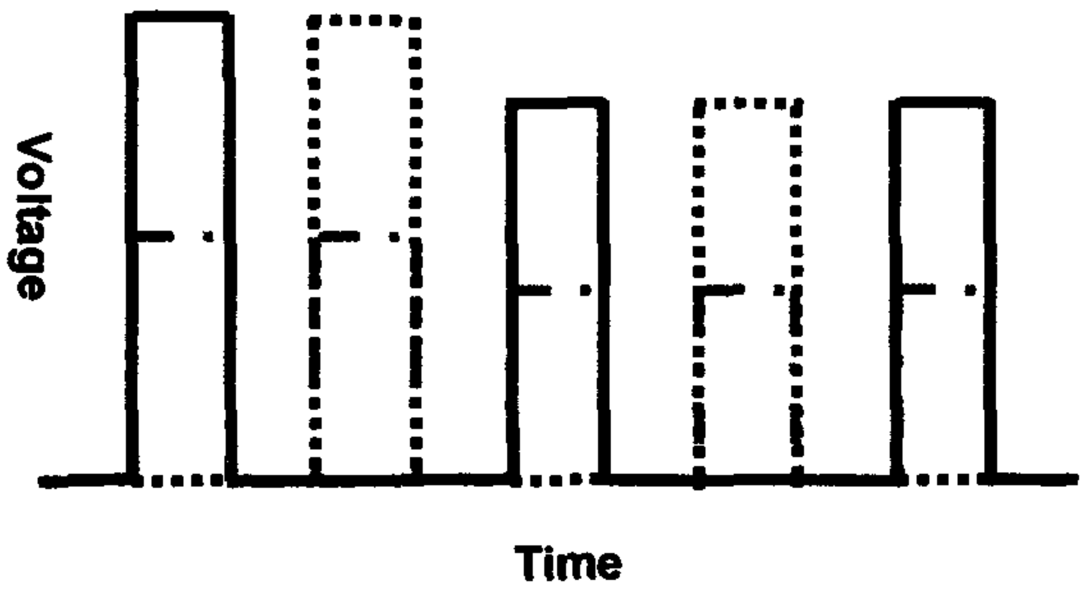

Figure 2. Applied voltage pulses for the simulation. The solid and dotted lines represent the squared pulse applied to the scan and sustain electrodes, respectively, and the dash-dotted line indicates the voltage pulse to the address electrode.

3. Results and discussions

In Table 1, notice that the Ne ion mobility (4.2) is much lower than that of the He ion mobility (16.0) in the Ne gas even though the mobility of Ne ion (16.7) is higher than that of the He ion (10.8) in the He gas. This is due to the fact that the charge exchange cross section of an atomic ion is very large in the parent gas.

As the reduced mass of the ion-gas pair becomes large, the ion mobility in the foreign gas gets lower in Table 1 as one can expect from Eq. (1). We have calculated field-dependent ion mobilities in their parent gas and in the He-Ne-Xe gas mixture by using Eq. (2) and Eq. (3) with the values of μ_0 and A given in Table 1. The results are shown in Fig. 3.

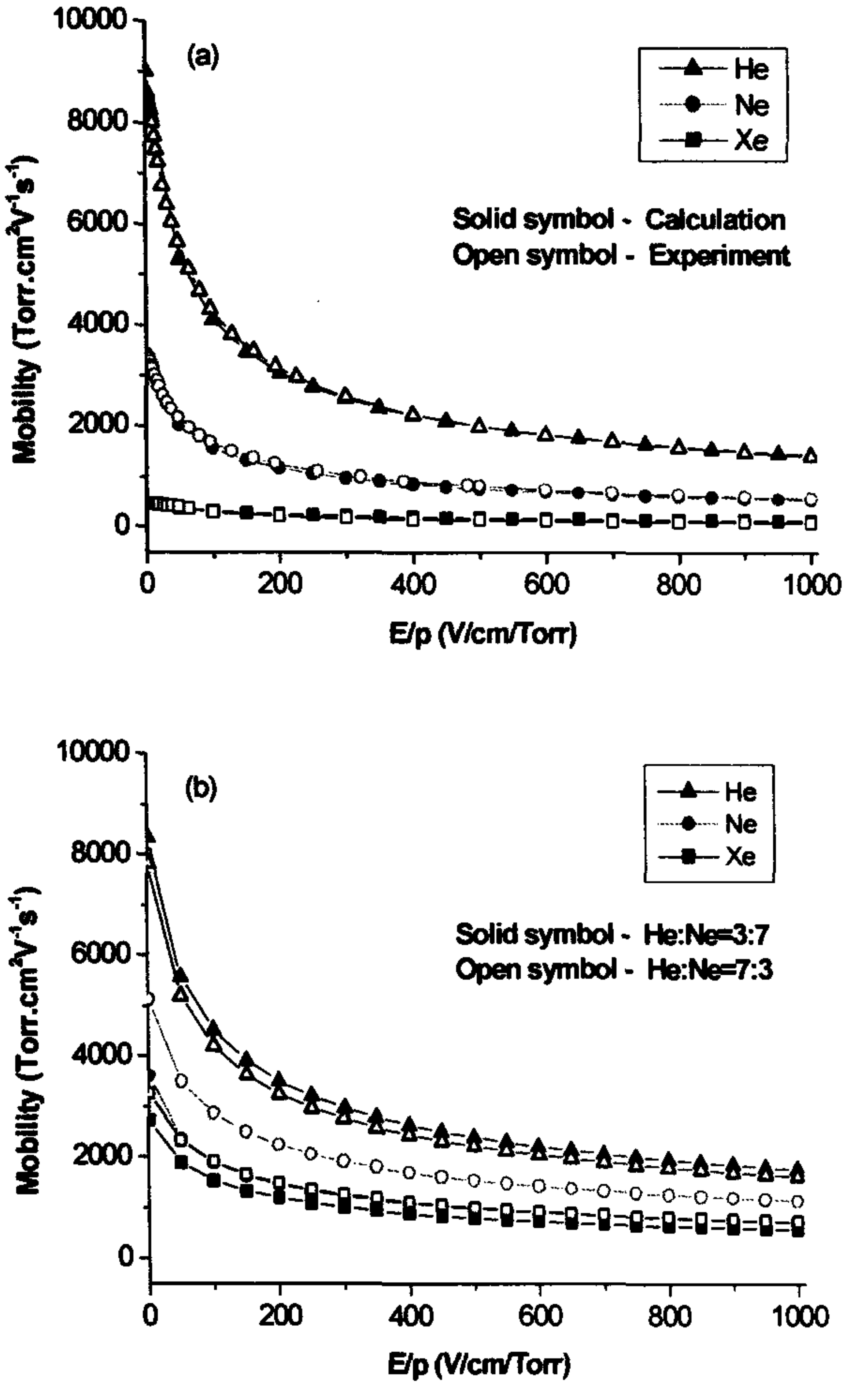

Figure 3 Calculated field-dependent mobilities of He^+, Ne^+ and Xe^+ in (a) their parent gas and in (b) the He-Ne-Xe10% mixture gas.

As shown in Fig. 3(a), our calculated ion mobilities in their parent gas are in good agreement with their experimental values given in Ref. 1. In the three species gas mixture He-Ne-Xe10%, mobilities of Ne^+ and Xe^+ are enhanced in Fig. 3(b), compared with the corresponding ion mobilities in the parent gas as shown in Fig. 3(a). As the He atoms are added to the Ne-Xe mixture, the mobilities of Ne^+ and Xe^+ increase while the mobility of He^+ decreases. Even though there is no guarantee that our method of calculation generates the correct values of field-dependent ion mobility in this three species mixture because experimental ion mobilities in this gas mixture are not available, most of the changes shown in Fig. 3 are acceptable on the basis that the charge exchange collision of an ion becomes more active as the partial pressure of the parent gas increases and vice versa.

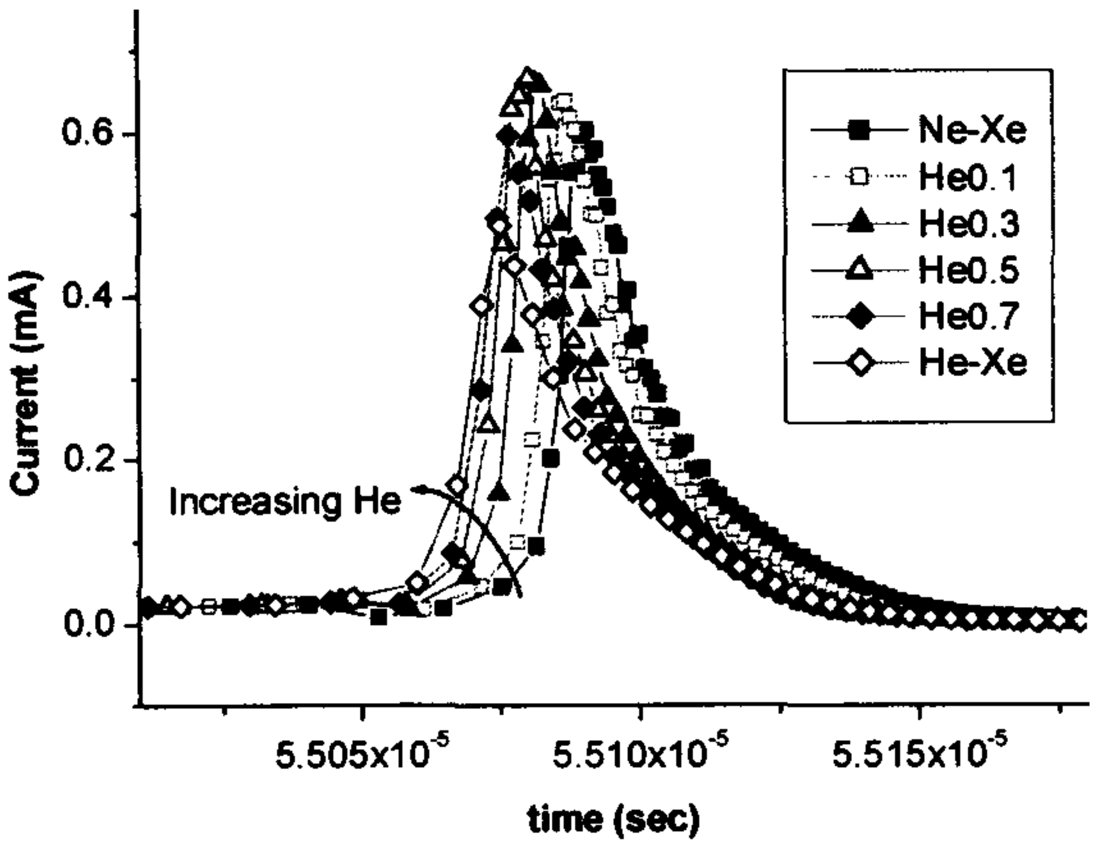

Figure 4. Discharge current shape for various He contents in the (He_x-Ne_{1-x})-Xe10% gas mixture at 500 Torr, at the given voltage of 240 V.

Figure 4 shows the dependence of the discharge delay time on the He concentration in the (He_x-Ne_{1-x})-Xe10% gas mixture at the given voltage of 240 V. The delay time depends on the positive ion drift velocity at the first stage of discharge formation [8]. As the He concentration increases, the ion mobilities in the mixture gas, especially for Ne^+, increase as shown in Fig. 3(b). This would result in the quicker breakdown in the He-Ne-Xe mixtures with higher He content. The corresponding experimental measurements are given in Ref. 8, which are in good agreement with our calculation shown in Fig. 4.

We have seen the discharge characteristics critically depend on ion mobilities in the discharge gas mixture [5]. In general, higher ion mobilities result in higher efficiencies. Using ion mobilities in Table 1, our simulation results show that the addition of He gas to the conventional gas mixture Ne-Xe results in the increase of efficiencies as shown in Fig. 5, which agrees well with experimental results [3, 5]. The enhanced ion mobilities by adding He atoms to the mixture play an important role in increasing efficiency. However, with ion mobilities which Rauf *et al.* [4] have used for their simulation, we have obtained the same results to theirs that is, luminous efficiencies get lower with the increasing He concentrations. Their Ne^+ mobility is higher than that of the He^+ in the Ne gas. Thus, the luminous efficiency was reduced with the increasing He content just as in Ref. 4, which tells that the ion mobility affects greatly on discharge and luminous characteristics as we have mentioned above. Note also that the discharge delay time would not become shorter with the increased He content, with the ion mobility values that Rauf *et al.* have used.

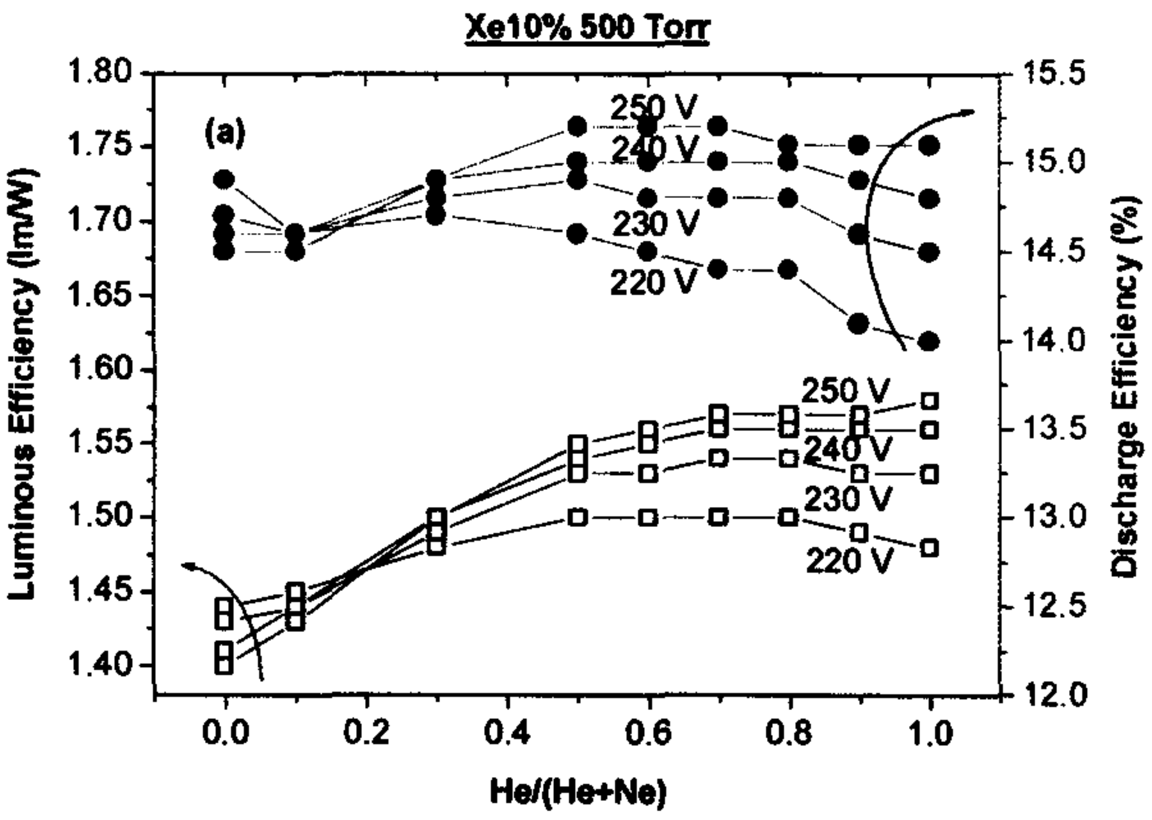

Figure 5. Simulation results on discharge and luminous efficiency of a 42" XGA PDP cell sustained in the (He_x-Ne_{1-x})-Xe10% gas mixture at 500 Torr.

4. Conclusion

We have examined the influence of ion mobilities on discharge characteristics, by performing simulations of an AC-PDP with the three species He-Ne-Xe gas mixture. First, we have discussed how to determine ion mobilities in the three species gas mixture, using the available experimental values. We have calculated field-dependent ion mobilities for various gas conditions and discussed how mobilities of ions in the three species gas mixture He-Ne-Xe are affected by adding He atoms to the conventional Ne-Xe discharge gas mixture.

In order to perform simulations for the He-Ne-Xe gas mixture, we have added necessary reaction equations for the He gas to the previous two-dimensional fluid simulation code for the Ne-Xe mixture [5]. A few rate coefficients for He were fitted in order to get more reasonable VUV emission spectra when the He content changes. We have successfully reproduced discharge and luminous characteristics, which are in good agreement with the experiments. Our results show that the addition of He to the Ne-Xe mixture leads to higher efficiency. The enhanced mobilities of ions by adding He atoms to the Ne-Xe gas mixture play an important role in increasing efficiency. Our simulation results have also shown that the discharge delay time becomes shorter with the increased He content, which is in good agreement with the experimental findings. As far as we know, our present work is the first simulation results that qualitatively agree with the experimental results on the discharge delay time and the efficiency with the He content sustained in the He-Ne-Xe mixture gas, which can be very useful in understanding discharge and luminous characteristics of (He_x-Ne_{1-x})-Xe mixtures and in developing high luminous efficiency AC-PDP using this three species mixture gas.

5. References

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