The Analysis of the He-Ne-Xe Gas Discharge Characteristics in an AC Plasma Display Panel by Two Dimensional Simulation

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Abstract

We examined (He_x-Ne_{1-x})-Xe gas discharge in an AC PDP cell by computer simulation to understand the gas mixing effects. The breakdown and sustain voltage were significantly lowered with the addition of Ne into He-Xe. The luminance and efficiency in (He_x-Ne_{1-x})-Xe also improved when compared with the He-Xe or Ne-Xe gas mixture. The luminance is maximum around 30~40% He addition, while the efficiency shows peak values at 70% He. Two-dimensional numerical simulation was done to explain these results.

Introduction

Plasma display panel (PDP) is one of the promising candidates for a large area flat panel display[1]. But it needs to improve the luminance and luminance efficiency. In this paper, we focused our concern on the gas mixing effect with respect to the improvement. A gas adopted for the application of PDP must basically satisfy four conditions: low driving voltage, good color purity, high luminance and efficiency, low sputtering yield. At early time of PDP research the use of mercury (Hg) vapor was examined, since it is widely used as an UV source in fluorescent lamps. However, in order to achieve high radiant intensities of UV light with Hg, the discharge panel must be heated to a relatively high temperature to obtain sufficient vapor pressure. This requirement is not practical for home-use display panels. Several molecular gases were also examined, such as H_2, D_2, CO, CO_2 and several kinds of Freons[2]. Each of these radiated stronger UV light than the rare gases under initial conditions, but these gases inevitably dissociated to monatomic form from the high energy electrons in the discharge, resulting in the gradual diminution of UV light.

Nowadays, He-Xe and Ne-Xe gas mixtures are usually used as the discharge gases. He-Xe mixture has a good color purity and fast response time, but its driving voltage is high and the lifetime of panel is short due to the high mobility of Xe ion in He gas. On the contrary, Ne-Xe mixture has a low driving voltage, high luminance and long panel lifetime but bad color purity. We suggested the He-Ne-Xe gas mixture to compensate the demerits of He-Xe and Ne-Xe mixture gases[3]. He-Ne-Xe gas mixture showed higher luminance and efficiency than Ne-Xe and He-Xe, but the exact mechanism has been unknown.

In this paper, we will explain the discharge characteristics of He-Ne-Xe gas mixtures such as the driving voltage, luminance and efficiency by 2 dimensional numerical simulation.

Description of the Simulation Model

The model equations consist of Poisson's equation, continuity and momentum equations. We assumed the local field approximation, therefore, the ionization and excitation rates are function of the local field. The continuity equation is solved using Scharfetter-Gummel method[4] to follow the dynamics in an ac PDP. The mobility and diffusion coefficient for ions and neutral species do not change significantly, thus constant values were used for the mobility and the diffusion coefficient of ion and neutral species.

The boundary flux for each neutrals species j is defined as $\Gamma_j = n_j v^{th}_j/4$, where v^{th}_j is the thermal velocity for the neutral species. Charged species have two components to the boundary flux, i.e. a drift flux due to the electric field and a diffusion flux. For the ion species j, $\Gamma_{+j} = a n_{+j} \mu_{+j} E + n_{+j} v^{th}_{+j}/4$ where v^{th}_{+j} is the thermal velocity of ion. a is set to 1 for charged particles only if the drift velocity is directed toward the wall and zero otherwise. In the case of electron, $\Gamma_e = -a n_e \mu_e E + n_e v^{th}_e/4 - \gamma_j \Gamma_{+j}$ where v^{th}_e is the thermal velocity of electron. γ_j is the secondary electron emission coefficient for the ion species j.

Results and Discussion

Figure 1 shows the firing and sustaining voltage curve as a function of He/Ne mixing ratio. The driving voltage of Ne-Xe gas mixture is lower than that of He-Xe. A slight addition of Ne gas to He-Xe mixture reduces abruptly the driving voltage.

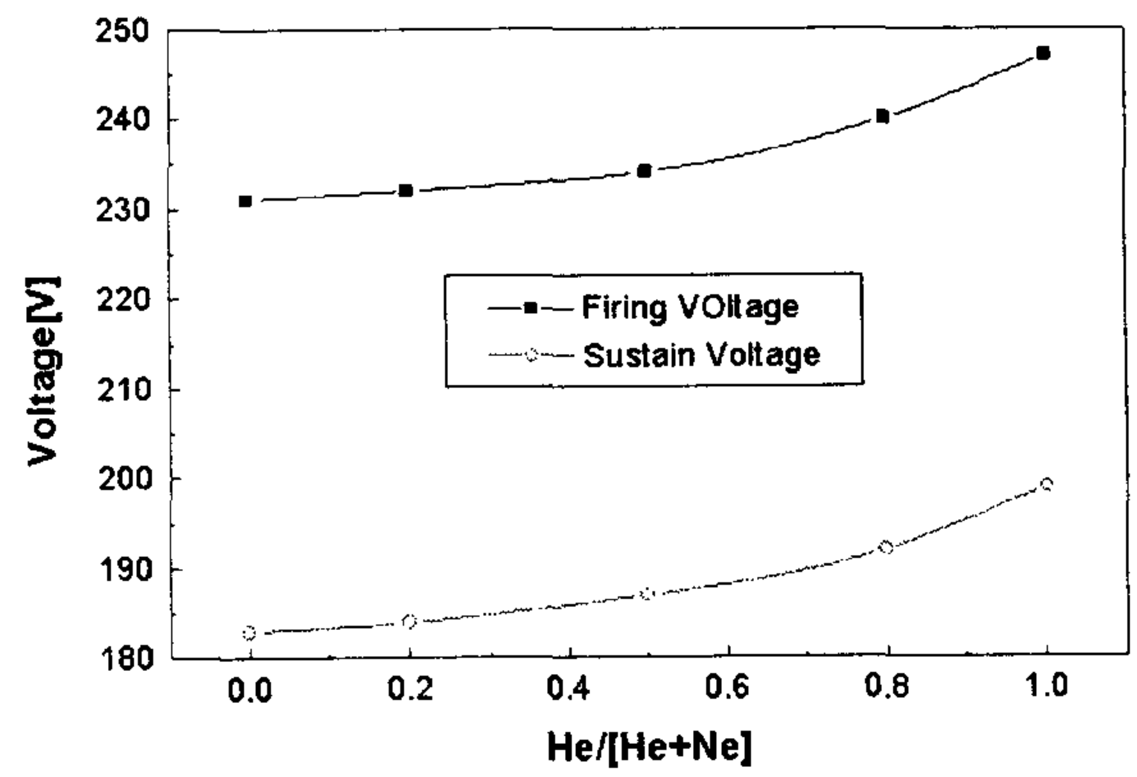

Figure 1. Firing and sustain voltage at He-Ne-Xe(5%).P=400Torr

According to Townsend's theory, the driving voltage is determined by α (Townsend's coefficient for ionzation) and γ (secondary electron emission coefficient) process[5]. When an electric field is applied to the electrodes the electrons and ions move toward the anode and cathode, respectively. Ions reaching the cathode may produce secondary electrons when they strike the surface of the cathode. If the electric field is high enough, these electrons on their way toward the anode may produce additional electrons and ions by ionization cascades. If the number of ions produced in the cascade, initiated by any one of secondary electrons from the surface, exceeds the number of ions necessary to produce that one electron due to a secondary emission, then the current grows in time and a breakdown occurs. Equation (1) describes the condition for initiating a self-sustaining discharge.

The meaning of Equation (1) eventually represents how many secondary electrons can be emitted from the cathode. If α becomes higher, the firing and sustaining voltage decrease and the same for the γ value.

$$\gamma[\exp(\int_0^L \alpha dl) - 1] \geq 1 \qquad (1)$$

L : ionization path length

To investigate the effect of α and γ on the secondary electrons, we introduce two parameters, the effective γ (γ_{eff}) and secondary electron flux (Γ_{se}) from the cathode.

$$\gamma_{eff} = \frac{\Gamma_{se}}{\sum_i \Gamma_i} \qquad (2)$$

$$\Gamma_{se} : \sum_i \gamma_i \Gamma_i$$

i : Ion species

Γ_i : Boundary flux of ion to the cathode

In the mixture gas, several kinds of ions having different γ exist and their densities are determined by the discharge conditions: Xe partial pressure, total pressure and driving voltage. γ_{eff} is a useful parameter explaining the variation of Γ_{se} which determines the firing and sustain voltage.

Figure 2 shows the γ_{eff} and Γ_{se} from the cathode with the variation of He/Ne mixing ratio. γ_{eff} increases monotonously with the addition of He. But, Γ_{se} decreases above 60% He. At the same Xe partial pressure, the electron temperature of He-Xe gas mixture is lower than that of Ne-Xe due to the higher elastic collision cross section at the voltage used in PDP. Therefore, ionization rate in Ne-Xe discharge is higher than that in He-Xe. But, γ value of Ne ion is lower than that of He ion and it causes the increase of γ_{eff} with the addition of He. In spite of small γ_{eff}, Γ_{se} in Ne rich gas is larger than that in He rich gas. It means that the ionization is easily occurred in Ne rich gas and then the boundary flux of ions to the cathode is increased. Large Γ_{se} in Ne rich gas results in low firing and sustaining voltage.

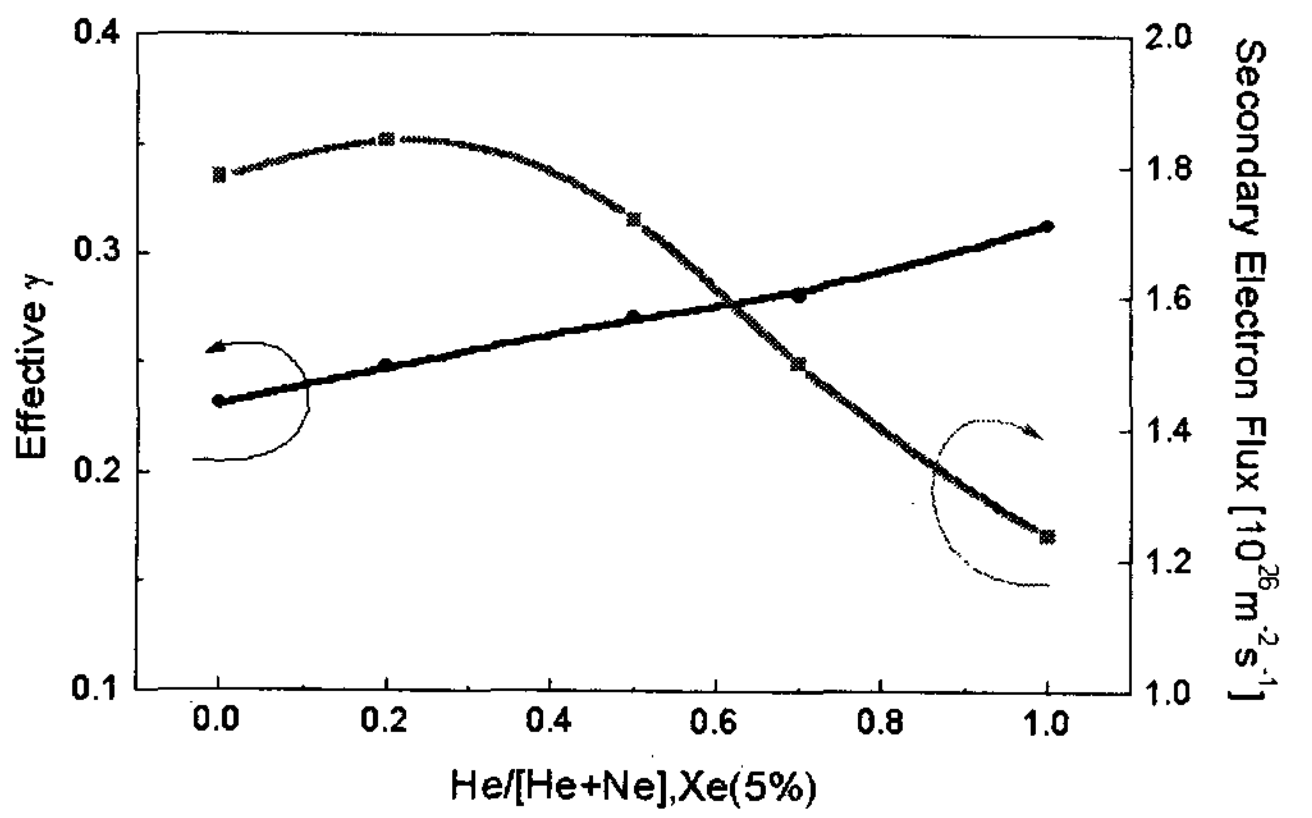

Figure 2. Effective γ and secondary electron flux from He-Ne-Xe(5%) discharge. P=400Torr

Besides the driving voltage, the luminance and efficiency are important parameters in the PDP. The luminance and efficiency sensitively depend on the gas composition.

Figure 3 shows the efficiency and the VUV output energy related with the luminance of the (He_x-Ne_{1-x})-Xe gas mixture. The operation voltage is 210V and 83.3kHz. The efficiency is highest at the 70% He addition. But, the VUV output energy has a maximum in the range of 20~40% He addition. With the increase of Ne, the electron temperature increases. It causes that the electrons mainly spend their energy on the ionization process rather than excitation. As a result, the efficiency is decreased with the addition of Ne. Above the 70% He, however, the driving voltage is increased and a small discharge occurs and confined around the gap compared with the Ne rich gas. During the discharge, high electric field is established in the front of the cathode and low electric field in the front of the anode. The VUV is emitted from the cathode and anode and the emission from the anode is more efficient than that from the cathode. Above 70% He addition, the discharge path is short and the efficient discharge region is smaller than that of Ne rich gas. This cause the low efficiency above 70% He addition. The luminance is closely related to α and γ process and the efficiency. From the secondary electron flux in figure 2, we can infer that the ionization is efficient at 20% He, therefore electron density is high. The high electron density will lead to high luminance. However, As the Ne content increases, the efficiency decreases. Hence, the luminance shows the characteristics as shown in figure 3.

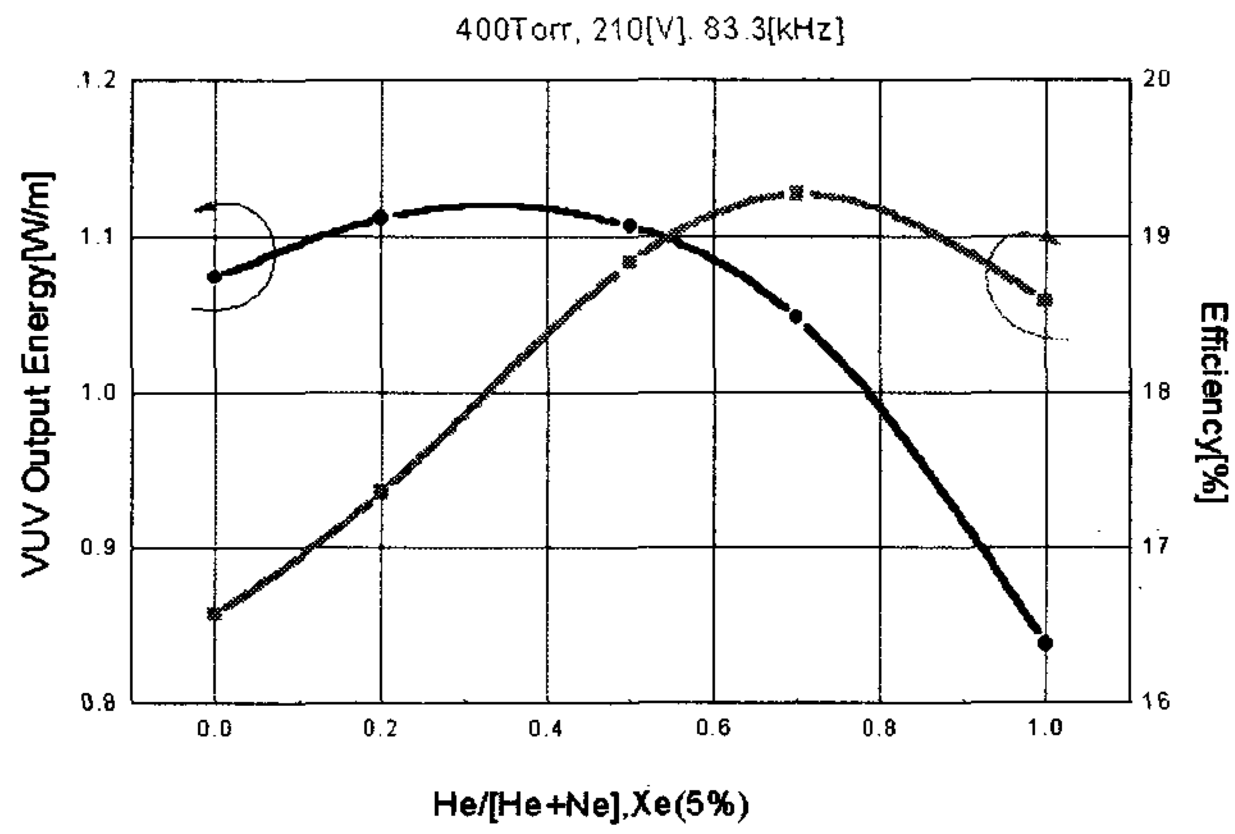

Figure 3. The VUV output and efficiency from He-Ne-Xe(5%) discharge. P=400Torr

Conclusion

The breakdown and sustain voltage is significantly lowered with the addition of Ne into He-Xe. The luminance and efficiency in (He_x-Ne_{1-x})-Xe is improved compared with He-Xe and Ne-Xe gas mixture. The luminance is maximum around 30~40% He addition, while the efficiency shows peak values at 70% He.

And these results could be well explained by the 2-dimensional simulation model.

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