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# Analysis of Energy Flow and Barrier Rib Height Effect using Ray-Optics Incorporated Three-dimensional PDP Cell Simulation

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## Abstract

Using ray-optics code incorporated with three-dimensional PDP cell simulation, we have analysed the energy flow in the PDP cell from the electric power input to the visible light output. Also, the visible light output profile and viewing angle distribution were obtained. We applied our code to the analysis of the barrier rib height effect on the visible light luminance and efficiency of the sustaining discharge. Although cells with higher barrier rib generate more VUV photons, less ratio of visible photons are emitted toward front panel due to the shadow effect. Thus, there exists optimal barrier rib height giving the highest visible luminance and efficiency. This kind of code can be a powerful tool in designing cell geometry.

**Keywords** : plasam display panel, VUV, visible efficiency

## 1. Introduction

Plasma display panel(PDP) is one of the promising flat panel display devices with size larger than 40-inch diagonal. A commercially successful PDP needs to be further improved with respect to luminance and luminous efficiency. To achieve such improvements, a thorough understanding is necessary of the factors that affect the luminance and efficiency. But it is not easie to obtain such information by experiment because the discharge in the PDP cell is too small to be diagnosed directly. For these reasons, computer simulation models have been developed and applied to the analysis of the discharge characteristics in the PDP cell.

In recent years, 2D and 3D simulations have well shown the discharge dynamics occurring in a PDP cell, and have begun to be applied to the analysis of the geometrical parameter effects on the discharge characteristics. In the analysis of the geometrical parameter effects, the most important discharge characteristics are the luminance and efficiency of the visible light. Because the PDP uses the VUV(Vacuum Ultra-Violet) generated by gas discharge to excite phosphor for visible light emission, there are two factors that affect luminance and efficiency. The first factor is the VUV generation, and the second factor is the transport of the visible light from phosphor to front panel. But most PDP cell simulations have given luminance and efficiency in terms of the VUV (Vacuum Ultra-Violet) or in terms of the visible light limited in 2D case[1-5]. Thus, there is a need to consider the transport of visible light in 3D geometry for the proper geometrical study, and we have developed the ray-optics code to deal with the transport of visible light, and combined this code with

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3D discharge code.

In this paper, we obtained luminance and efficiency of the visible light using 3D PDP cell simulation including a ray-optics code. First, we analysed the energy flow in the PDP cell from the electric power input to the visible light output. Also, the visible light output profile and viewing angle distribution were obtained. As the first step of the geometrical study, we applied our code to the analysis of the barrier rib height effect on the visible light luminance and efficiency of the sustaining discharge.

## 2. Simulation Conditions

The discharge model equations consist of Poisson, continuity and drift-diffusion equations. We assumed a local field approximation (LFA), where the ionization and excitation rates are functions of the local field. The detailed model equations and kinetic reactions are described in the previous paper[4].

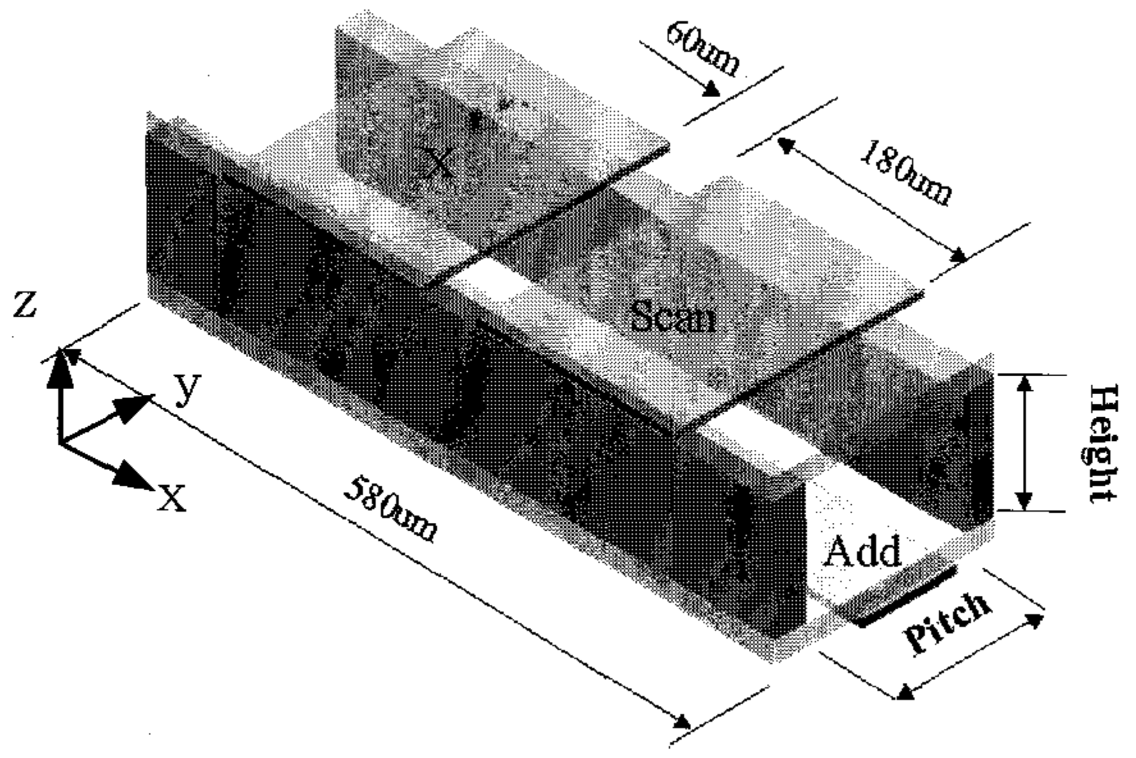


**Fig. 1.** Schematic of the PDP Cell.

Fig. 1 shows the schematic of the PDP cell used in this simulation. The cell has a barrier rib height of 140 μm, 20 um phosphor thickness of and cell pitch of 280 μm. The discharge gas condition is Ne/Xe 5 % and 300 torr. For the energy flow analysis, we used 205 V as the sustain voltage. And the parametric study was done for 100, 120, 140, and 160 μm rib height cases.

Phosphors are deposited on rear plate that has two kinds of surfaces, which are side surfaces of barrier ribs and bottom surface between barrier ribs. We refer to these two kinds of phosphor surfaces as side phosphor and bottom phosphor. In cenerall the side phosphor is not vertical and has some slopes. In this simulation, the side phosphor is assumed to have 20° deviations from the vertical.

First, we obtained 3D spatial VUV(147 nm, 150 nm, 173 nm) distributions integrated over one sustain pulse having 1.5 μsec duration from 3D discharge simulation, and fed those into the ray-optics code, where the VUV distributions on phosphor surfaces are calculated with the assumption that the VUV photon emission is isotropic. The obtained VUV photons on phosphor surfaces are converted in to visible photons using corresponding UV-visible photon conversion efficiency, and then, the visible light output to the front panel is calculated using the ray-tracing techniques. Here, we assume that phosphor emission is isotropic in all direction.

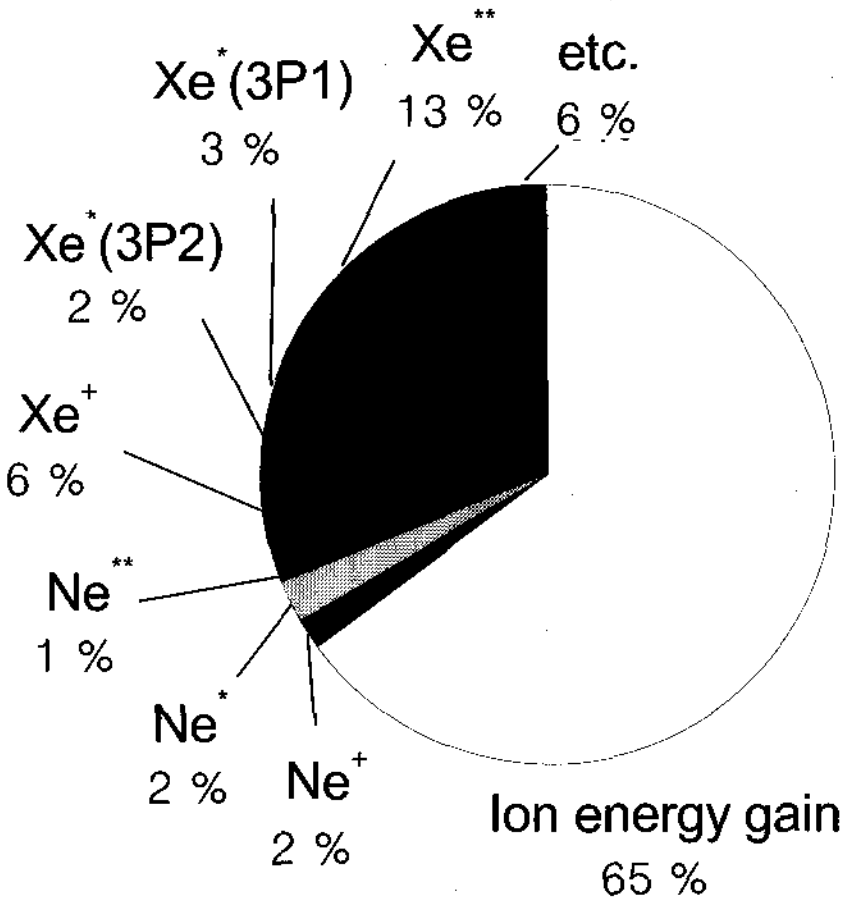


**Fig. 2.** Energy loss channel of electron and ion.

## 3. Energy Flow Analysis

Fig. 2 shows the energy usage channel of electron and ion energy during one sustain pulse-on time. The electric field deposits power to charged particles during the discharge. The power deposited to ions cannot be used to generate excited species, and only a fraction of the power deposited to electron can be used to generate excited species that emits VUV. Ions consume 65 % of the total deposited power, and this is due to their long stay in the discharge volume and acceleration by high electric field region, cathode fall. Even ions generated in low field region are inevitably accelerated through cathode fall, while electrons in low field region do not suffer cathode fall. Thus, ions consume more power than electrons. According to our simulation results, electrons consume 35 % of the total deposited power, and the excitation efficiency was calculated to be 18 %. The 47 % of the energy deposited to Xe excited species was used to emit VUV during sustain pulse-on time, and thus, the VUV efficiency in energy was calculated to be 8.5 % from 3D discharge cell simulation.

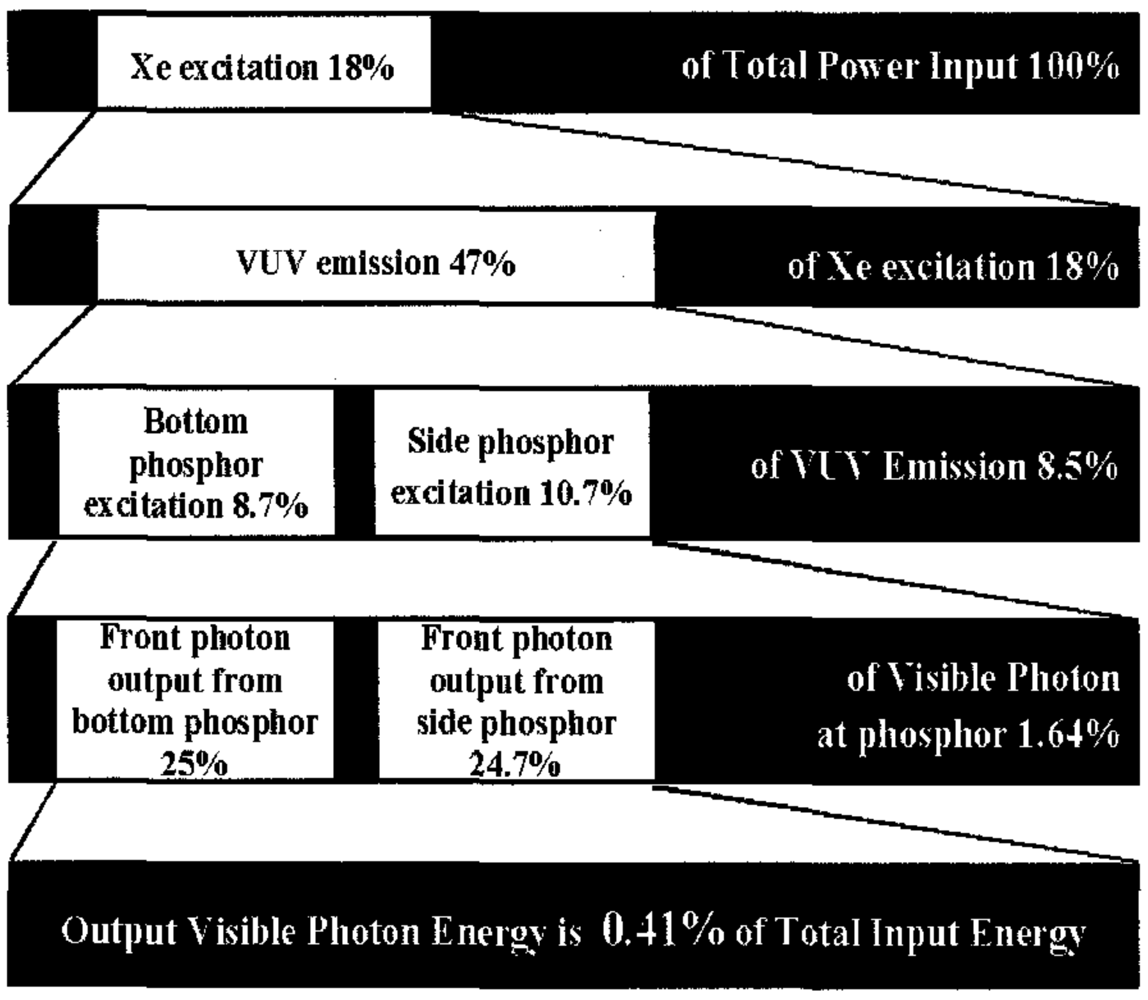


**Fig. 3.** Energy flow.

Fig. 3 shows the energy flow diagram from the electric power input to the visible photon power output in case of 140 μm rib height with 205 V sustain voltage condition. Among VUV photons generated during the discharge, 32 % of those reach the side phosphor, and 24 % reach the bottom phosphor. With the UV-visible photon efficiency in energy to be assumed as 0.3267, 0.3333, 0.3844 for 147 nm, 150 nm, 173 nm VUV, respectively (These values are obtained with the assumption that one VUV photon at phosphor generates one 450 nm visible photon), the 10.7 % of the total VUV energy is used to generate the visible photons on the side phosphor, and the 8.7 % on the bottom phosphor. This means that only 1.64 % of the total electric power input is used to generate visible photons. Furthermore, only 24.7 % of the visible photons emitted from the side phosphor go out through the front panel, and so do the 25 % of the photons from the bottom phosphor. Thus, the total visible photon output power is 0.41 % of the total input power, where the contribution of the side phosphor is 0.23 %, and that of the bottom phosphor is 0.18 %.

Figs. 4(a) and (b) show the visible photon profiles at the bottom and the side phosphor surfaces. These represent the profiles of the VUV photons arriving at the phosphor surfaces and the starting visible photon profiles at the phosphor surfaces. Only a portion of the photons starting at phosphor can escape through the front panel. The photons emitted at the bottom phosphor suffer the hindrance of barrier ribs, and the escape ratio of the photons at side phosphor strongly depends on the side phosphor slope as a matter of fact. As the slope deviates from the vertical, the more photons can go out through front panel. But, this may cause a decrease in discharge volume, which in turn, decreases VUV generation.

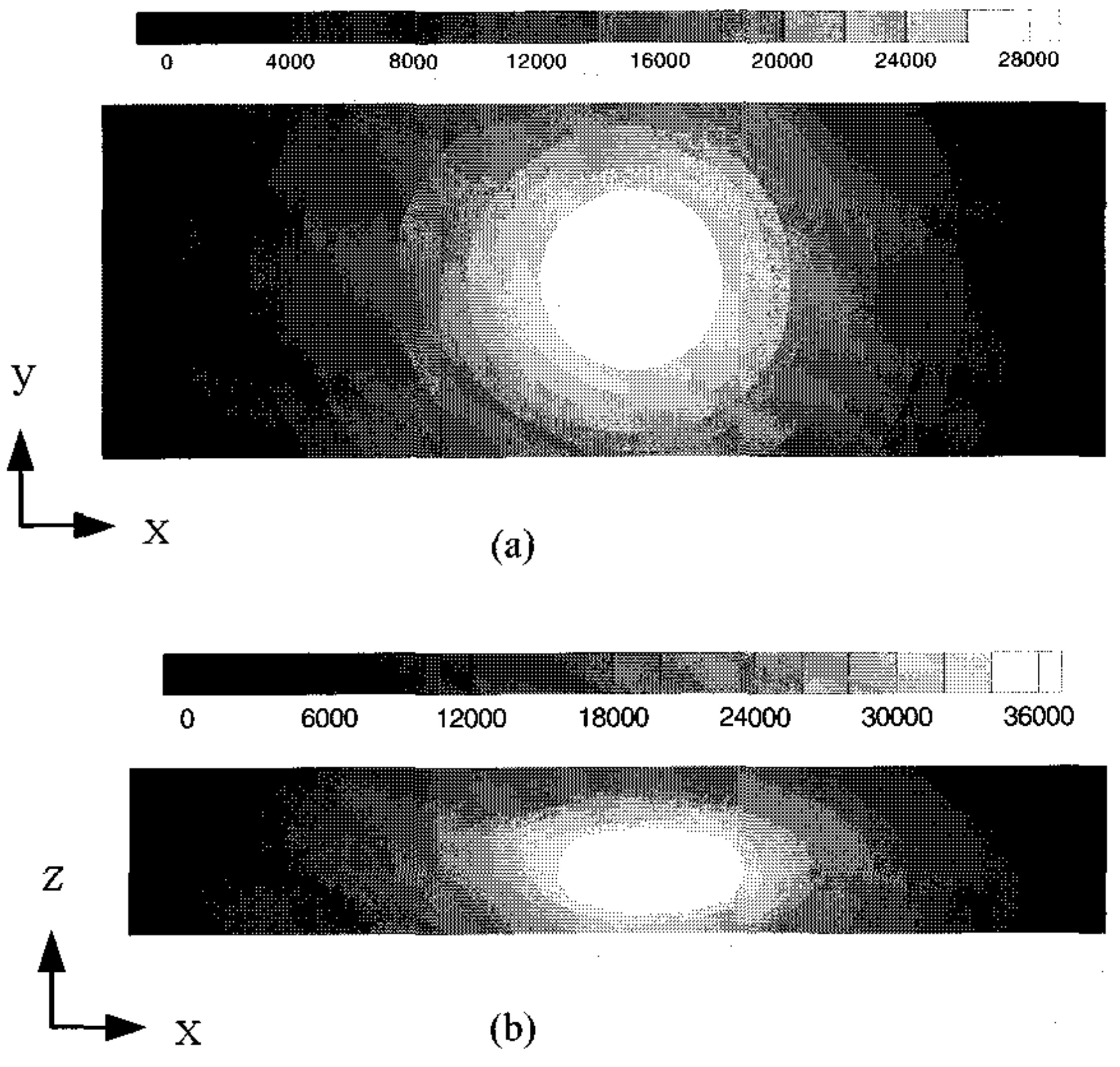


**Fig. 4.** Photon distribution at (a) bottom and (b) side phosphor surface (Units : photon # /100 μm$^2$)

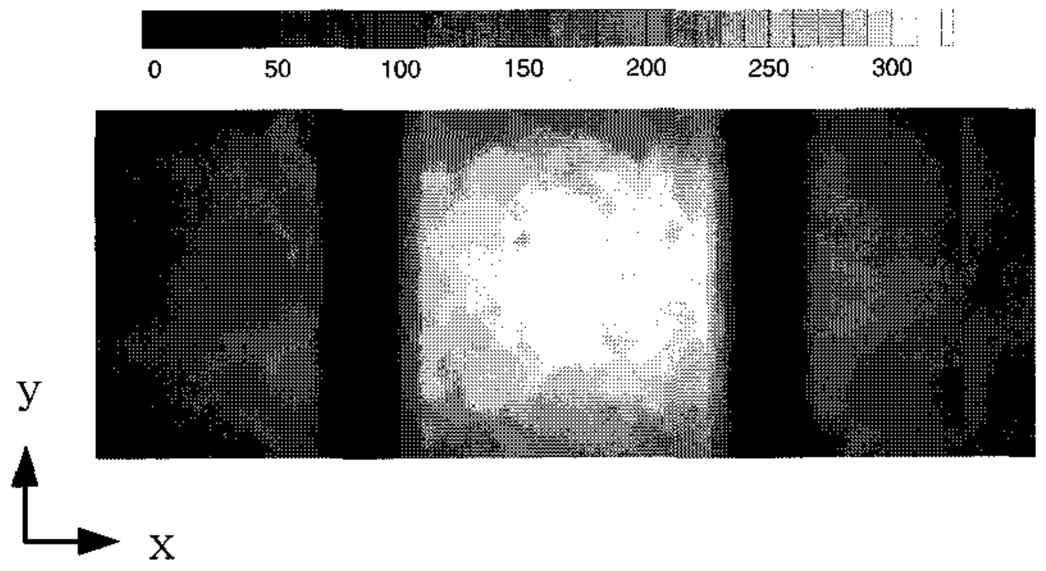


**Fig. 5.** Output photon distribution (Units : 50 photon # /100 μm$^2$)

The front output photon profile is obtained at the surface of the 10 μm front glass thickness to cover all visible photon output, and is shown in Fig. 5. The shading of the visible photons by 50 μm width bus electrode is clearly seen. We plotted the viewing angle distribution in Fig. 6. From this figure, it is found that rather uniform angle distribution is obtained up to 80°(θ), except 70°(θ) of up and down(±90° of ϕ). Such high angle distributions at 70°(θ) and ±90° of ϕ are due to the side phosphor slope at barrier ribs having 20° deviations from the vertical. This may not be the real case, because the real side phosphor surface is not a plane and has some gradual slope variation toward the bottom surface. Nonetheless, Fig. 6 shows clearly the wide viewing-angle characteristics of the PDP cells.

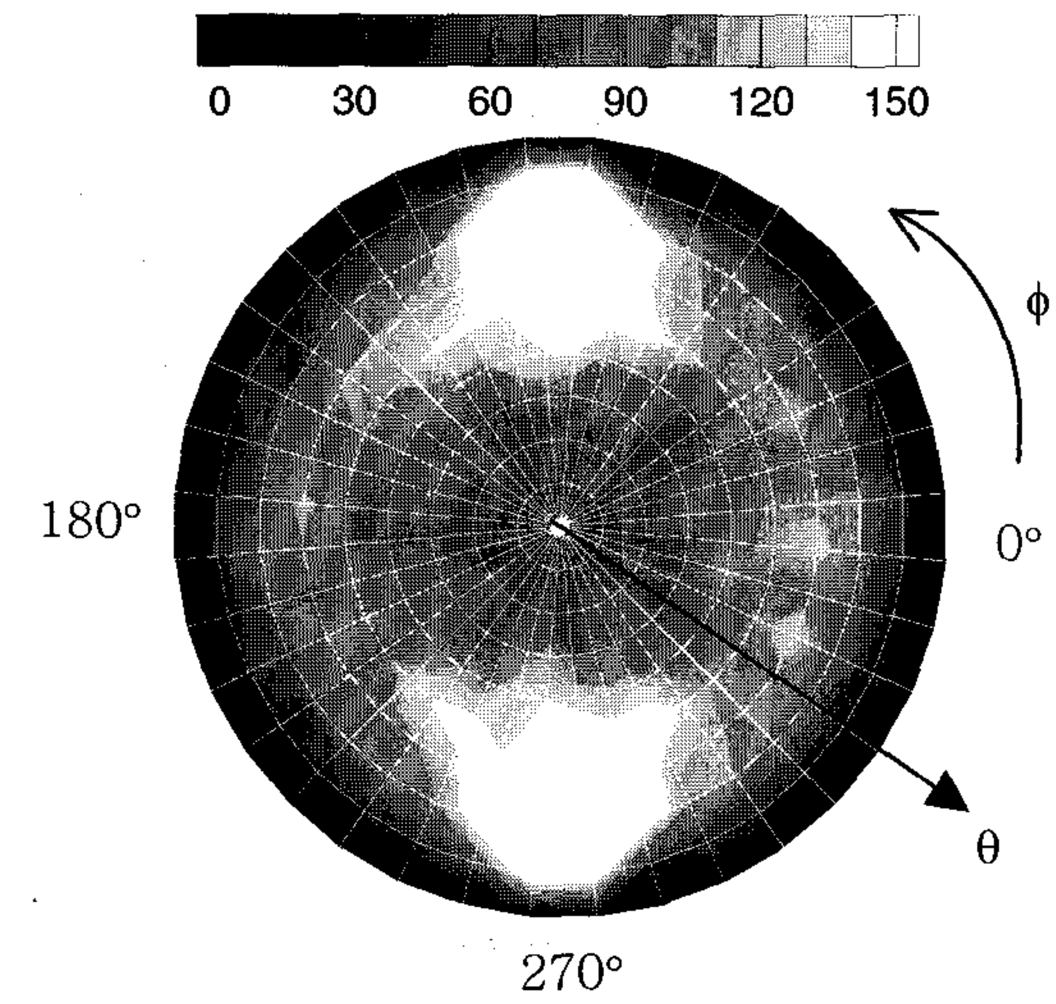


**Fig. 6.** Viewing angle distribution (ϕ, θ : spherical coordinate)

## 4. Barrier Rib Height Effect

The sustaining discharges are strongly affected by the barrier rib height. Because the barrier rib height has a direct correlation to the possible volume of the discharge, lower barrier rib hinders the formation of sustaining discharge, resultsing in the increase of stable sustain discharge voltages. Fig. 7 shows the sustain voltage range variation according to barrier rib height. As the rib height increases, the minimum and maximum sustain voltage decrease.

Fig. 8 shows the luminance and efficiency dependence on sustain voltages for various barrier rib heights in terms of VUV(Fig. 8(a)) and visible light(Fig. 8(b)), where the curves of each barrier rib height are plotted for corresponding sustain voltage range. Because of the different sustain voltage ranges, careful interpretation should be given to figures. For example, we can compare the barrier rib height effect on the luminance and efficiency with the same sustain voltage or the same luminance output condition. Or we can compare those at the middle value of each sustain voltage range, which is plotted in Fig. 6 where 220, 210, 204, and 200 V sustain voltage were used for 100, 120, 140, and 160 μm rib, respectively.

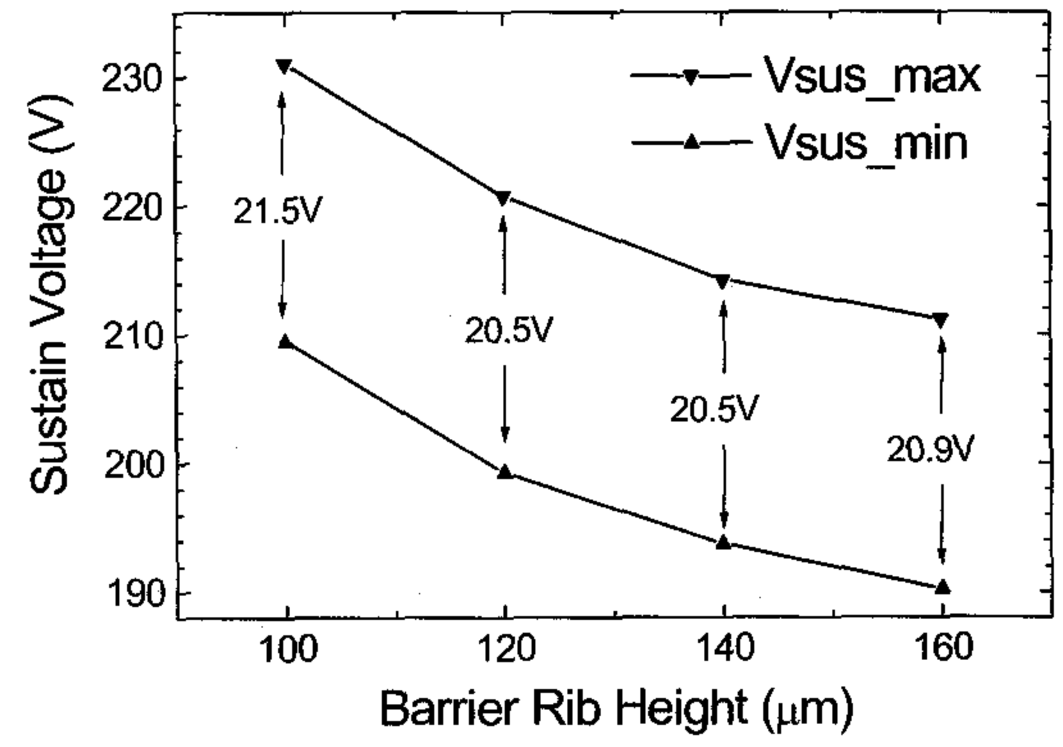
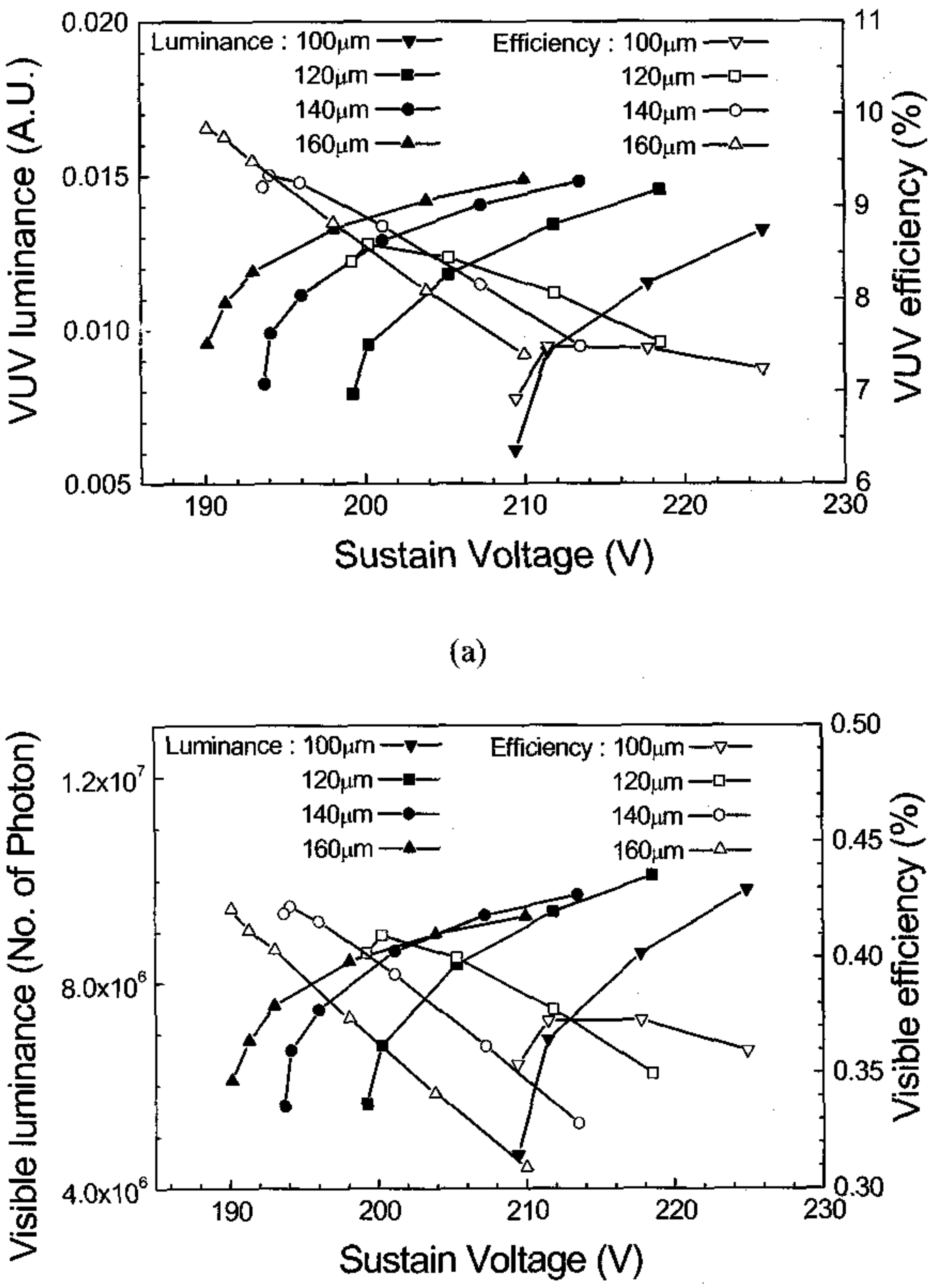


**Fig. 7.** Sustain voltage ranges according to barrier rib height.

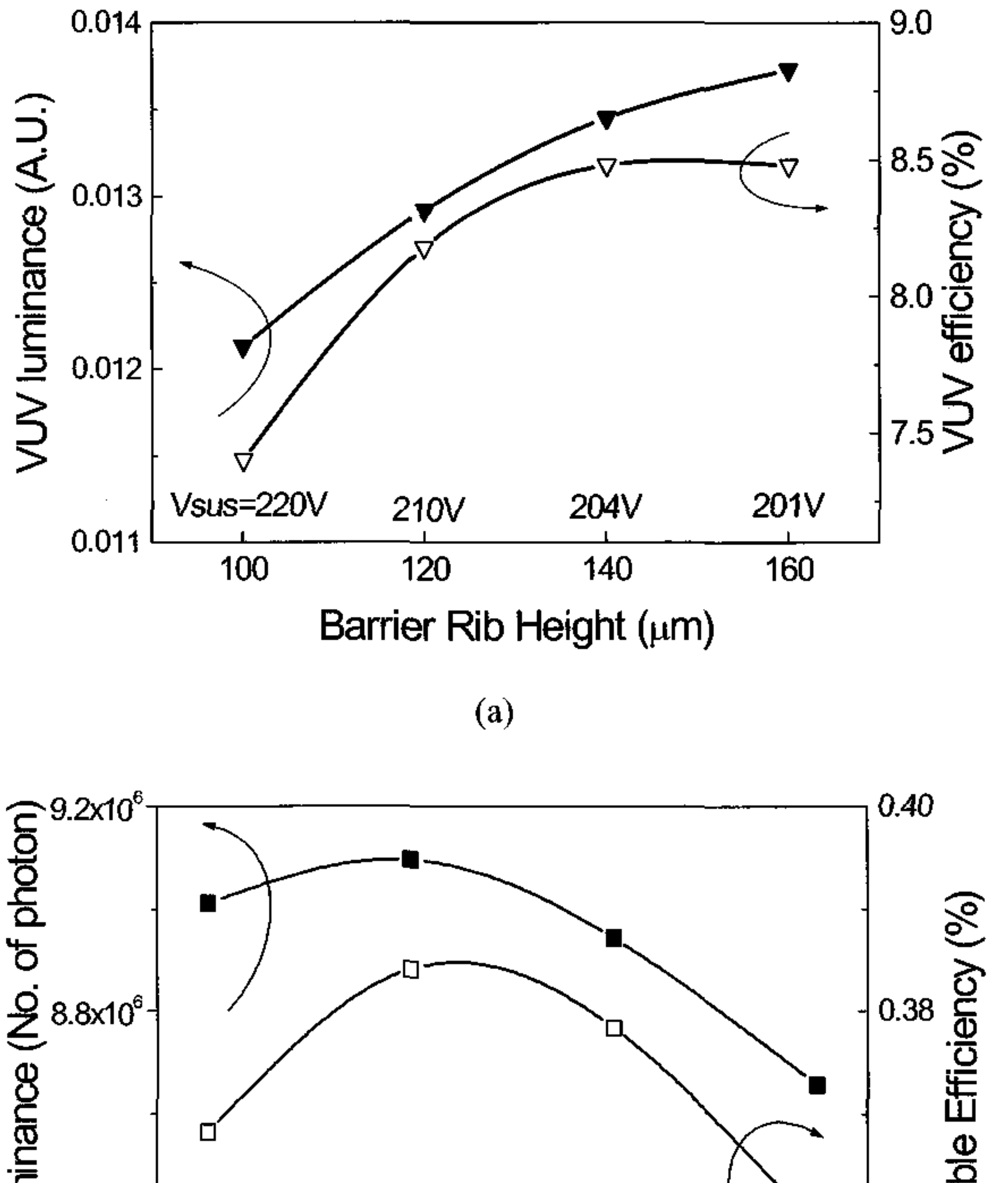


(a)

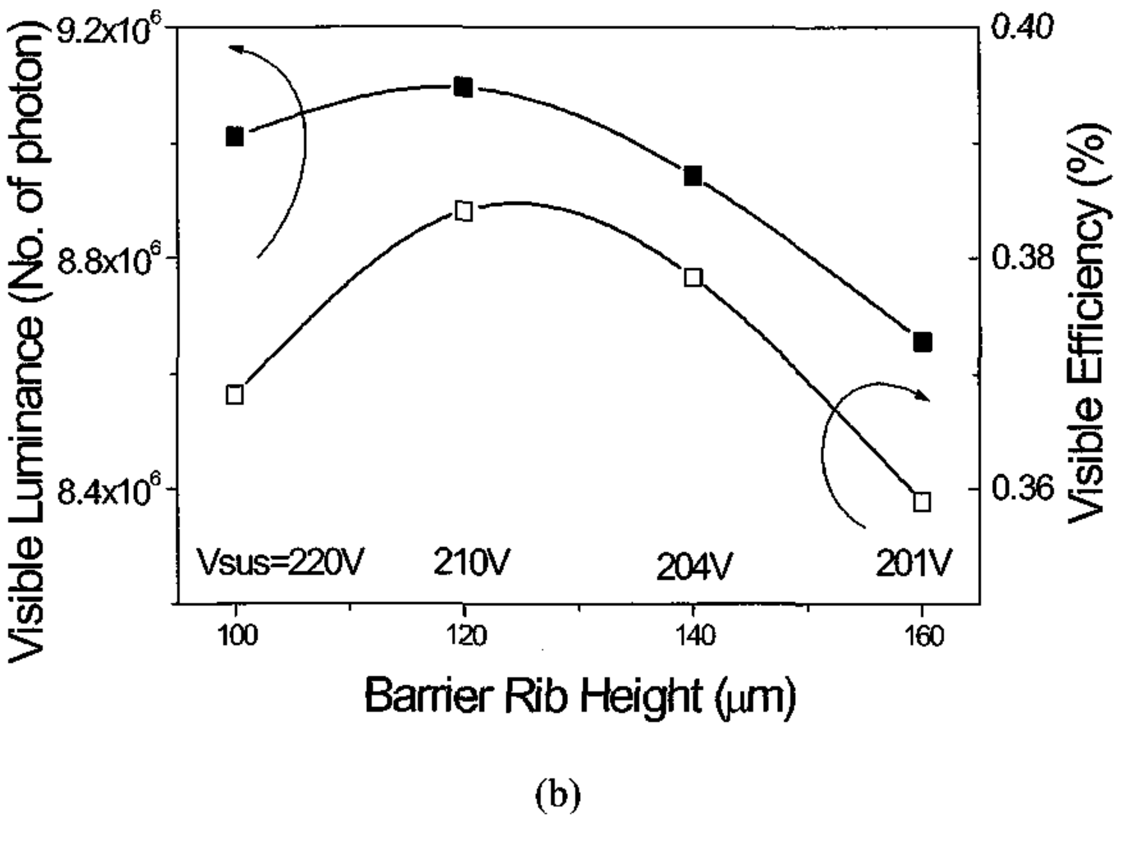
(b)

**Fig. 8.** Luminance and efficiency according to sustain voltage with various barrier rib heights in terms of (a) VUV and (b) visible light.

At the middle values of the sustain voltage ranges, the VUV luminance increases as the rib height increases, while the VUV efficiency increases until 140 μm rib height(Fig. 9(a)). But, the visible luminance and efficiency show different dependence on the barrier rib height. They have maximum values between 120 μm and 140 μm rib height, which means that there exists optimal barrier rib height in the viewpoint of luminance and efficiency(Fig. 9(b)). The reason is that in case of lower rib than optimal height, the VUV generation efficiency is not sufficient, and in case of higher rib, the photons emitted at the phosphor surfaces suffer difficulties in escaping through front panel due to the shadow effect. Although higher barrier rib gives more VUV photons and higher VUV generation efficiency, lower barrier rib gives higher escaping probability of photons through the front panel, thus there exists the optimal barrier rib height.



(a)



(b)

**Fig. 9.** Luminance and efficiency at the middle of the sustain voltage range according to various barrier rib height in terms of (a) VUV and (b) visible light.

## 5. Conclusions

Using ray-optics code incorporated with three-dimensional PDP cell simulation, we have analyzed the energy flow in the PDP cell from the electric power input to the visible photon output. Also, the visible photon output profile and the viewing angle distribution were obtained. The total visible photon output power is 0.41 % of the total input power. Although we made several assumptions in this work, such as the analysis only for 1.5 μm pulse-on time, the assumed quantum efficiencies, the simplified phosphor surfaces as a plane, and the isotropic photon emission of phosphor, the results means that the visible light efficiency in a PDP cell is much lower than 1 %.

Using ray-optics code incorporated with 3D PDP cell simulation, we have analysed the barrier rib height effects on the visible light luminance and efficiency of the sustaining discharge. According to our results, there exists optimal barrier rib height that gives the highest visible luminance and efficiency, which are determined mainly by two competing factors. The first is how many and how efficiently VUV photons are generated, and the other is how many visible photons succeed in escaping through the front panel. As the barrier rib height increases, the VUV luminance and efficiency increase, while the escaping probability of visible photons through front panel decreases due to the shadow effect. One more thing to note is that as the rib height increases, the minimum and maximum sustain voltage decrease.

The mechanism where PDP emits visible light is very complicated correlation of various parameters are very complex. But our results show that there still remains room for efficiency enhancement. For example, design of new cell structure that enables phosphor surface to increase, or photons at phosphor to easily go out through front panel can be one of the ways. And this ray-optics code incorporated with 3D PDP discharge simulation can be a tool to design such new cell structure.

## 6. Appendix

VUV efficiency is defined by $\rho_{VUV} = \frac{W_{VUV}}{W_{dissipated}}$, where $W_{VUV}$ is the energy of the VUV photons during one sustain pulse, and $W_{dissipated}$ is the energy dissipated in the discharge, which are defined by

$$W_{VUV} = \int_V \int_T \sum_k n_k \frac{1}{\tau_k} \varepsilon_k dtds \quad \text{and}$$

$$W_{dissipated} = \int_V \int_T \vec{J} \cdot \vec{E} dtds$$

$n_k$, $\tau_k$, $\varepsilon_k$, $T$, $\vec{J}$, $\vec{E}$, are the density of species k, radiation life time, the energy of emitted photon, one sustain pulse duration, current, and electric field, respectively.

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