Simulation of Photons from Plasmas for the Applications to Display Devices

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Abstract

Numerical modeling of the photon transport of the ultra violet (UV) and the visible lights are presented for plasma based display devices. The transport of UV lights which undergo resonance trapping by ground state atoms is solved by using the Holstein equation. After the UV lights are transformed to visible lights at the phosphor surfaces, the visible lights experience complicated traces inside the cell and finally are emitted toward the viewing window after having some power loss within the cell. A three-dimensional ray trace of the visible lights is calculated with a radiosity model. These simulations for the photons strengthen plasma discharge modeling for the application to display devices.

Key words: radiation transport; ray trace model; plasma display

1. Introduction

The liquid crystal display (LCD) and the plasma display panel (PDP) are spotlighted as the most promising candidates for large size flat panel displays, but still they need lots of improvement. For PDP, it is demanded to improve the luminance efficiency which is much lower than that of cathode ray tube by 2.5 times [1]. For LCD, the cost for a backlight unit (BLU) is more than 30% of the total module cost. The conventional cold cathode fluorescent lamps or external electrode fluorescent lamps are not suitable for LCD TVs which have larger diagonal size than 42 inch because of poor luminance uniformity and slow responding time. In order to simplify the structure and reduce the production cost of a large size BLU, intense efforts have been focused on the development of flat fluorescent lamps (FFLs) since late 1990s [2–4].

As shown in Fig. 1, both discharges in a PDP cell and in a LCD BLU have similar structures and the same discharge mechanism, and thus can be treated with the same fluid simulation. The difference exists mainly on gas pressure (more than 400 Torr for a PDP compared with tens of Torr for FFL), the size of discharge cells, and the driving voltage.

For the research of plasma based display devices and lamps, not only the dynamics of plasma and neutral particles but also the transport of ultra violet (UV) and visible lights are important for the precise calculation of luminance and luminance efficacy. In this paper, the way how to treat photons from plasmas is explained.

2. Radiation transport for UV lights

In the fluid simulation, the radiation trapping is calculated by using the Holstein equation [5] for a radiative state which is optically thick. It is Xe $^3P_1$ excited state (147 nm) for a PDP, and Hg $^3P_1$ (254 nm) and $^1P_1$ (185 nm) states for Hg FFLs.

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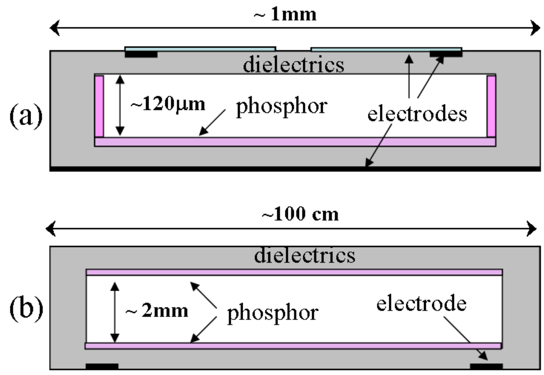

Fig. 1. Structure of a discharge cell for (a) a PDP and (b) a FFL.

$$\frac{\partial n^*(\mathbf{r},t)}{\partial t} + \nabla\cdot\Gamma(\mathbf{r},t) = P(\mathbf{r},t) - \frac{1}{\tau_v}\,n^*(\mathbf{r},t) + \frac{1}{\tau_v}\int n^*(\mathbf{r}',t)G(\mathbf{r},\mathbf{r}')d\mathbf{r}' \quad (1)$$

where $n^*(\mathbf{r},t)$, $\Gamma(\mathbf{r},t)$, and $P(\mathbf{r},t)$ are the radiative state density, its flux, and the production rate, respectively. τ_v is the radiative decay time in vacuum, which is 3.56 ns for the Xe $^3P_1$ state, and 125 ns for the Hg $^3P_1$ state. $G(\mathbf{r},\mathbf{r}')$ is the probability function for a resonance photon emitted at the position $\mathbf{r}'$ to be absorbed at the position $\mathbf{r}$. This integral equation is solved by using propagator function method as reported in Refs. 6 and 7. From simulation results, it was observed that the effect of UV radiation trapping is less than 10% for a PDP cell because the cell size is small and because there are also other optically thin radiations like 173 nm from Xe_2^*. However, the radiation trapping effect becomes dominant in FFL because the size of discharge space is enough large and the decay time of the Hg $^3P_1$ state is very slow. The peak plasma density is order of 10^{13} cm^{-3} in a PDP cell and 10^{10} cm^{-3} in a FFL. The emitted UV photons are order of 10^{13} s^{-1} in a PDP cell.

3. Ray trace model for visible lights

When the UV lights are absorbed by phosphor, it is converted to visible lights. The visible lights are reflected or absorbed at other phosphor surfaces, and finally transmitted through the front panel. As the surface of phosphor is not smooth, it is very important to consider both the specular and the diffusive reflections. The way how to calculate the visible light intensity is to solve the radiosity (light energy per unit time per unit area) equation,

$$B_i(\hat{u}) = E_i(\hat{u}) + \sum_{j\neq i}\rho_i(\hat{u};\hat{u}')F_{ij}B_j(\hat{u}')\ , \quad (2)$$

where $B_i(\hat{u})$ and $E_i(\hat{u})$ are the radiosity and emissivity at the ith patch on the phosphor surface in the direction of solid angle $\hat{u}$. The second term of the rhs of Eq. (2) calculates the effect of the reflected lights from the other phosphor surfaces. $\rho_i(\hat{u};\hat{u}')$ is the reflectivity in the direction of $\hat{u}$ for the light with an incident angle $\hat{u}'$, which is coming from the jth patch. F_{ij} is the form factor for the lights emitted from the jth patch to the ith patch. The form factor can be calculated with the integral of the direction cosines of the lights to the normal vector of the surfaces over each area of the considered patches.

$$F_{ij} = \frac{1}{A_i}\int_{A_i}\int_{A_j}\frac{\cos\phi_i\cos\phi_j}{\pi R_{ij}^2}dA_j dA_i. \quad (3)$$

With these equations, the visible lights emitted from the phosphor surface are calculated iteratively for each cycles of discharge. Finally, it is possible to get the position and angle distribution of the emitted visible lights at the front surface.

4. Summary

The calculation methods for UV lights and visible lights are presented for the simulation of lighting devices using plasmas. The Holstein equation and the radiosity method with form factor are adopted for the UV transport and visible ray trace, respectively.

Acknowledgements

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