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The Effects of Electrons on the Electro-Optical Characteristics of Mercury-Free Flat Fluorescent Lamps

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New mercury-free Flat Fluorescent Lamps (FFLs) with a different kind of phosphor layers were fabricated in order to investigate the effects of electrons with the surplus energy on the electro-optical characteristics. Discharge characteristics of the FFLs were compared as functions of the gas pressure and the mixture ratios, and with or without phosphor layer on the front plate. The experimental results revealed that FFLs with the PL (Photoluminescence) phosphor layer on the front and the rear plates show the highest luminance. However, it is found that the difference of luminance between FFLs with the CL (Cathodoluminescence) phosphor layer and FFLs with the PL phosphor on the front plate is considerably decreased in the cases of the gas pressure below 50 Torr and the discharge cell with a cell depth of 0.8 mm, indicating that the electrons play a role in the excitation of the phosphor under a certain discharging condition.

Keywords Cathodoluminescence; discharging condition; flat fluorescent lamps; phosphor layer; photoluminescence

Introduction

Mercury-free Flat Fluorescent Lamps (FFLs) have been studied for the pollution-free high-efficiency high-luminance backlights of Liquid Crystal Display (LCD). Recently, LED is replacing the conventional backlight of LCD as the restriction of the use of environmental pollutants. Moreover, LED has merits of improvement of the power consumption effiency and contrast ratio by using the local dimming driving method. However, LED requires complex optical parts to convert spot lighting into areal lighting in order to use as backlight of LCD. In addition, LED has problems of relatively low luminance application area, unstable uniformity of luminance and additional compensation circuit.

In this study, we fabricated the 4″ type FFLs with a different kind of phosphor layers and investigated the effects of electrons with the surplus energy on the electro-optical characteristics in order to improve the luminance problem of the

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backlight of LCD. The FFL has a unique structure without dielectric layers by using the glass substrates as dielectrics.

Experimental

Figure 1 shows the structure of the FFLs which have the simple structure where the glass substrates were used as the dielectric layer. Discharge cells were prepared by etching the glass substrates to the amount of 1.5 mm and 0.8 mm. In order to enhance the effects of the electron, we reduced the dimension of the discharge cell, of which the depth is 0.8 mm. The thickness of the front glass is 1.1 mm. The ITO electrode was formed at the outside of the front substrate and the metal electrodes were formed at the outside of the rear substrate by the screen-print method, so that we could remove the conventional dielectric layers.

As phosphors of interest, a cathodoluminescence (CL) phosphor which is excited by electron and a photoluminescence (PL) phosphor which is excited by UV were used on the each front plates in the FFL structure, similar to the plasma display panel. ZnS:Ag (NICHIA) was used as a CL phosphor and $BaMgAl_{10}O_{17}$:Eu (NICHIA) was used as a PL phosphor. The phosphor powders were mixed with a

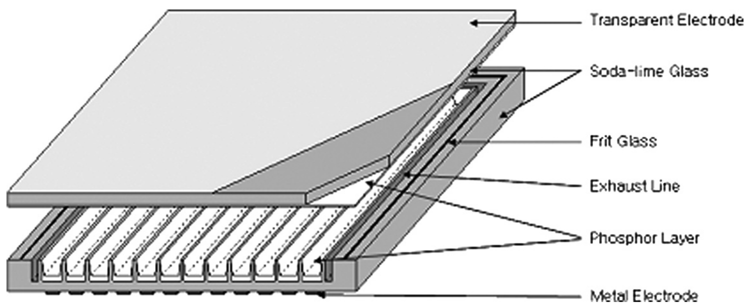


Figure 1. Structure of the mercury-free FFL.

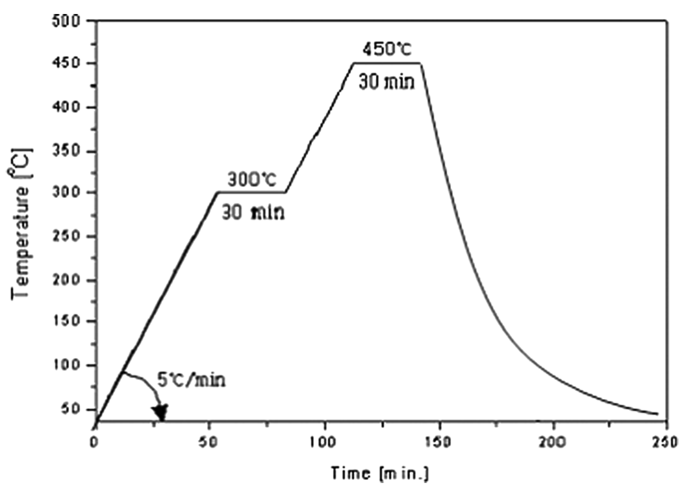


Figure 2. Profile of drying and firing the phosphor.

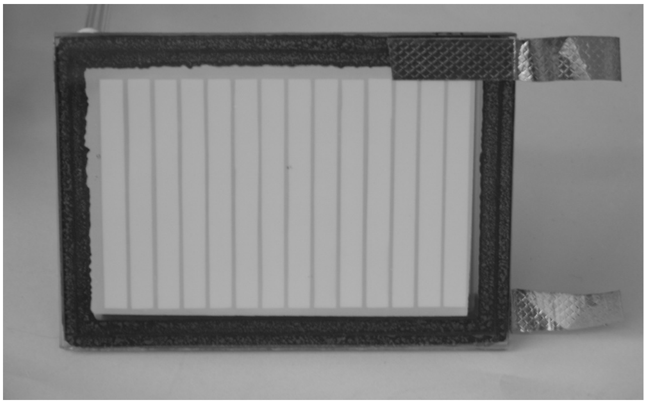


Figure 3. Picture of the fabricated FFL.

vehicle which was composed of Diethylene Glycol Monobyuthyl Accetate (DGMA; 80 wt%), Diethylene Glycol Monobyuthyl Ether (DGME; 10 wt%) and Ethylcellulose (10 wt%) in order to make the paste. The front phosphor layer was formed by the screen-print method and the rear phosphor layer was formed by the dispensing method using the paste. The phosphor layers were dried at 350°C for 30 min, and then fired at 450°C for 30 min as shown in Figure 2 in order to remove organic solvents. Figure 3 is the FFL fabricated by prior process.

Discharge characteristics of the FFLs were investigated as conditions of several gas pressures, mixture ratios and the applied voltages, and with or without the phosphor layers on the front plates. The driving pulse with a frequency of 20.1 kHz and the duty rate of 20.1% were applied to the FFLs. The peak voltage was set to 3.0 kV. All measurements were performed in the darkroom.

Results and Discussion

Figure 4 shows the luminance characteristics as a function of applied voltages at 50 Torr and 100 Torr gases. As the voltages increase, the electrons in the discharge cell get higher energies and the excitation of phosphors actively happen. This leads to an increase of luminance. When only Xe gas is used in the discharge, a higher firing voltage is required because of the low ionization ratio. Thus, Penning effect is used to raise ionization ratio and excitation ratio of Xe gas using Ne gas. The FFL with the PL phosphor layer on both the front and the rear plate shows the highest luminance, and the FFL with the CL phosphor layer on the front plate obtained higher luminance than the FFL without phosphor layer on the front plate at low pressure of 50 Torr. This means that the effects of electrons with the surplus energy on the CL phosphor layer added to the effects of the UV on the PL phosphor layer are higher than only the effects of the UV.

Table 1 shows the firing voltages according to the gas pressures. The firing voltages of the FFL with the CL phosphor layer were lower than those of the FFL without phosphor layer and the FFL with the PL phosphor layer at 50 Torr gas. This also indicates the effects of electrons with the surplus energy on the CL phosphor layer.

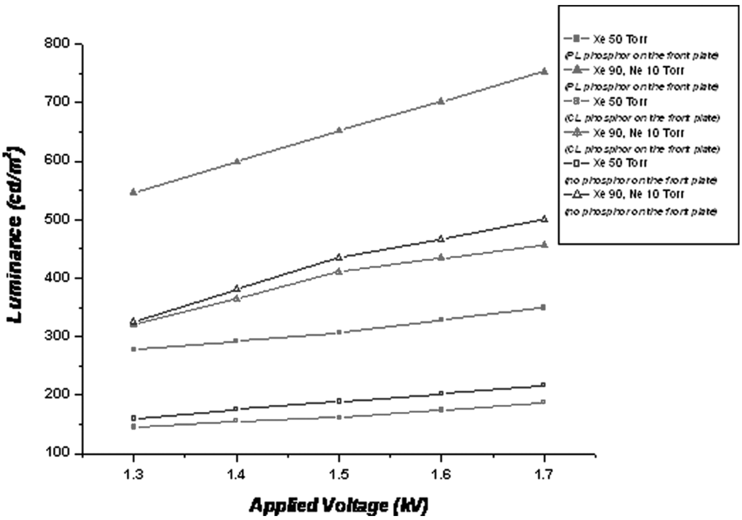


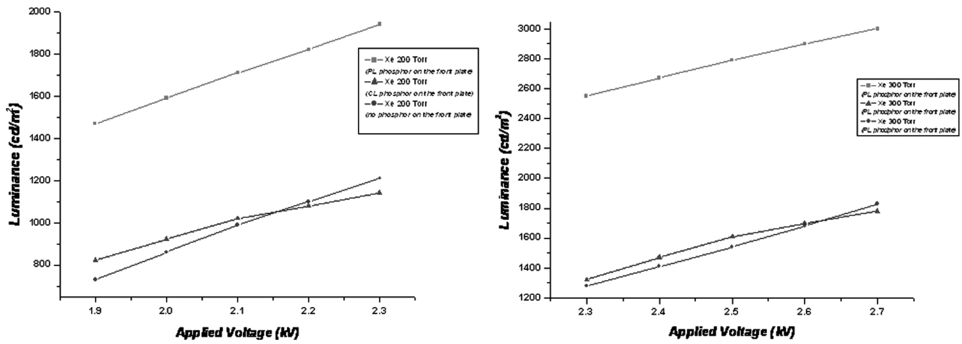
Figure 4. Luminance-voltage characteristics of FFL with different phosphor layers on the front plate at 50 Torr and 100 Torr Xe gas.

Figure 5 illustrates the luminance characteristics as a function of applied voltages at 200 Torr and 300 Torr gases. The FFL with the PL phosphor layer on both the front and the rear plate shows the highest luminance. The result represents that the effects of the UV on the PL phosphor layer increase and the effects of electrons on the CL phosphor layer on the other hand decrease with increasing the gas pressures. Moreover, the luminance of the FFL with the CL phosphor layer is lower than that of the FFL without phosphor layer at high voltages.

Figure 6 represents the luminance characteristics as a function of applied voltages at 50 Torr and 30 Torr gases. As seen in Figure 6, the FFL with the PL phosphor layer on both the front and the rear plate obtained the highest luminance. However, the difference of luminance between the FFL with the CL phosphor layer and the FFL with the PL phosphor layer on the front plate was considerably decreased with decreasing Xe pressures. This implies that the electrons play a role in the excitation of the phosphor under certain discharging conditions such as the low gas pressure and the small dimension of the discharge cell, because the electron energy E can be expressed by $E = eF_c\lambda$ with the electric field $F_c(=V_a/d)$ in cells and the mean free path λ, λ is inversely proportional to the gas pressures. In addition, we measured the input powers of FFL with CL and PL phosphors on the front plate by using Sawyer-Tower circuit and found that there is no significant difference

Table 1. Firing voltages at 50 Torr and 100 Torr gases

	Xe 50 Torr	Xe 50 Torr Ne 50 Torr	Xe 90 Torr Ne 10 Torr	Xe 100 Torr
None/PL	0.85 kV	1.07 kV	1.07 kV	1.08 kV
PL/PL	0.86 kV	1.10 kV	1.10 kV	1.13 kV
CL/PL	0.83 kV	1.04 kV	1.07 kV	1.08 kV



(a) (b)

Figure 5. Luminance-voltage characteristics of FFL with different phosphor layers on the front plate at 200 Torr (a) and 300 Torr (b) Xe gas.

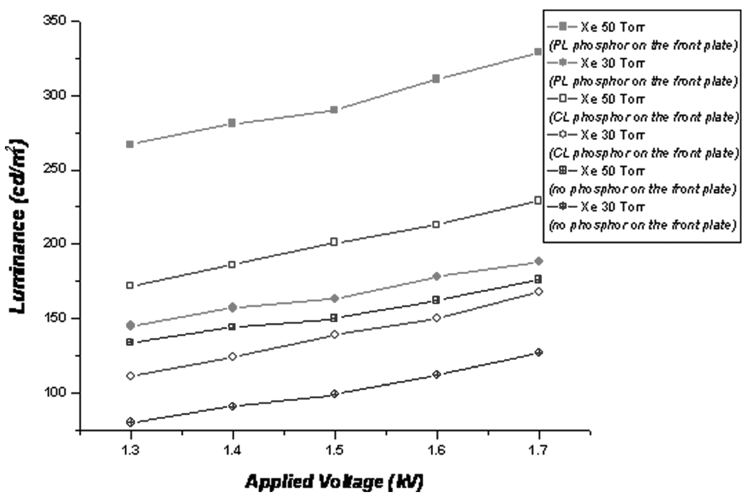


Figure 6. Luminance-voltage characteristics of FFL with different phosphor layers on the front plate at 50 Torr and 30 Torr Xe gas.

between them. This implies that there is not so much difference in the phosphor's capacitances and the electrical currents are almost same for both cases. Thus, the difference of efficiencies between the FFL with the CL phosphor layer and the FFL with the PL phosphor layer on the front plate is also expected as much as the difference of the luminance, because the efficiency is simply proportional to the luminance under the same input power condition.

Table 2. Firing voltages at 50 Torr and 30 Torr Xe gas

	Xe 50 Torr	Xe 30 Torr
None/PL	0.84 kV	0.72 kV
PL/PL	0.85 kV	0.74 kV
CL/PL	0.82 kV	0.71 kV

Table 2 shows the firing voltages according to the gas pressures indicating the effects of electrons with the surplus energy on the CL phosphor layer.

Conclusions

In this study, we developed new mercury-free FFLs with a different kind of phosphor layers, and investigated the luminance characteristics and the firing voltages under several conditions. It was found that the difference of luminance between the FFL with the CL phosphor layer and the FFL with the PL phosphor layer on the front plate was considerably decreased. The results suggest that the effects of electrons on the CL phosphor layer increase with decreasing the gas pressures and the dimension of the discharge cell.

Acknowledgments

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