Luminous Characteristics of Surface Discharge Structure with Patterned Electrodes for Mercury-Free Flat Fluorescent Lamp

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ABSTRACT

The Luminous characteristics of a surface type discharge structure with various patterned electrodes on 6-in. Mercury-free flat fluorescent lamp are examined for investigating the basic property of an avoidance of discharge instability and an improvement of the luminous efficiency. In particular, the discharge characteristics including the firing/sustaining voltages, the luminance and luminous efficiency are measured in each case of a patterned electrode shape and discharge gap. As a result, it is found that the electrode shape and the discharge gap have strong effects on the luminous efficiency in the surface discharge structure with a patterned coplanar electrode.

INTRODUCTION

FFL with the xenon gas not only is friendly to environment but also has fast response time [1, 2, 3], thus it has great advantage to an application of the improvement technique of picture quality such as scanning or local dimming technique. However, since FFL with the xenon gas generates the visible light using UV source with the wavelengths of 147 and 173 nm, the light conversion efficiency from UV to visible light in phosphor layer is lower than that using mercury gas with UV source of 254 nm wavelength. In addition, FFL with the xenon gas should be working in high pressure condition in order to achieve the satisfying luminance, thus high driving voltage is demanded, resulting in high power consumption. In these reasons, the investigations to improve the luminance and luminous efficiency are needed. In FFLs with the xenon gas, discharge structures mainly adopt surface type discharge due to an easy control of the discharge gap between the electrodes. However, high pressure discharge sometimes induces the discharge instability so called "plasma contraction" in the distance of mm or cm order, which cause the collective behavior of the plasma. Plasma which has a collective behavior would like to produce intensively along the some discharge paths where the discharge can be produced easily, resulting in a discharge instability and the adverse effect of the visible light uniformity. One method to achieve the discharge uniformity is the use of the patterned coplanar electrode in surface discharge structure. The intended plasma contractions by patterned electrode have a periodicity, therefore regular patterns of visible light can be achieved on FFL. In this paper, for investigating the basic discharge property of mercury-free FFL with a patterned coplanar electrode, the electrode shape and the discharge gap dependences on the surface type discharge structure are investigated. The discharge characteristics including the firing/ sustaining voltages, luminance, and luminous efficiency are measured relative to various electrode shapes and discharge gaps.

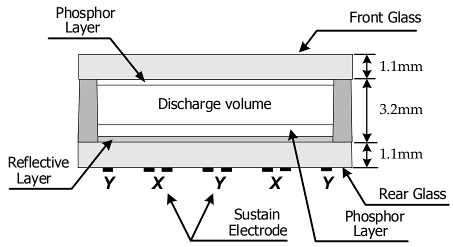


Fig. 1. Schematic diagram of AC surface type discharge structure

EXPERIMENTAL SET UP

Fig. 1 shows the AC surface-type discharge structure of the 6-in. test lamp with X and Y coplanar electrodes of 6~7 pairs. It is a typical dielectric barrier discharge (DBD) structure. The thickness of the front and rear glasses are 1.1 mm,

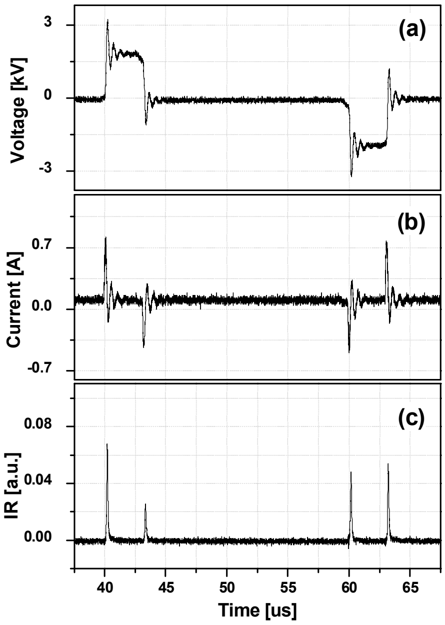


Fig. 2. (a) Voltage difference (V_{XY}=V_X-V_Y), (b) current and (c) IR emission waveforms in the surface discharge structures when adopting square pulse waveforms generated by inverter circuit.

respectively and the plate gap between the front and rear glasses is 3.2 mm. The rear glass plays a role of dielectric barrier which separates the discharge volume and electrode. The phosphor layers of white mixed R, G and B are deposited on both sides of front and rear glasses. A reflective layer of white dielectric material is formed between the bottom and rear glasses. Total gas pressure is 250 Torr and gas mixture is Ne - Xe (30 %) which has the Xe partial pressure of 75 Torr. An inverter circuit is used for generating a square pulse with a high voltage range (>1 KV). The square pulse waveform from the inverter circuit has an overshoot waveform when the pulse rises and also an undershoot waveform when the pulse falls. The square pulses with a width of 3 μs are applied at a frequency of 25 kHz.

Figs. 2 (a), (b), and (c) show the voltage difference between the X and Y electrodes, the corresponding currents and infrared emission measured from the 6-in. test lamp when adopting the square pulse waveforms generated by the inverter circuit. As shown in Fig. 2 (a). the overshoot and undershoot voltages are observed in the applied square sustain waveform. Since the discharge should be produced when the electric fields changes abruptly, the overshoot voltage makes the current and IR emission stronger. In addition, the undershoot voltage induces another discharge as shown in Figs. 2 (b) and (c). The

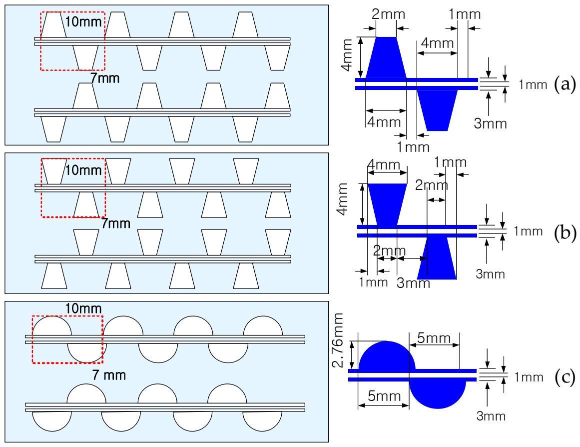


Fig. 3. Patterns of electrode shape, their arrangements and specifications: (a) trapezoid electrode, (b) reverse trapezoid electrode, and (c) semicircle electrode.

extra discharge caused by the undershoot voltage helps to increase the luminous efficiency. This phenomenon is similar to a self-erasing discharge [4].

RESULTS AND DISCUSSION

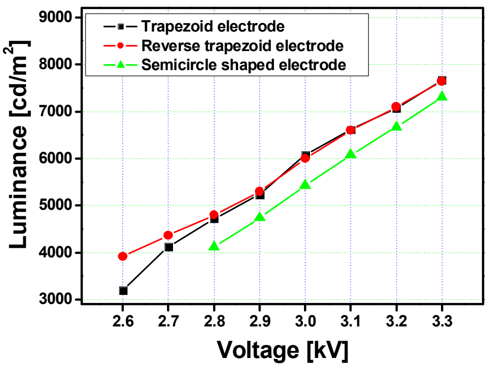
I. Luminous Characteristics Relative to Coplanar Patterned Electrode Shapes

First, the luminous characteristics, such as luminance and luminous efficiency, which are deeply related to the electrode shape, are investigated under various patterned electrodes with surface electrode structure. Fig. 3 shows three different electrode shapes, such as (a) the trapezoid shaped, (b) reverse-trapezoid shaped and (c) semicircle shaped electrodes, respectively. The area of the electrode shapes shown in Fig. 3 is exactly the same, so as to exclude the electrode area effect. In general, the DBD structure has a voltage margin due to the memory effect caused by the wall charge accumulation. In this experiment, the voltage difference between the firing voltage and minimum sustain voltage is measured, which shows the voltage margin. Table 1 shows the firing/minimum sustain voltage and the voltage margin in three cases. In the semicircle shaped case, the firing voltage is lowest and the minimum sustain voltage is highest. Therefore, its voltage margin is smallest among three electrode shapes.

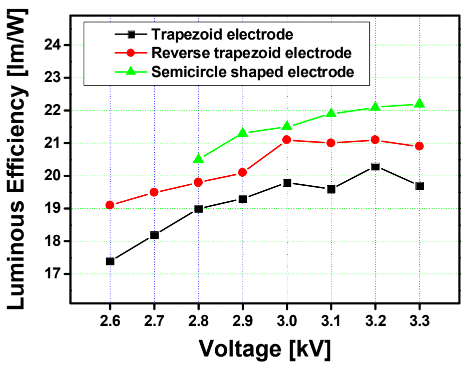
Fig. 4 shows the variations in the luminance and luminous efficiency relative to the patterned electrode shapes. The luminance and luminous efficiency are measured from the minimum sustain

Table 1. Firing and minimum sustain voltages in surface discharge structure with various patterned electrode shapes.

Electrode shape	Firing voltage (V_f)	Minimum sustain voltage ($V_{s,min}$)	Voltage margin (ΔV)
Trapezoid shaped elec.	3.44 KV	2.52 KV	0.92 KV
Reverse-trapezoid shaped elec.	3.36 KV	2.52 KV	0.84 KV
Semicircle shaped elec.	3.12 KV	2.72 KV	0.40 KV



(a)



(b)

Fig. 4. Changes in (a) luminance and (b) luminous efficiency relative to applied voltage for three cases: trapezoid, reverse trapezoid, and semicircle electrodes.

voltage to 3.3 KV. The luminance increases with an increase in the sustain voltage in all cases, as shown in Fig. 4 (a). Both the trapezoid and reverse trapezoid electrodes show almost the same luminance, but the semicircle electrode shows the lowest luminance among the three electrode shapes. The luminance of semicircle case is lower by about 300 ~ 800 cd/m^2 when compared to that of trapezoid and reverse trapezoid cases. It is observed that the luminous efficiencies increase, are saturated and then decrease gradually with an increase in the voltage, as shown in Fig. 4 (b). That is, the luminous efficiency has a maximum value in the sustain voltage region. In addition, it is also observed that the luminous efficiency of the

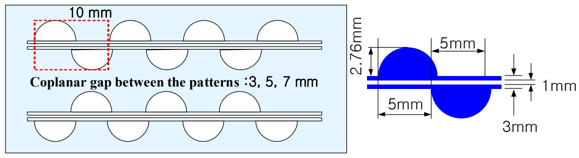
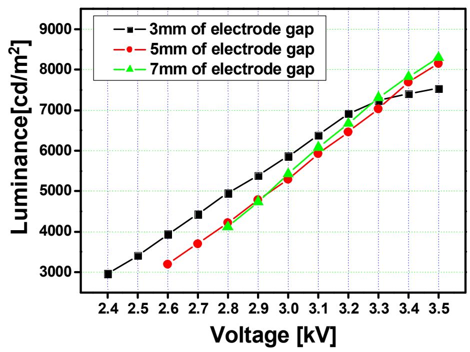


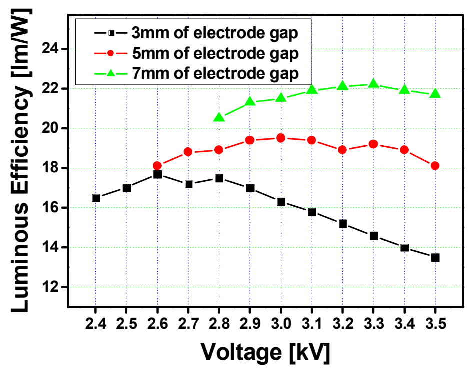
Fig. 5. Three different discharge gaps between patterned coplanar electrodes and specification of pattern

Table 2. Firing and minimum sustain voltage with three different discharge gaps between semicircle electrodes

coplanar electrode gap	Firing voltage (V_f)	Minimum sustain voltage ($V_{s,min}$)	Voltage margin (ΔV)
3 mm	2.70 KV	2.32 KV	0.38 KV
5 mm	3.04 KV	2.56 KV	0.48 KV
7 mm	3.12 KV	2.72KV	0.40 KV



(a)



(b)

Fig. 6. Luminance (a) and luminous efficiency (b) of the surface discharge structures with the discharge gap

semicircle case is highest and the trapezoid case is lowest among the three electrode shapes.

II. Luminous Characteristics Relative to *Coplanar Patterned Electrode Gap*

Second, the luminous characteristics which are deeply related to the coplanar electrode gaps, are measured in the semicircle electrodes. Fig. 5 shows the three different discharge gaps between the coplanar semicircle electrodes where the discharge gaps between the coplanar electrodes are varied to 3, 5 and 7 mm. Table 2 shows the firing/minimum sustain voltages and corresponding voltage margin in three cases. The firing and minimum sustain voltages increase with an increase in the discharge gap. Fig. 6 shows the luminance and luminous efficiency variations relative to the changes in the discharge gap. The luminance also increases with an increase in the sustain voltage. However, for the two cases, i.e., 5 and 7 mm, no luminance difference is observed, but for the 3mm case, the improved luminance is observed up to 3.3 kV. This feature might be attributed to the use of plasma contraction. The light emitting pattern of the FFL with the discharge gap of 3 mm has the distinctive difference of brightness between the light emissive and non-emissive areas in the lamp. If the brightness difference between the light emissive and non-emissive areas is larger, the light emissive areas can produce the more intensive plasma contraction. A use of plasma contraction can achieve high luminance. However, a use of plasma contraction is adverse to a high luminous efficiency. Moreover, when the discharge gap increases, the positive column region of glow discharge process also increases in the distance of mm or cm order [5]. Thus, the luminous efficiency increases with an increase in the discharge gap, as shown in Fig. 6(b).

Conclusion

The Luminous characteristics of a surface discharge are examined with the variation of electrode shapes and the discharge gaps in the mercury-free flat fluorescent lamp. It is found that both the electrode shape and discharge gap have strong effects on the luminous efficiency in the surface discharge structure with a patterned coplanar electrode. Consequently, the luminous efficiency of the FFL with semicircle shape electrode is highest among three electrode shapes under the same area condition. In addition, the luminous efficiency increases with an increase in the discharge gap.

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