Determination of the voltage distribution in the external electrode fluorescent lamps for the backlight unit of large-size LCD

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Abstract

The voltage distribution of an external electrode fluorescent lamp(EEFL) having a gas pressure of 50 torr and a gas composition of Ne:Ar with a ratio of 90:10 has been estimated by varying the distance between the two external electrodes and monitoring the change of the lamp voltage. The estimated voltage gradient, which represents the electric field in the positive column of the EEFL, was very sensitive to the electrode area of EEFL and was in the range of 13 ~ 27 V/cm at the electrode length of 15 ~ 31 mm. Changing the lamp current in the range 3 ~ 5 mA did not make noticeable difference in the electric field of the positive column. Theses results may serve as basic data for the optimization of electric and optic characteristics of EEFL.

1. Introduction

External electrode fluorescent lamps(EEFL) have recently been adopted as one of the light sources for the applications of LCD TV. EEFL backlight technology has been adopted in 30” LCD TV in 2003 for the first time, and it has extended its available size in the range 23 ~ 37” LCD TVs. EEFL has been used mainly in the direct-lit backlight for LCD TV applications because multiple EEFLs can be operated parallel by a single inverter, which is a very attractive point for cost competitiveness of LCD among various FPD(flat panel display)s. In addition to the cost merit, EEFL has other advantages such as a lower power consumption, longer lifetime, simpler backlight structure, etc., than the conventional CCFL(cold cathode fluorescent lamp) backlight technology. Since the main technological requirements toward the backlight unit are higher efficiency and lower cost, it would be very important to understand the exact electrical and optical characteristics of light sources for further improvements.

Several interesting and important experimental results on EEFL have already been published[1-8]. The discharge induced in the EEFL is basically a dielectric barrier discharge(DBD). The lamp glass plays the role of the dielectric barrier through which the displacement current is passed by alternating electric field. The capacitance of the dielectric layer, which limits the current in the discharge is determined by the dielectric constant, thickness of the glass and electrode area. This is the main reason why EEFL needs no ballast elements and many EEFLs can be driven parallel by a single inverter. In addition, the wall charges accumulated during the main discharge on the inner surfaces underneath electrodes may be utilized to make self-discharges when the driving voltage falls to zero[1]. This wall-charge effect is more effective in the case when EEFL is driven by a square wave voltage having a sharp rising edge. These results show that the light-generating efficiency of EEFL is sensitive to discharge conditions such as the electrode area, frequency, driving waveform, etc.

However, there has been no detailed report on the voltage distribution of the glow discharge in EEFL. Since the main reason for the lower efficiency of CCFL and EEFL compared to that of hot-cathode fluorescent lamp(HCFL) is their larger electrode losses owing to the larger sheath voltages, it would be important to decrease the electrode loss by some methods from the viewpoint of efficacy. In this context, it would be meaningful to investigate the voltage distribution in EEFL, which can serve as basic data for the optimization of electrical and optical properties of EEFL. The present contribution reports on the measurement of voltage distribution, in particular, the electric field in the positive column of EEFL. Measured results will be compared to the data of CCFL reported by several CCFL manufacturers.

2. Reviews on the voltage distribution in CCFL

For the direct measurement of the voltage distribution in CCFL, we would have to insert, for example, the Langmuir probe in the lamp and adjust its location while monitoring its potential. Another convenient way for obtaining the same information would be to check the change in the lamp voltage of several kinds of CCFLs having the same diameter but different lengths while being operated at the same lamp current. The relationship between the lamp voltage(V_L) and the discharge length(l) of CCFL has been investigated using the reported data[9-10]. Figure 1 shows the V_L-l relationship of the CCFL of which the outer diameter and the lamp current(I_L) were 7 mm and 6 mA, respectively[9]. The inside was filled with Ar at a pressure of 20 torr. The cold cathodes were made by 0.7-mm thick, nickel-plated iron tabs formed into a "V" shape. Linear relationship between V_L and l is very clear from the figure, and the voltage gradient, i.e., the electric field in the positive column denoted as E_{pc}, is 8.1 V/cm. Extrapolation of the data points to the ordinate gives the voltage of 108$\pm$1 V in the limit of $l \sim 0$ mm. This value can be interpreted to represent the sheath voltage(V_{sh}) of CCFL at this design.

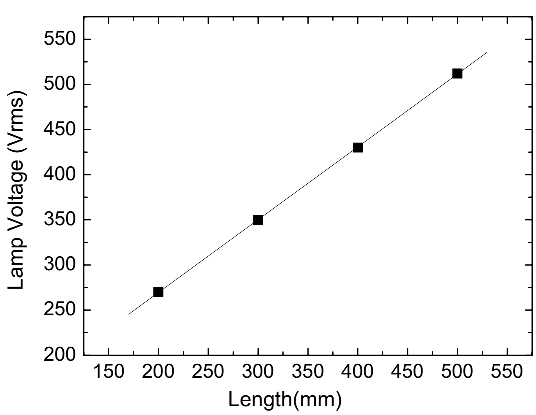

Figure 1. The linear relation between the discharge length and the lamp voltage of CCFL of which the outer diameter and the lamp current were 7 mm and 6 mA, respectively[9].

Second example would be the typical CCFL having outer diameter of 4 mm and pressure of 60 torr, made by Harrison-Toshiba Lighting Co. The ratio between Ne and Ar was not mentioned in the catalogue, and the electrode material was molybdenum. The V_L-l relationship was digitized from the data of [10], and the same fitting procedure shown in Figure 1 was carried out. Figure 2 shows the dependence of the sheath voltage on the lamp current. It is in the range

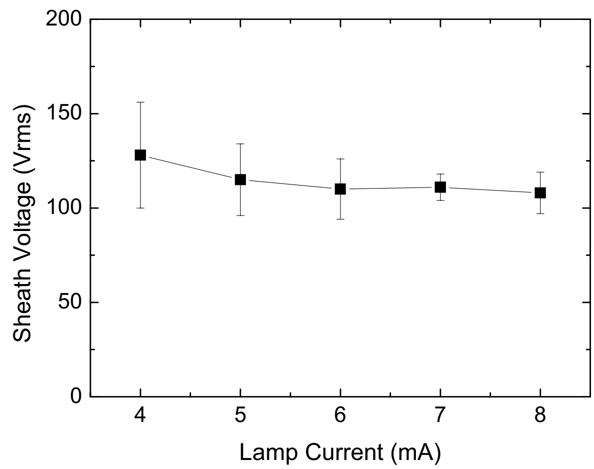

Figure 2. The dependence of the sheath voltage on the lamp current of CCFL having an outer diameter of 4 mm and the pressure of 60 torr[10].

between 110 ~ 130 V, and seems to decrease slightly with the lamp current. Figure 3 summarizes the dependence of E_{pc} on the lamp current. E_{pc} decreases with the lamp current when I_L is larger than 5 mA.

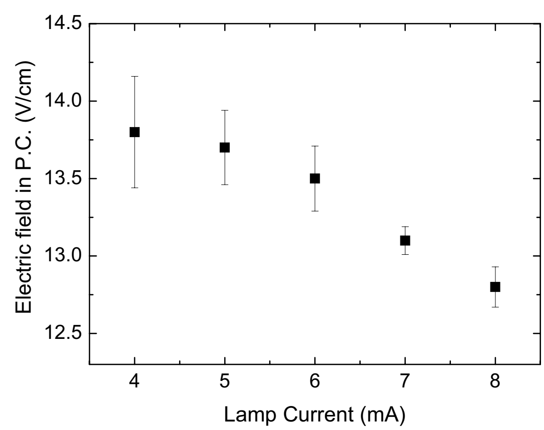

Figure 3. The dependence of E_{pc} on the lamp current of CCFL having the outer diameter of 4 mm and the pressure of 60 torr[10].

This review on electric characteristics of CCFL reveals that V_{sh} is in the range of 100~130 V when the tube diameter is 4 ~ 7 mm and that E_{pc} increases with decreasing diameter. Estimated V_{sh} is comparable to the data in the literature and much larger than that of

HCFL[11]. E_{pc}'s of CCFL are also much greater than that of HCFL[9].

3. Voltage distribution in EEFL

A standard EEFL for 32" backlight unit, whose length was 715 mm, was used for the measurement. The outer diameter was 4 mm with a glass thickness of 0.5 mm. The gas pressure and composition were 50 torr and Ne:Ar with a ratio of 90:10, respectively. A small amount of liquid mercury was added as a source for the ultraviolet radiation. On the outer side, two cupper electrodes having a width of 15 ~ 31 mm were attached, and the distance between the electrodes were changed.

A sine-wave driving voltage having a frequency of 50 kHz was used to ignite and maintain the glow discharge in EEFL. During the measurement, the discharge current was fixed to a certain value in 3 ~ 5 mA using the current probe(Tektronics P6022), and the lamp voltage was monitored by the high voltage probe(Tektronics P6015A) as a function of the distance between the two external electrodes. The ambient temperature during the measurement was kept to 25±1°C. Therefore, the cold spot temperature was not strictly controlled to have a constant value during the measurement.

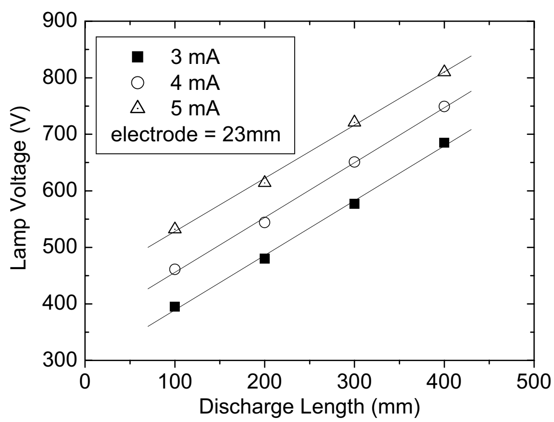

Figure 4. The linear relation between the discharge length and the lamp voltage of EEFL of which the outer diameter was 4 mm at several lamp currents.

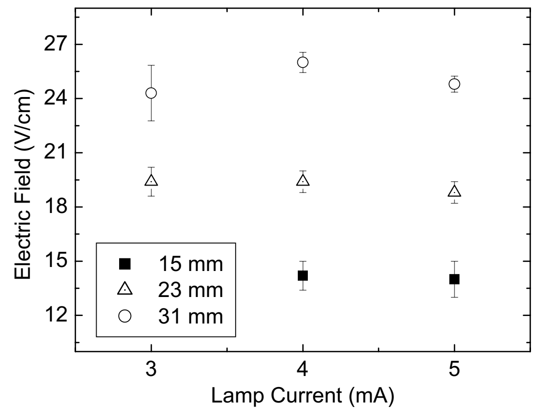

Figure 5. The dependence of E_{pc} on the lamp current at three electrode lengths of EEFL.

Figure 4 shows the V_L-l relationship of EEFL having an electrode length of 23 mm at three lamp currents. Each data set exhibits a linear behavior, from which E_{pc} can be derived. Figure 5 summarizes the obtained E_{pc} at different electrode lengths. E_{pc} increases with the electrode length. Figure 6 shows the estimated E_{pc} at the lamp current of 5 mA at four different electrode lengths. E_{pc} seems to be linearly proportional to the electrode length. The slope is 7.0±0.3 V/cm^2 and the extrapolated value in the limit of the zero electrode length is 3.0±0.8 V/cm.

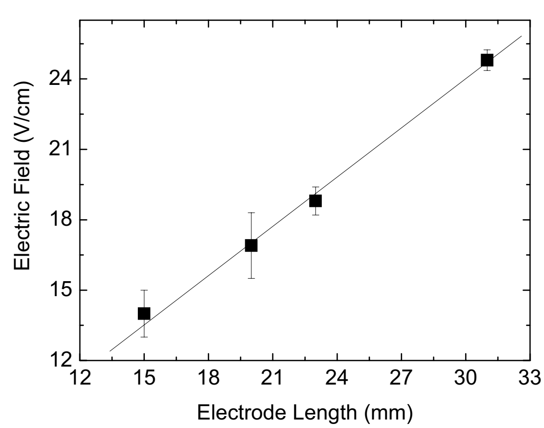

Figure 6. The dependence of the electric field in the positive column on the electrode length at the lamp current of 5 mA of EEFL.

4. Discussion and Summary

The discharge in EEFL is induced and maintained by capacitive coupling through the glass wall. It is thus expected that the voltage distribution and the efficacy will depend on the capacitance of the glass wall at the external electrodes, which will in turn affect the amount of wall charges and the voltage distribution of the EEFL. The applied voltage will be divided into two parts, the voltage upon the glass tube (V_G) at the electrode parts and the voltage in the glow discharge(V_P). As the capacitance increases, the ratio of V_P to the total applied voltage($V_G + V_P$) will increase, which will in turn increase the discharge energy and efficacy to some degree. The same effects can be accomplished by changing the thickness or dielectric constant of the glass tube.

In the present contribution, it was demonstrated that the voltage gradient of the glow discharge in EEFL becomes larger with the electrode length. Since the larger electrode means larger capacitance at the electrode parts, $V_P/(V_G + V_P)$ becomes higher resulting in the higher electric field in the positive column. Therefore, a larger fraction of the total lamp power might be used in light generation rather than being used in the sheath and in the glass as a dielectric loss. This change in voltage distribution may have some effects on the efficacy, and one report showed that the efficacy first increased and then became saturated with increasing electrode length[2]. Preliminary results on the EEFL used in the present investigation also showed that the efficacy becomes higher with the electrode length. However, longer electrode means a wider bezel, which is against to the requirement of narrow bezel. One way to solve this problem would be to enlarge the diameter of only the electrode part. Recent study revealed that optical and electrical characteristics of EEFL would remain the same if the total electrode area does not change[13]. The present result showed that the electric field can be controlled by the area of the external electrode in EEFL. Theses results may serve as basic data for the optimization of electric and optic characteristics of EEFL.

In order to estimate the sheath voltage in EEFL quantitatively, voltage-current and charge-voltage waveforms during the operation were recorded at the same current, and the power consumption was calculated at each discharge length. The extrapolated value of the power consumption as the length goes to 0 was interpreted as the power consumption in the sheath, from which the sheath voltage could be estimated. However, both techniques did not show consistent values to each other. More sophisticated measurement technique including accurate measurement of the phase difference between the lamp current and voltage seems to be necessary for the correct estimation of the sheath voltage in sine-wave driven EEFL.

5. Acknowledgments

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6. References

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