Influence of Glass Tube Dielectrics on the New Generation of External Electrode Fluorescent Lamps

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Abstract

An EEFL with the sodium free alumino-silicate glass of high K and low tanδ, has been investigated. As compared with borosilicate and the soda-lime EEFLs, the luminous efficiency as well as the pinhole stability of new EEFLs improves remarkably without blackening of $NaHg_2$.

1. Introduction

The external electrode fluorescent lamps (EEFLs) comparable with CCFLs in luminance and efficiency have been developed since 2000, with the same operational frequency of 100 *kHz* and below [1-3]. The LCD-TV equipped with backlight units of multi-EEFLs driven by a single inverter has recently been commercialized, with a number of merits, including long lifetime, simple manufacturing process, and low cost.

EEFL uses the capacitive-coupled discharge through the external electrode. The capacitor consists of the external electrode and the glass itself; therefore the permittivity of the glass is a crucial factor. However, the glass tube presently used for EEFLs, has been produced to adjust for CCFLs by matching the coefficient of thermal expansion (CTE) of the glass material to the CTE of the electrode lead material of the cold cathode. This study was accomplished to find the glass tubes optimized for EEFLs in terms of dielectric constant-K, dielectric loss angle tanδ and dielectric loss factor-$D=\tan\delta/K$ [4], pinhole and blackening of Hg consumption.

2. Dielectric Properties on the EEFLs

The capacitance C can be represented as a complex quantity with a real C_r and an imaginary C_i. The dielectric constant K is related to the actual capacitance. The imaginary C_i corresponds to the dielectric power loss when the AC power is applied. The magnitude of dielectric loss is represented with the dielectric loss angle $\tan\delta=C_i/C_r$ [5]. When operating the EEFL with AC power, the energy dissipation takes place at the complex capacitance of the electrodes. The smaller the value of $\tan\delta$ is, the better is the efficiency of the EEFL since the generation of heat is low at the external electrode. The pinhole creation is also related to the heat on the electrode [6]. A small value of $\tan\delta$ reduces the risk of pinhole. Therefore, a high K as well as a low $\tan\delta$ turns out to be desirable for the glass tube of EEFLs.

Considering the complex capacitance as $C=C_r+jC_i$ with the operating AC voltage, the current is calculated from $I(t)=C^*\{dV(t)/dt\}$ with the complex conjugate $C^*=C_r - jC_i$. In this case the phase difference between current and voltage is $\theta=\pi/2-\delta$ where the angle δ comes from the complex value of C_i with the relation of $\tan\delta=C_i/C_r$.

With the capacitive reactance $X_c=1/j\omega C_r$ and the resistance $R_c=1/\omega C_i$, the power consumption due to the resistance R_c is given by the time average of $P=Re\langle I^*V\rangle/2$ and results as,

$$P=\frac{V_o^2}{2\cdot|X_c|}\tan\delta \qquad (1)$$

The above equation presents the dielectric power loss due to the imaginary C_i. Where V_0 is the voltage,

The equivalent circuit of an EEFL is analyzed with the lamp plasma resistance R_L and the capacitance of the external electrode itself. The electric powers at the discharge lamp and the capacitance of external electrode are calculated respectively. The equivalent circuit of the EEFL is shown in Figure 1.

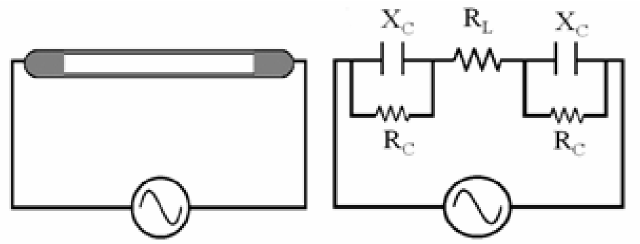

Fig 1. Circuit of EEFL (left) and it's equivalent circuit (right)

The lamp resistance of R_L is the resistance of the plasma. When the EEFL is operated at the normal glow discharge, the order of R_L is about 10~100 $k\Omega$. The capacitive reactance of the external electrode itself is considered as X_c and R_c. X_c comes from the real part of capacitance and R_c comes from the imaginary capacitance.

The ratio of the power consumption, the power of the external electrode capacitor over the power of the lamp itself, is represented as $\eta=P(C)/P(R_L)$ with $\tan\delta << 1$;

$$\eta = P(C)/P(R_L) \approx \frac{2\cdot\tan\delta}{\omega C_r R_L} \sim D \qquad (2)$$

where the dielectric loss factor contains only material properties of the glass tube and is defined by $D \equiv \tan\delta/K$. The ratio of power in Eq. (2) shows that the power loss at the capacitor of the external electrode is proportional to the dielectric loss factor D.

3. Experiments

For the purpose of optimizing the material properties of the glass tube for EEFLs, four samples are prepared with different glass compositions and therefore different dielectric constant, K, and dielectric loss angle, tanδ. According to the analysis of the previous section, we expect the best glass material for EEFL to be the glass having a high-*K and low* tanδ as dielectric properties.

In this experiment, the dielectric data measured in four different tube glasses are presented with the luminance and efficiency is compared for the four different EEFL tube glasses. The pinhole stability and the blackening are also described.

The glass samples are listed in Table 1 with the dielectric values measured in this experiment. The samples are 4-kinds of glass materials: two conventional borosilicate tubes, currently used in CCFLs and EEFLs, a soda lime glass, and an alkaline-free aluminosilicate glass as a new glass for EEFL. The conventional borosilicate tubes have an adapted coefficient of thermal expansion (CTE) to seal the end of tube with the metal feed-through of the cold cathode electrode. One sample of CCFL tube glass is adapted to the CTE of Tungsten lead line, represented as CCFL(W). The other tube has a CTE which matches to Kovar, a Fe-Co-Ni alloy, noted as CCFL(KO).

In Table 1, the values of glass dielectric properties measured with a LRC meter at the ambient temperature 25 ^oC and the high temperature of 150 ^oC and 250 ^oC with the frequency of 65 kHz, are listed as the dielectric constant K, the dielectric loss $\tan\delta$, and the D-factor.

At the temperature of 25 ^oC , the dielectric values of two tube samples of borosilicate glass currently used for CCFLs are K=4.9~5.3, $\tan\delta$~(23~24)×10^{-4}, and D~(4.3~4.9)×10^{-4}. New alkaline-free alumino-silicate glass tube has a higher dielectric constant of K=6.0, a lower dielectric loss of $\tan\delta$ =8×10^{-4}, and a lower dielectric loss factor of D=1.4×10^{-4} as compared with the conventional borosilicate glasses. Soda-lime glass has the highest value of K =7.2, the highest dielectric loss of $\tan\delta$=70×10^{-4}, and the highest dielectric loss factor of D=9.7×10^{-4}. The value of the dielectric loss in the soda-lime glass is almost 10 times higher than that of the alumino-silicate glass. As compared with the borosilicate CCFL-glass samples, the alumino-silicate glass has a 20% higher K and a three times lower $\tan\delta$ than borosilicate glass.

Table 1. Temperature dependence of the dielectric parameters

65 kHz	Temp.	Dielectric Constant (K)	Dielectric Loss tanδ (10^{-4})	D-factor (tanδ/K) (10^{-4})
CCFL (W) glass	25 ℃	4.9	24	4.9
	150 ℃	5.0	94	18.8
	250 ℃	5.4	498	92.9
Alumino-silicate glass	25 ℃	6.0	8	1.4
	150 ℃	6.1	10	1.6
	250 ℃	6.1	13	2.1
CCFL (KO) Glass	25 ℃	5.3	23	4.3
	150 ℃	5.4	54	10.0
	250 ℃	5.6	163	29.1
Soda-lime Glass	25 ℃	7.2	70	9.7
	150 ℃	8.3	450	54.6
	250 ℃	11.1	3453	311.1

The dependence of dielectric loss on the temperature is an important issue since the temperature at the external electrode increases as the lamp current increases during the operation of an EEFL. The temperature dependence of the dielectric parameters for CCFL(W), CCFL(KO), the alumino-silicate glass, and soda lime glass, is listed at the temperature of 25, 150, and 250 (^{o}C) in Table 1. The variation of dielectric loss for the alumino-silicate is very low, while the values of dielectric loss of the borosilicate and soda-lime increase very high as the temperature increases. Those high values of dielectric loss is expected to be low performance during the operation of the lamps since the temperature at the external electrode increases with the lamp current due to the heat dissipation caused by the dielectric power loss.

In the circuit of the EEFL shown in Figure 1, the power loss at the dielectric capacitor of the external electrode can be estimated with the power ratio of $\eta \sim tan\delta/(\omega C R_L) \sim P(C)/P(R_L)$ in Eq. (2). Generally, the EEFL has a capacitance of approx. $C \sim 10$ *pF* and a resistive load of $R_L \sim 20$ *kΩ*. With the operation frequency $\omega \sim 2\pi f$ of $f \sim 60$ *kHz*, the power ratio is obtained as $\eta \sim$ 13.9$tan\delta$. At room temperature of 25 ^{o}C, the ratio of power consumed at the dielectric capacitor of the external electrode is about $\eta \sim 3.3$ *%* for the borosilicate glass, $\eta \sim 1.1$ *%* for the alumino-silicate glass, and $\eta \sim 9.7$ *%* for soda-lime glass. For example, when the total input power is $P \sim 10$ *W* at room temperature in each EEFL-glass sample, the power consumption at the external electrode itself due to the dielectric loss is estimated as *P(C)* ~0.33 *W* for the borosilicate CCFL glass, *P(C)* ~0.11 *W* for the new alumino-silicate glass, and *P(C)* ~0.97 *W* for soda lime glass. However, those powers will be dissipated into heat on the external electrode so that the temperature of the glass of the external electrode escalates and the power loss ratio η increases dramatically when the value of $tan\delta$ depends strongly on the temperature as shown in CCFL glasses and soda lime glass in Table 1. When the temperature increases from 25 ^{o}C to 150 ^{o}C as shown in Table 1, the power loss is *P(C)* ~ 1.3 *W* in the CCFL-glass and *P(C)*~0.1 *W* in the new aluminosilicate glass for the total lamp power of 10 *W*. The power loss in a soda lime glass EEFL is from 0.7 W at room temperature to 4.3 W at 150 °C for the total input power of 10 W. The loss power converts to heat at the external electrode, this heat causes the increase of temperature, and the high temperature results in a dielectric loss, so that the value of $tan\delta$ escalates with increasing temperature at the external electrode.

The luminance and efficiency is investigated for the four different glass tube samples. All the glass tubes have an outer diameter of 4.0 *mm*, a glass thickness of 0.4 *mm*, and a length of 400 *mm*. The RGB phosphor was coated on the inside surface and the external electrode was pasted with silver and has a length of 20 *mm*. The operation frequency is 65 *kHz* with the sinusoidal wave of a DC-AC inverter.

Figures 2(a)~2(b) show the performance of EEFLs made with four glass tube samples. The luminance versus input power is represented in Fig. 2(a) and the relative efficiency versus the input power, normalized with the efficiency of borosilicate CCFL-glass, which is set to 100% in efficiency, is presented in Fig. 2(b).

In Fig. 2(a), the luminance increases and saturates as the input power increases. For the conventional EEFLs made with CCFL-glasses, the saturated luminance is about 20,000~25,000 cd/m^2 at the power of 8 *W*. In the alumino-silicate EEFL, the saturated luminance reaches 30,000 cd/m^2 at the power of 10 *W* and the luminance increases above 30,000 cd/m^2 maintaining a stable operation even when the input power increases up to 38.8 *W*.

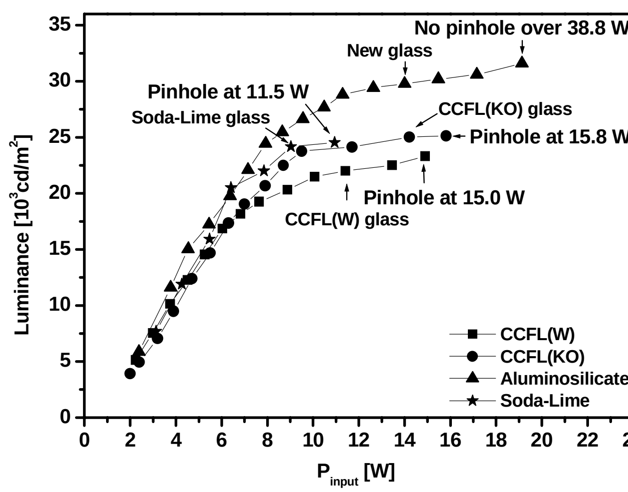

Fig 2 (a) Luminance versus input power for the four EEFL sample glasses: CCFL(W)-glass, CCFL(KO)-glass, alumino-silicate glass, soda-lime glass

The EEFL made with soda lime glass shows almost the same trends in luminance as the conventional borosilicate CCFL glasses, while the EEFL of soda-lime glass is very weak against pinhole stability. Even if the soda-lime glass has a high dielectric constant K, the high value of dielectric loss tanδ causes a larger power loss at the capacitor of external electrode itself and leads to a low performance.

Fig. 2(b) shows the relative efficiency compared with the CCFL-glasses. The EEFL using the new alkaline-free alumino-silicate glass shows a 15~25% higher efficiency than the borosilicate glasses. Especially, the EEFL made with the new alumino-silicate glass keeps its high luminance with a high efficiency.

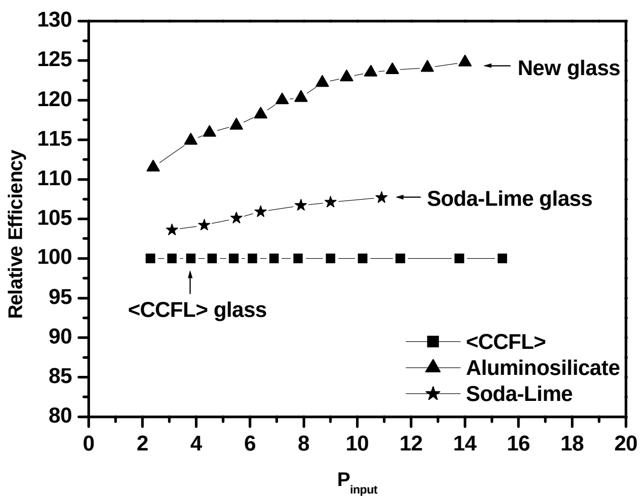

Fig 2. (b) Relative efficiency versus input power for the EEFLs with alumino-silicate glass and soda-lime glass in comparison to the conventional EEFLs of CCFL-glass which is 100.

It reflects two facts. One is that even if the input power increases with increasing lamp current and lamp luminance, a relatively small portion of the input power is dissipated at the glass dielectric capacitor of the external electrode itself so that the high efficiency is sustained at the high luminance. In addition, the new alumino-silicate glass has some potential to be used in an EEFL with the high luminance of 20,000 cd/m^2 as compared with the conventional EEFLs of borosilicate glasses currently used with the luminance of 10,000 cd/m^2.

The pinhole is also strong relation to the temperature of glass during EEFL operation [6]. In the above EEFL samples, the pinhole occurs at 15.0 *W* for CCFL(W)-glass tube, at 15.8 *W* for CCFL(KO)-glass, while a pinhole was not detected even at a high power 38.8 *W* for new aluminosilicate glass, and it occurs at 11.5 *W* for the soda lime glass, respectively. As shown in this experiment, the soda-lime glass is the weakest against pinhole formation since the soda-lime glass has the highest value of $tan\delta$, which increases steeply with increasing temperature. While the EEFL made of alumino-silicate glass is strong against pinhole formation due to the low value of $tan\delta$, whose value is nearly constant with increasing temperature.

Regarding the blackening experiments, the sodum-free glass tube of alumino-silicate has no blackening observed in a long run operation of EEFL.

4. Summary and Conclusion

Four glass tube samples are prepared with identical geometries with different K and $tan\delta$. Two samples of conventional borosilicate glasses having K=4.9~5.3 and $tan\delta$=(23~24)×10^{-4}, a new alkaline-free alumino-silicate glass tube having high K~ 6.0 and low $tan\delta$~8×10^{-4}, and a soda-lime glass tube with high K~7.2 and high $tan\delta$~70×10^{-4} at room temperature. The new alumino-silicate glass tube sample of high-K with low-$tan\delta$ shows a high luminance, a high efficiency: the luminance reaches above 20,000 cd/m^2 sustaining high efficiency, the efficiency is 15~25 % larger than that of the other three EEFLs containing borosilicate and soda-lime glass. In the new alumino-silicate glass the pinhole does not occur even at a high input power over 38 W and the blackening of Hg consumption has not observed.

The sodium free alumino-silicate glass tube of high-K and low $tan\delta$ will be a new generation of EEFLs improving the performance even at the high luminance, the high reliability, and the life time for the BLU-technology of LCD-TV.

5. Acknowledgments

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6. References

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