EFFECT OF STRUCTURAL PARAMETERS ON TEMPERATURE DISTRIBUTION OF ORGANIC LIGHT EMITTING DIODE PANELS

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This paper describes the temperature distribution of an organic light emitting diode (OLED) panel calculated by a finite element method (FEM) and measured. Organic LEDs (OLEDs or organic electro luminescence) are examples of solid-state lighting (SSL) that have been rapidly developed and applied in many practical fields owing to their high efficiency and on mercury-free operation. However, energy is lost as heat from OLEDs; therefore, a solution to the problems of heat transfer technology is important. It is preferable to operate an OLED below 50 °C in order to avoid degradation and change of colour at higher temperatures. Some of the authors have reported the influence of structure, materials, and dimensions on the temperature distribution of an OLED panel calculated by FEM [Kobayashi 2012&2014]. However, the analysis was conducted under a condition where heat radiation was neglected. In the present paper, both heat transfer and radiation were considered, then temperature distributions of an OLED panel having a glass substrate were measured by an infrared thermography. As a result, it was found that the maximum temperature of the OLED panel with a heat generation of 333 W/m2 was around 37 °C and the values obtained by one dimensional equations were consistent well with those obtained 3D-FEM analysis, and the temperature difference between the panel center and the end was around 14 °C. The estimation was verified by the measurement using thermography.

KEYWORDS

OLED, organic LED, temperature, FEM, design of experiment, heat transfer

1 INTRODUCTION

Light emitting diodes (LEDs) and organic LEDs (OLEDs or organic electro luminescence) are examples of solid-state lighting (SSL) that have been rapidly developed and applied in many practical fields owing to their high efficiency and on mercury-free operation, as shown in Table 1 [Nozawa 2008], [DOE 2011]. The lighting efficiency is expressed by lm/W. However, energy is lost as heat from LEDs and OLEDs; therefore, a solution to the problems of heat transfer technology is important, especially for LEDs that act as point heat sources [5]. It is preferable to operate an OLED below 70–80 °C in order to avoid degradation at higher temperatures. Fortunately, owing to the geometry of a thin and planar light source, the generated heat is dispersed and the heat flux is small, enabling a relatively easy control of temperature. On the other hand, LEDs, which are inorganic light-emission devices, have a relatively good heat resistance, but degrades thermally [DOE 2011]. Therefore, it is embedded in a transparent organic resin. In addition, an LED has a small tip that generates high luminescence with a large heat flux emanating from a point, i.e., it is a high-density heat source. Hence, to obtain high light flux with an LED, numerous LED tips must be embedded onto a flat substrate, resulting in a high cost for the parts and their assembly. To overcome this shortcoming, a small number of LED tips with higher power is generally mounted onto the substrate with an aluminum plate for heat conduction, [Qin 2010], the point heat source is converted into a planar heat source. Recently, such a thermal design has been employed to address heat dissipation problems. In particular, the panel temperature of SSL not only influences the lifetime but also the color of light and efficiency [Chou 2007]. Thus, reduction and uniformity of the lighting panel temperature are important. We herein study the influence of structure, materials, and dimensions on the temperature distribution of OLED and LED panels.

Light source	Efficiency [lm/W]	Mercury	Geometry
Light bulb	15	Free	Bulk
Fluoresce	60-100	contain	Bulk
LED	40-100	Free	Bulk, Point
OLED	15-60	Free	Thin, Planar

Table 1. Characteristic of typical light sources

2 TYPICAL STRUCTURE OF AN OLED PANEL

A cross-sectional view and a schematic illustration of a typical OLED panel are shown in Figs 1 and 2. An OLED panel has a multilayer structure because OLED device layers must be encapsulated by a glass cover plate to prevent degradation due to humidity. In general, the encapsulated space is filled with dry nitrogen or insulation oil. A desiccant may be inserted in the space to absorb the residual moisture and outgas from the polymer adhesive. Barium oxide is a common desiccant owing to its high moisture absorbing capability. In addition, a metal plate may be attached to the encapsulation glass as a countermeasure against the heating problems.

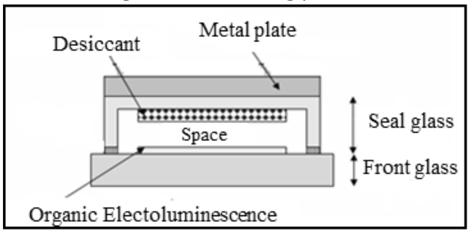


Figure1. Typical cross-section of an OLED panel

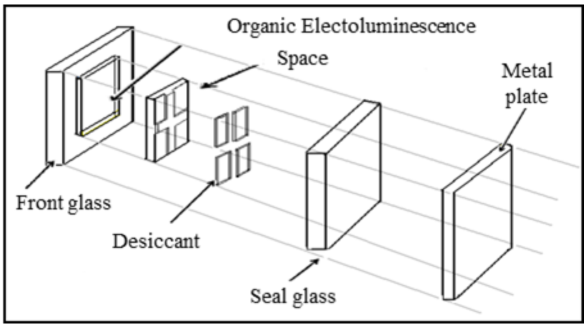


Figure 2. Schematic diagram of an OLED panel structure

3 ANALYSIS METHOD

3.1 One-dimensional Analysis

To estimate temperature distribution in the direction of panel thickness, one dimensional calculation was conducted. The model for the calculation is shown in Fig.3, and equations of heat flux are shown as following,

$$q = (q_R + q_R') + (q_L + q_L') \quad (1)$$

$$q_R + q_R' = \alpha(T_{R2} - T_A) + \varepsilon\sigma(T_{R2}^4 - T_A^4) \quad (2)$$

$$q_R + q_R' = \lambda s(T_{R1} - T_{R2})/d_s \quad (3)$$

$$q_R + q_R' = \lambda g(T_{L1} - T_{R1})/d_g \quad (4)$$

$$q_L + q_L' = \lambda s(T_{L1} - T_{L2})/d_g \quad (5)$$

$$q_L + q_L' = \alpha(T_{L2} - T_A) + \varepsilon\sigma(T_{L2}^4 - T_A^4) \quad (6)$$

where T_{L1} [°C] is the temperature at organic thin film layers, T_{L2} [°C] is the surface temperature at front glass, T_{R1} [°C] is the inner surface temperature at back plate (encapsulation glass), T_{R2} [°C] is the surface temperature at back plate. Heat flux generated at the organic layers is q [W/m^2], heat flux to the front glass side is q_L [W/m^2], radiation heat flux from the front glass is q_L' [W/m^2], heat flux to the back plate side is q_R [W/m^2], radiation heat flux from the back plate is q_R' [W/m^2], λs [W/m/K] is the thermal conductivity of the glass substrate, λg [W/m/K] is the thermal conductivity of the substance encapsulated in the space, ds [m] is the thickness of the front glass, d_g [m] is the thickness of the space in seal glass. α [W/m^2/K] is the heat transfer coefficient [W/(m^2·K)], ε is emissivity of the surface and T_A [°C] is the ambient temperature. Parameters used are shown in Table 2.

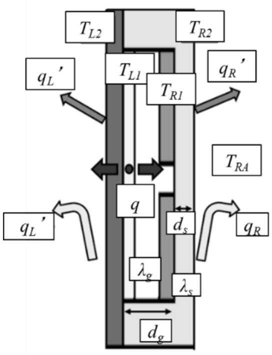


Figure 3. Cross sectional drawing of a one dimensional calculation model of an OLED panel

q [W/m^2]	λ_S [W/m/K]	λg [W/m/K]	ds [m]	dg [m]	α [W/m^2/K]	T [℃]
333	0.55	0.0241 (air) 0.1553 (Helium) 0.1849 (Si oil)	0.7	0.0007	5	20

Table 2. Parameters and constants used in one dimensional calculation

3.2 Three-dimensional Analysis

A three-dimensional model was constructed and the temperature distribution and thermal deformation were calculated by FEM analysis. The analysis involved around 9000 elements and 18000 nodal points. An example of the meshing model and the temperature distribution of an OLED panel obtained by FEM analysis are shown in Fig. 4 and Fig.5 respectively.

3.3 Multiple regression analysis

Eight parameters were selected for the OLED panel shown in Fig.3. Three levels for each parameter were considered in a range of applicable condition for practical design as shown in Table 3. Design of Experiments (DOE) was employed to reduce the calculation cases rationally, that is the parameters were allocated in the L_{18} orthogonal table shown in Table 4. The result obtained by the calculations was analysed by multiple regression analysis, then two regression equations were created where the effects of the parameters on the maximum temperature and the temperature difference between the center of panel and end are obtained, further the influence factor of each case was calculated. The influence factor is the value obtained by multiplying the weight and the range of each parameter.

Factor	Level1	Level2	Level3
Desiccant	With	Without	-
Emissivity	0.6	0.8	1
Heat flux generated[W/m^2]	1.67E+06	3.33E+06	5.00E+06
Thermal conductivity[W/m/K]	0.0241	0.1553	0.1848
Thickness of metal plate[mm]	0	0.5	1
Thickness of glass substrate[mm]	0.3	0.7	1
Coefficient of heat transfer[W/m^2/K]	5	10	15
Ambient temperature[K]	283	293	303

Table 3. Parameters used for multiple regression analysis

No.	Desiccant	Emissivity	Heat flux generated [W/m^2]	Thermal conductivity [W/m/K]	Thickness of metal plate [mm]	Thickness of glass substrate [mm]	Coefficient of heat transfer [W/m^2/K]	Ambient temperature [K]
1	1	0.6	1665000	0.0241	0	0.3	5	10
2	1	0.6	3330000	0.1553	0.5	0.7	10	20
3	1	0.6	5000000	0.1848	1	1	15	30
4	1	0.8	1665000	0.0241	0.5	0.7	15	30
5	1	0.8	3330000	0.1553	1	1	5	10
6	1	0.8	5000000	0.1848	0	0.3	10	20
7	1	1	1665000	0.0241	0	1	10	30
8	1	1	3330000	0.1553	0.5	0.3	15	10
9	1	1	5000000	0.1848	1	0.7	5	20
10	0	0.6	1665000	0.0241	1	0.7	10	10
11	0	0.6	3330000	0.1553	0	1	15	20
12	0	0.6	5000000	0.1848	0.5	0.3	5	30
13	0	0.8	1665000	0.0241	1	0.3	15	20
14	0	0.8	3330000	0.1553	0	0.7	5	30
15	0	0.8	5000000	0.1848	0.5	1	10	10
16	0	1	1665000	0.0241	0.5	1	5	20
17	0	1	3330000	0.1553	1	0.3	10	30
18	0	1	5000000	0.1848	0	0.7	15	10

Table 4. L_{18} orthogonal table

4 RESULT

4.1 Effect of the thermal conductivity of encapsulated substance multiple regression analysis

An example of the meshing model and the temperature distribution of an OLED panel obtained by FEM analysis are shown in Fig. 4 and Fig.5 respectively. Fig.6 shows the effects of the thermal conductivity of the encapsulated substance in the space on the surface temperature (T). The maximum temperature can be reduced by around 2°C if the encapsulating nitrogen gas, which has a thermal conductivity (λ_g) of 0.02 [W/(m /K)], is replaced by another substance with a thermal conductivity of around 0.15 [W/(m /K)], for example helium gas or silicon oil. With increasing the thermal conductivity of the encapsulated substance in the space, the front panel temperatures T_{L2} and T_{L1} decrease as above mentioned, however the back panel temperatures T_{R1} and T_{R2} increase since heat fluxes toward front and back direction are varied due to the change of thermal resistance of each direction. For example, heat flux to the front side $q_L + q_L'$ and to the back side $q_R + q_R'$ are 190 and 143 [W/m^2] in the case of λg =0.0241 [W/m/K] , and 170 and 163 [W/m^2] in the case of λg =0.1848 [W/m/K], respectively. The obtained values by one dimensional analysis were consistent well with that of three dimensional analysis, although the maximum temperature obtained by three dimensional temperature shows a little lower owing to the existence of the sealing area where no heat generated and heat is dissipated.

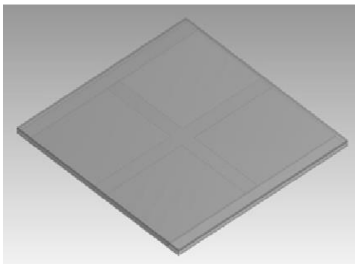


Figure 4. An example of meshing model for FEM analysis

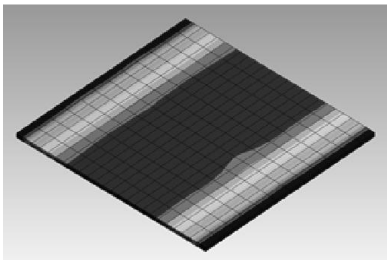


Figure 5. An example of temperature distribution of an OLED panel obtained by FEM analysis

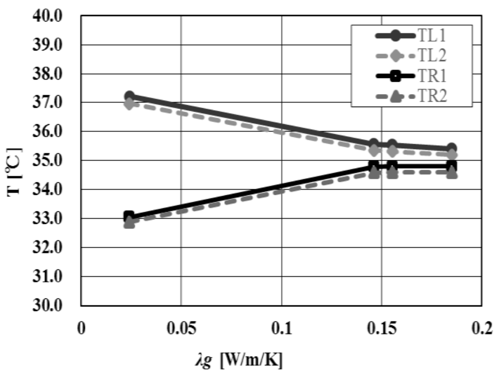


Figure 6. Influence of the thermal conductivity of the substance encapsulated in the space on the maximum temperature of OLED panel

Figure 7 shows the effects of the thermal conductivity of the encapsulated substance in the space on the temperature difference between the center and end surfaces. The temperature difference is decreased by 3.5 °C when the substance is changed from nitrogen to silicon oil or helium gas. The reason is suggested that the maximum temperature decreases as shown in fig.6 and the temperature of the sealing area also decreases.

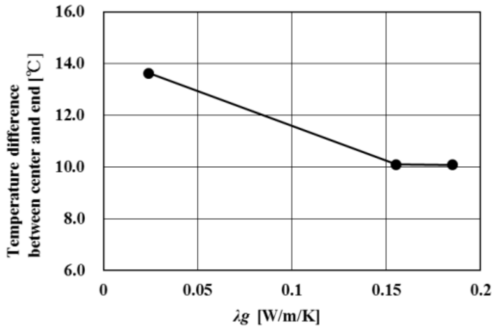


Figure 7. Influence of the thermal conductivity of the substance encapsulated in the space on the temperature difference between the center and end surfaces of the OLED panel

4.2 Effect of a metal plate

A metal plate may be attached to the capsulation glass to facilitate heat radiation. The effect of the metal plate on the OLED plate was investigated quantitatively. The metal plate was assumed to be made of aluminum, with a thickness of 1 mm. Other parameters were the same as those shown in Table 2. The calculated results are summarized in Fig. 8. Without metal plate, the temperature difference between the center and end surfaces is around 14 °C, however the temperature difference will be decreased to 6 °C by attaching aluminum plate, further the maximum temperature can be decreased by 4 °C.

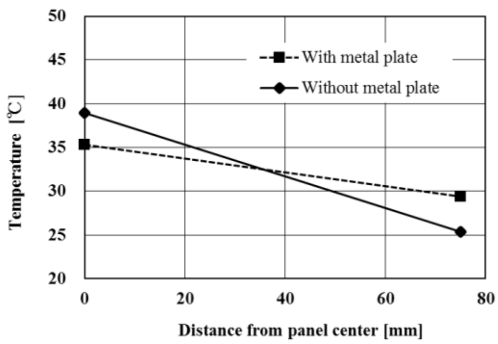


Figure 8. Influence of the metal back plate on distribution of surface temperature of the OLED panel

4.3 Result of multiple regression analysis

The 18 conditions allocated into orthogonal table were analyzed, and then multiple regression analysis on the effects of the parameters on the maximum temperature and the temperature difference between the center and end surfaces were conducted using the temperature distribution obtained. The obtained regression equations are shown below.

$$T_{max} = 27.8 + 1.57Q_a - 7.92Q_b + 2.21\text{x}10^{-6}Q_c - 83.2Q_d - 0.0830Q_e + 2.00Q_f - 1.51Q_g + 0.340Q_h \qquad (7)$$

$T_{diff} = 9.19 - 0.299Q_a - 0.354Q_b - 2.20\times10^{-7}Q_c + 73.7Q_d - 2.12Q_e + 10.7Q_f - 0.398Q_g - 0.117Q_h$ (8)

where, T_{max} : maximum temperature, T_{diff} : temperature difference between the center and end, Q_a : with or without desiccant, Q_b : emissivity, Q_c : heat flux generated, Q_d : thermal conductivity, Q_e : the thickness of metal plate, Q_f : the thickness of glass substrate, Q_g : coefficient of heat transfer, Q_h : ambient temperature. Using the regression equation obtained by the FEM calculation results, the T_{max} and T_{diff} can be estimated without the change of CAD diagram and FEM analysis in a range of the present condition.

As shown in Fig.9, it was found that the influence factor on the maximum temperature T_{max} is greater in the order of the coefficient of heat transfer, the thermal conductivity of the encapsulated substance, the heat flux generated and the ambient temperature. Fig.10 also shows the influence of the parameters on the temperature difference between center and end surfaces of the OLED panel. The influence factor on the T_{diff} is greater in the order of the thermal conductivity of the encapsulated substance, thickness of the metal plate and the coefficient of heat transfer. These result and the method is useful for designing OLED panels in a range of practical application.

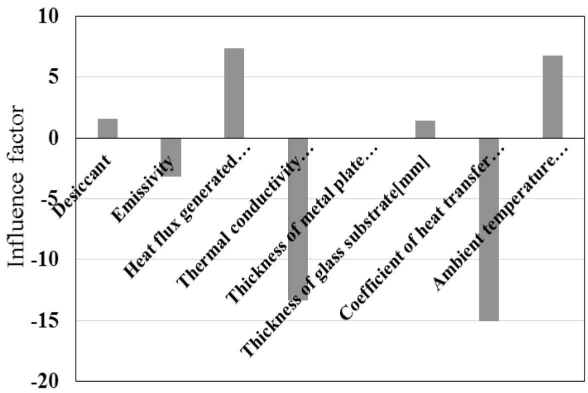


Figure 9. Influence of the parameters on the maximum temperature of the OLED panel

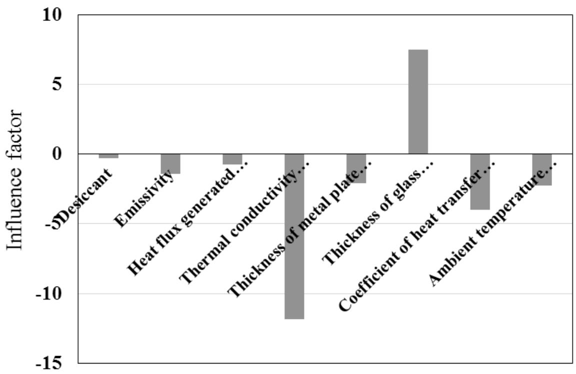


Figure 10. Influence of the parameters on the temperature difference between center and end surfaces of the OLED panel

5 EXPERIMENTAL RESULT AND DISCUSSION

Experimental results are required to verify the calculated results. However the large OLED panels having an emission area of 100 mm x 100 mm shown in Fig.4 have not been on sale. Therefore, a smaller panel with a dimension of 30mm x 34 mm which was trial manufactured by the author's group was examined, that is, both FEM analysis and experimental measurement were carried out in order to confirm the modeling method and the parameter values used. The layer structure is glass/ITO/CuPc/NPD/CBP/BAlq/Alq_3/LiF/AgMg which is a typical structure for fluorescent type device. The pattern of the OLED panel proto-typed is shown in Fig.11.

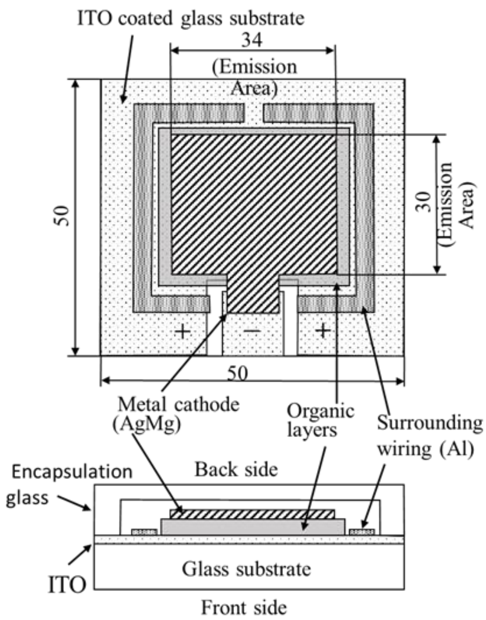


Figure 11. A pattern of the OLED panel proto-typed

The transparent conductive oxide (TCO) of anode has much lower electric conductivity than that of metal cathode, thus the current density in remote area from power feeding point is lower resulting in uneven distribution of brightness. Therefore surrounding wiring made of metal thin films were deposited outside of the emission area with a dimension of 30mm x 34 mm, to improve the uneven distribution of brightness.

5.1 Experimental method and result

The specimens for measuring current-voltage-luminance (I-V-L) performance and temperature distribution were prepared using glass substrate with an indium tin oxide (ITO) as transparent anode. The multi layers were deposited on the substrate using a multi chamber vacuum deposition equipment in a vacuum pressure of 1-2 x 10^{-4} Pa and a deposition rate of 0.1-0.2 nm/s. In the case of LiF deposition, the deposition rate was 0.01 nm/s. Before coating, the substrates were cleaned in an organic solvent then rinsed by an organic alkali solution and purified water. At the last stage the ultra-violet ozone treatment was processed. Immediately after vacuum deposition, the specimens were covered by the encapsulation glass cap in a globe box filled with dry nitrogen that the degradation of the organic layers are prevented. The current-voltage-luminance (I-V-L) performance was measured by an OLED I-V-L Measuring System. The temperature distribution of the OLED panel was measured by an infrared thermo-viewer (CHINO; CPA-0170A). In Fig.12, an appearance of the trial manufactured panel is shown.

In Fig.13, a typical I-V characteristic and emission efficiency of the proto-typed OLED panel are shown. The measurement of temperature distribution was conducted under a condition of 8 V, 4.16 mA/cm^2. The temperature distribution measured on the front and back side are shown in Fig.13. Comparing the calculated result shown in Fig.5 with this empirical result, the difference was only a few degrees, although the specimen has a dimension of 30mm x 34mm, less than one fourth of the calculated model as above mentioned. Therefore the analysis of the smaller panel was carried out as the next section.

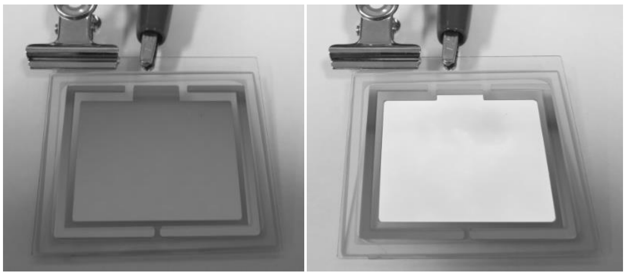


Figure 12. An appearance of the trial manufactured panel with an emission area of 34mm x 30 mm (Lift: Power off state, Right: Power on state)

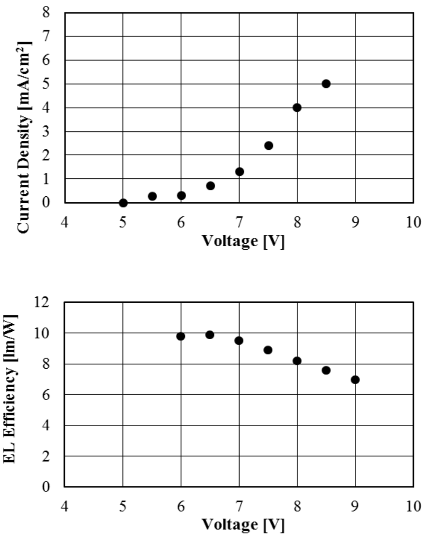


Figure13. Typical I-V characteristic and emission efficiency of the proto-typed OLED panel

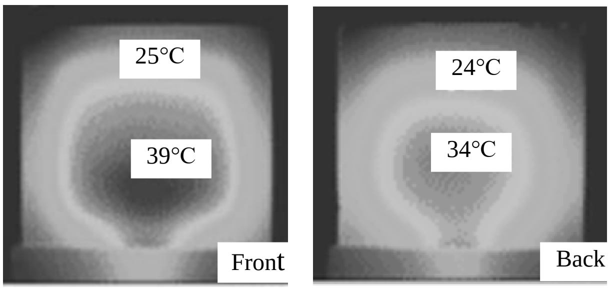
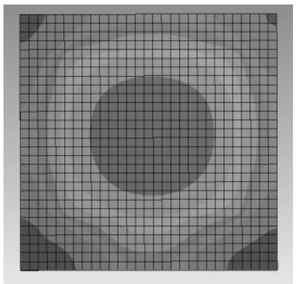


Figure 14. Temperature distribution of an OLED panel measured by a thermo-viewer (CHINO; CPA-0170A)

5.2 Analysis for confirmation

An series of thermal electric analysis was conducted, since it was found that the distribution of current density needs to be considered as shown in Fig.14. In the calculation, the following physical properties were applied: ITO 5x10^{-4} Ω·cm, Al 2.65x10^{-8} Ω·cm, Ag 1.59x10^{-8} Ω·cm, organic layer >1x10^{4} Ω·cm. The other parameters were pickup from Table 2 and Table 3. The obtained results are shown in Fig.15. In the case of an emissivity ε=0.95, the difference of temperature from Fig.14 is around less than two degrees. Consequently, it has been suggested that the results obtained in the present study are verified by the confirmation test as far as the parameters are used within the present study.



Front side

Figure 15. Result of thermal electric analysis considering the distribution of current density

6 CONCLUSIONS

The influence of structure, materials and dimensions on the temperature distribution of OLED was studied and following results were obtained..

(1) It has been suggested that the maximum temperature can be reduced by around 2 °C if the encapsulating nitrogen gas, which has a thermal conductivity (λ_g) of 0.02 [W/(m /K)], is replaced by another substance with a thermal conductivity of around 0.15 [W/(m /K)], for example helium gas or silicon oil.

(2) Further he maximum temperature can be decreased by 4 °C by attaching an aluminum plate having a thickness of 1mm.

(3)It was found that the influence factor on the maximum temperature T_{max} is greater in the order of the coefficient of heat transfer, the thermal conductivity of the encapsulated substance, the heat flux generated and the ambient temperature.

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