Passive thermal management of an OLED TV display

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In this study, passive thermal management of a 15'' OLED TV display is studied. In addition to the OLED display, the effect of other heat generating electronic components on the device is taken into account. Experimental temperature measurements are conducted on the OLED display. The CFD model of the device is developed in order to be able to predict the temperatures and validated with experimental results. A good agreement is obtained between CFD simulation and experimental measurements. To eliminate hot spots and homogenize the temperature distribution, heat spreaders like copper and graphite are used and the effects of them are discussed in detail.

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1. Introduction

Currently, it is preferred to use organic semiconductors in flat panel display devices due to their physical, optical and electrochemical properties. The basic Organic Light Emitting Diode (OLED) consists of a single organic electroluminescent layer between anode and cathode electrodes which are deposited on a glass substrate [1]. There is an increasing interest in OLED display technology over the last decade due to their superior properties. OLED displays have some important advantages such as low power consumption, being slim and lightweight, self-emissive, wide viewing angle, high contrast ratio, fast pixel response time. In addition, OLED layers can be deposited on the flexible substrate. Nowadays, OLED displays began to be preferable due to the fact that they provide advantages in so many products in consumer electronics, mobile telecommunication, military applications and medical fields. The disadvantages of OLEDs are mostly associated with their lifetime. Organic materials are sensitive to humidity and oxygen which degrade device performance. Thus appropriate encapsulation is required to prevent device degradation. Moreover, image sticking problem is one of the important problems for big size displays to be solved. In addition, OLED displays still compete with cost-effective Quantum Dot(QD) displays [2].

OLED cells are connected to backplanes which are comprised of OLED driver and components. This structure is called OLED module [3]. Thin structure of OLED display causes performance problems regarding device reliability. OLED devices generate heat during operation. This heat leads to temperature increase on the surface of the display. This situation becomes crucial especially for high gloss/brightness that needs high power applications. High temperatures affect the electro-optics features of organic semiconductors negatively [4]. In addition, nonhomogeneous temperature distributions lead to tension and deformations on the surface which means that the reliability of the device decreases rapidly [5-9]. Especially in transparent OLEDs, poor thermal conductivity substrate materials are used. Therefore, effective thermal management becomes more critical in this type of devices. The lifetime of an OLED working at 60-70 ^{o}C is reduced by half compared with room temperature [10]. Effective thermal management is an important topic in the area of OLED studies [11]. Many studies have been conducted on the thermal management of OLEDs in literature [12-15].

Slawinski et al. [16] investigated the electro-thermal behavior of a *5x5* inch OLED display through finite elements method. They indicated that temperature affects the current distribution and the brightness of the display crucially. Schwamb et al. [17] examined the passive method cooling mechanism of OLEDs. It is observed that the coefficient of the thermal conductivity is not stable and it changes the display. Therefore, the temperature distribution is not homogeneous. Chung et al. [18] analyzed the effects of the substrate thermal conductivity on the expected lifetime of OLEDs. They used silicon, glass and stainless steel foil as the substrate. It is observed that silicon substrates that have high thermal conductivity yield to lower OLED temperature. Therefore, it has a longer life. Ji-Hoon Choi et al. [19] studied power consumption control. Modeling is needed to reduce the power density in power consumption [20].

Low power consumption is achieved with minimum perceptual color distortion. In the above-mentioned studies, OLEDs are modeled at the pixel base/level. In the literature, to the best knowledge of the authors of this article, there has not conducted a detailed thermal management study at the display base. The aim of the present study is to analyze the heat transfer of an OLED TV display. Temperature distribution on the surface of the device is obtained by taking into consideration the effects of the other heat generating electronic components. Considering OLED device sizes and energy efficiency, the effects of heat spreaders like copper and graphite on the device are analyzed in response to improper methods like finned surfaces and active cooling.

This study focusing analysis of the passive thermal management of a 15’’ OLED TV display. In the last section of the study, Computational Fluid Dynamics (CFD) analysis is implemented with experimental results.

2. Heat transfer mechanism in OLED

OLED displays have a composite structure that consists of different layers which are placed on a substrate. The heat is generated due to electrical current passing through the organic layer which is placed between anode and cathode. The heat transfer mechanism of OLED is shown in Fig. 1 schematically.

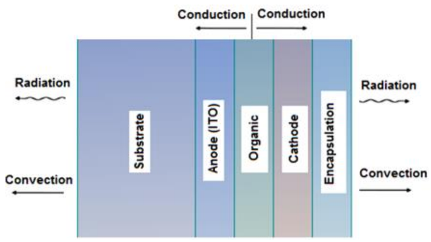

Fig. 1. The OLED heat transfer mechanism

The heat is generated in the OLED $Q_{thermal}$ is obtained;

$$Q_{thermal} = JV - Q_{optic} \tag{1}$$

where $Q_{thermal}$ is the thermal power generation of the device, J and V are the current density and voltage required for device operation, and Q_{optic} is the power removed in the form of emitted light. As can be seen from the figure, the basic transfer mechanism in the OLED is conduction. When multilayered composite mechanism of OLED is taken into consideration, effective thermal conductivity of the display is found by;

$$\frac{\sum t_i}{k_{effective}} = \sum \frac{t_i}{k_i} \tag{2}$$

where t_i is thickness of the layer and k_i is thermal conductivity of the layer. The thickness of the substrate in order of mm while that of the other layers in order of nm. Therefore, it is obvious that substrate is the most important element in terms of heat transfer.

Consequently, neglecting the effects of other layers in heat transfer analysis does not cause a remarkable loss in the accuracy of the solution.

The rate of heat transfer through radiation from the surfaces may be expressed by the Stefan-Boltzmann equation;

$$Q_{radiation} = \varepsilon \sigma A_s \left(T_s^4 - T_{surr}^4 \right) \tag{3}$$

where ε is emissivity of the surface, $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4 is the Stefan-Boltzmann constant, A_s is a surface area, T_s is surface temperature and T_{surr} is environment ambient temperature. The remaining part of the heat from radiation is transferred to the environment through convection. The convective heat transfer mechanism in OLED displays is natural convection which is also called passive cooling. According to Newton’s cooling law, the rate of heat transfer through convection is found by;

$$Q_{convection} = hA_s \left(T_s - T_\infty \right) \tag{4}$$

where h is the convective heat transfer coefficient and T_∞ is the ambient air temperature. Natural convection is a complicated physical problem which contains fluid motion and heat transfer. In this study, heat transfer analysis is performed by using the commercial finite volume code, Ansys Icepak.

3. Experimental temperature measurement

The OLED device used in experimental temperature measurement is shown in Fig. 2. The display is bottom emitted OLED and has a diagonal dimension of 15" and with aspect ratio 16:9. The device consists of OLED display, electronic circuit components, an interface plate and a metal case. The thickness of the OLED display, interface plate and metal back cover is 0.65 mm, 0.75 mm and 0.5 mm, respectively. The total heat generation in the display is 21 W and 4.7 W for the electronic integrated circuits on the board. Thermal conductivity values of the device components are given in Table 1.

Table 1. Thermal conductivities of OLED device components

Component	*k(W/m ^{o}C)*
Metal Case	205
Interface Plate	0.2
OLED Display	0.76

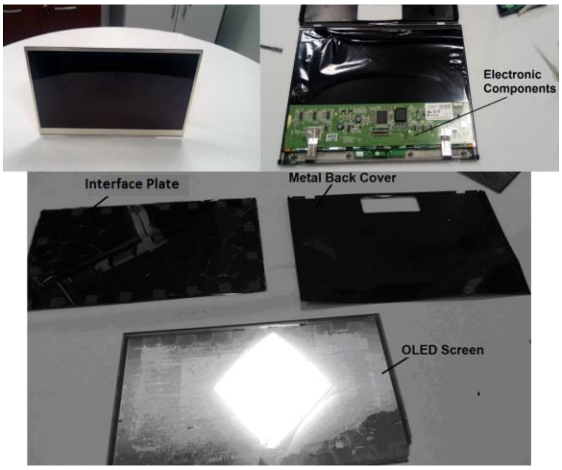

Fig. 2. OLED device components

The device is operated at full power in the temperature controlled cabinet at 40 ^{o}C. After the steady state condition is reached, temperatures are recorded with *k-type* thermocouple and thermal camera on the display screen. The placement of the thermocouples on the screen is given in Fig. 3.

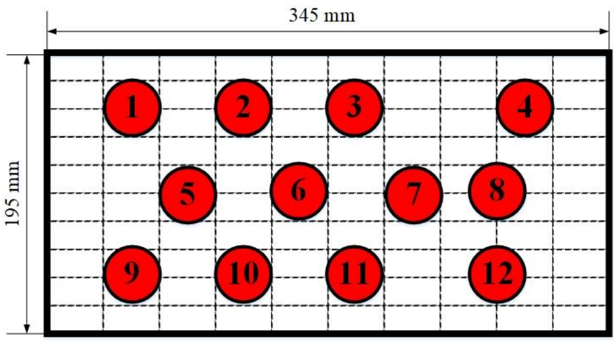

Fig. 3. Placement of the thermocouples

The thermal camera output of OLED display for this experimental work is given in Fig. 4. In addition to that, the temperature values of the thermocouples are shown in Fig. 5.

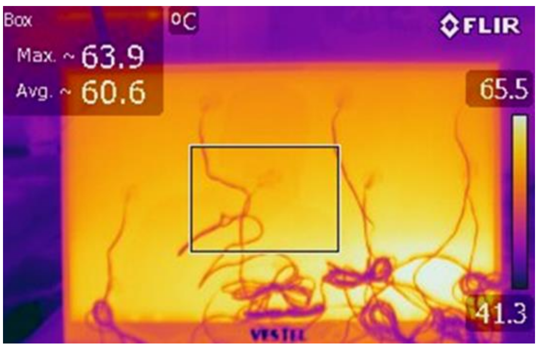

Fig. 4. OLED Thermal camera temperature distributions

As seen in Fig. 4 and Fig. 5 the heat generating electronic components significantly affect temperature values and distribution. On the contrary of natural convection temperature distribution, the maximum temperatures are located in the lower right section of the screen. In addition, an increase in the maximum temperatures is observed. That causes a problem for the reliability of the device.

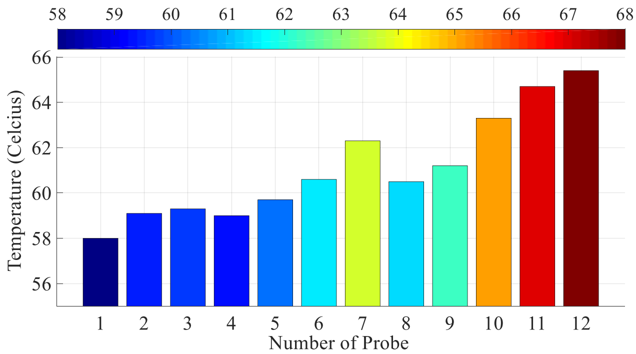

Fig. 5. Thermocouple temperature measurements

4. CFD simulation analysis

The temperature fields of OLED display device are numerically obtained by commercially available computational fluid dynamics software Ansys Icepak. The 3D solid model of the OLED device is built. In order to take into consideration the effect of natural convection device is taken into a 0.6m × 0.2m × 1m control volume as demonstrated in Fig. 6.

The flow is assumed steady and laminar. The open boundary condition is applied to the boundaries of control volume where pressure and temperature equal to ambient values. The heat generating components on the electronic board are power block, main ICs and amplifiers.

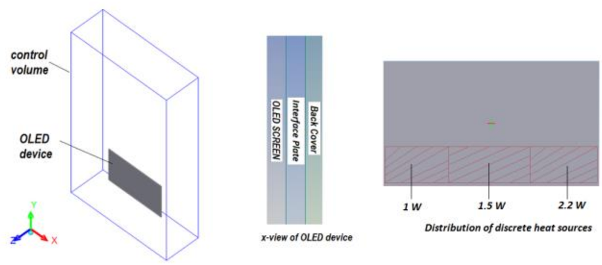

Fig. 6. Simulation model of OLED device

The effects of them are imposed as discrete surface heat flux on the OLED display. The radiative heat transfer from the surfaces is also taken into consideration. Governing equations related to the problem are solved by finite volume code.

The second order upwind scheme is used to discrete the convective and diffusive terms. The Simple algorithm is employed for the pressure and velocity coupling [21]. The convergence criteria residuals are set as 10^{-6} for the momentum, continuity and energy.

Several grid distributions are examined on the computational domain to ensure grid independent results. Table 2 illustrates the convergence of the maximum temperature with grid refinement.

Table 2. The convergence of the maximum temperature with grid refinement

Number of Elements	*Max. Temperature (^{o}C)*
11550	67.4302
60500	65.1251
153120	64.4654
1845580	64.4512

As can be seen from the Table 2, *153120* elements are enough for the model to be converged results without much computational effort and time.

5. Results

The simulated temperature distributions with the effects of electronic components are given in the Fig. 7a, while in the case of without effects of electronic components is presented in the Fig. 7b. It is clear that from the Fig. 7a that is a consistency between experimental measurements and simulation results. As can be seen from the Figs. 7a and 7b, the heat generating electronic components significantly affect the temperature values and distribution. This situation causes non-uniform current density on the display and reduces device performance. Moreover, non-homogeneous temperature distribution creates thermal stress and strain. As a result, device reliability is negatively affected.

The aim of this study is to obtain homogeneous temperature distribution on the display screen and increase the device reliability. For this purpose, different types of heat spreader are applied between the OLED display and interface plate. These are a copper sheet having isotropic thermal conductivity and graphite sheets having orthotropic thermal conductivity.

Graphite sheets are produced from pyrolytic graphite (PG) and annealed pyrolytic graphite (APG) materials at different thickness. All of the heat spreaders are covered with a very thin polyethylene terephthalate (PET film) layer for electrical isolation.

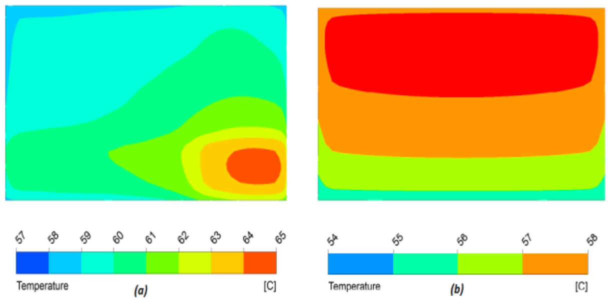

Fig. 7. Simulation results of the temperature distribution on the OLED display screen

Thermal conductivity and density values of copper and graphite materials are given in Table 3.

Table 3. Thermal conductivity and density values of heat spreader materials

Property	*Direction*	*Copper*	*PG*	*APG*
Density *(g/cc)*	X,Y,Z	8.89	1.7-2.2	1.7-2.2
Thermal Conductivity *(W/m ^{o}C)*	X,Y	388	400	1500
Thermal Conductivity *(W/m ^{o}C)*	Z	388	3.7	3.5

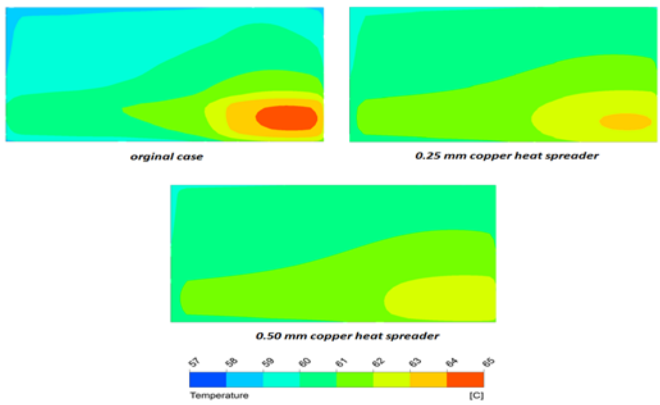

Fig. 8. Temperature distributions for copper heat spreader at different thickness

The effects of heat spreaders at a different thickness on the temperature distribution are shown in Figs. 8-10. It is obvious that most homogeneous temperature distribution is observed in APG heat spreader due to its superior thermal properties. Moreover, the effect of the heat spreader decreases with the decrease of the thickness. In Fig. 11, maximum and minimum temperature values on the OLED display are given when the original situation and heat spreaders are used. As it can be seen from the table, maximum and minimum temperature difference reduces considerably when graphite is used as a heat spreader. Thus, deformations that are caused by thermal stresses minimized and device reliability increases significantly.

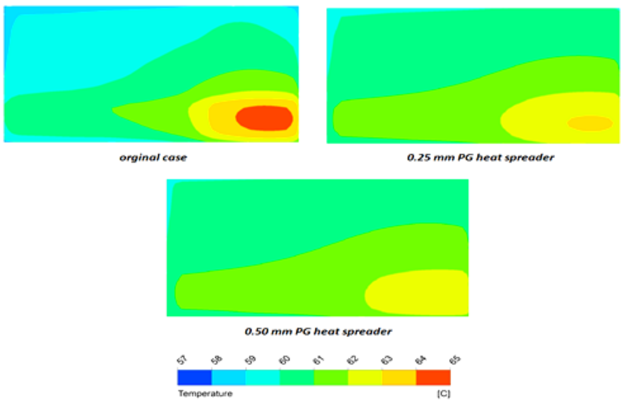

Fig. 9. Temperature distributions for PG heat spreader at different thickness

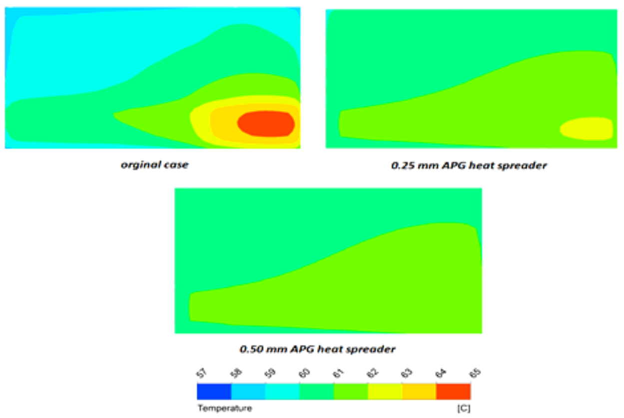

Fig. 10. Temperature distributions for APG heat spreader at different thickness

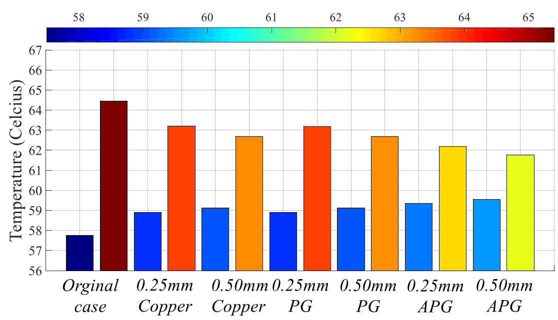

Fig. 11. Maximum and minimum temperatures on the OLED display

6. Conclusions

In this study, passive thermal management of a 15.6'' OLED TV display is considered. In addition to the OLED display, the effect of the other heat generating electronic components on the device is taken into account. Results show that, in addition to the OLED display, the heat generating electronic components on the device significantly affect the temperature values and distribution. To eliminate hot spots and homogenize the temperature distribution, copper and graphite heat spreaders are used. Additionally, the reliability of OLED display is investigated. Variable types of heat spreader are applied between the OLED display and interface plate to perform this research. These are a copper sheet having isotropic thermal conductivity and graphite sheets having orthotropic thermal conductivity. Thermal conductivity and density values of copper and graphite materials are investigated on OLED display. A good agreement is obtained between CFD simulation and experimental measurements. The most homogeneous temperature distribution is obtained in APG heat spreader. Copper and PG heat spreaders show similar temperature distribution. Consequently, the application of heat spreader significantly contributes to reliability of OLED devices.

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