

Design and Evaluation of Thermal Conductive Sheet Structure for Enhancing Thermal Stability of Transparent OLED

Se-Min Lee^{1,2}, Ju-Won Jung¹, and Young-Joo Kim^{1,*}

*yjkim40@yonsei.ac.kr

¹Department of Mechanical Engineering, Yonsei University, Seoul 03722, Korea

²Foundation Technology Laboratory, LG Display, Seoul 07796, Korea

Keywords: Transparent OLED, Thermal conductivity sheet, Carbon-black, Louver, Thermal stability

ABSTRACT

In the transparent OLED displays, both characteristics for optical and thermal uniformity are strongly required. To realize high thermal conductivity with low loss of transparency, we proposed and optimized a thermal-conductive sheet structure. After fabricating the sheet, the optical and thermal characteristics were evaluated experimentally to confirm the effectiveness of new proposed thermal-conductive sheet in the transparent OLED displays.

1 Introduction

OLED displays are sensitive to technical issues such as optical efficiency and color deviation under high temperature conditions. [1] [2] However, the driver IC that drives the OLED emits a relatively large amount of heat, causing localized heat concentration. The local temperature deviation impairs the optical uniformity in the display. Therefore, a thermal-conductive structure such as Al plate or graphite sheet is usually applied to OLED displays. Since the same thermal issue occurs with transparent OLEDs, thermal-conductive components must be applied. However, since typical thermal-conductive components are opaque, it is difficult to be applied for the transparent OLED displays. Thus, in order to improve both optical and thermal characteristics of transparent OLED displays, a research on novel component with high thermal-conductive property while being transparent is absolutely necessary.

2 Concept of Thermal Conductive Sheet Structure

2.1 Design and Fabrication

In general, materials with high thermal-conductive property are optically opaque. The examples are aluminum, graphite, carbon-black, and so on. According to the recent research trends, there have been many studies on transparent materials with high thermal conductivities. Currently, it seems that the best research result shows the transmittance of 75% or more and thermal conductivity of 2.5W/mK. [3] [4] In this study, we design an optimized sheet structure using an opaque material to take the advantage of its high thermal-conductive property. At the

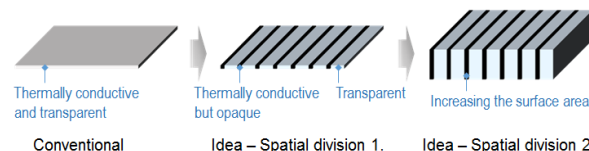


Figure 1. Concept of thermal-conductive sheet

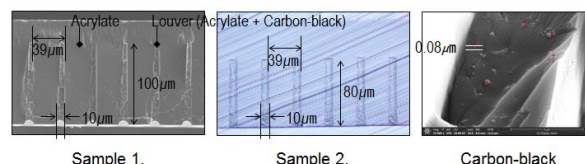


Figure 2. Fabricated thermal-conductive sheet

same time, since the sheet must be transparent, a structurally transparent area should be included spatially. Figure 1 shows the concept of our proposed sheet structure with the controlled heights. Then, a louver structure was optimized to realize best spatial division based on the optical and thermal simulation.

For the evaluation of thermal and optical characteristics, a feasibility sample was prepared with acrylate UV resin on a PET base film of 125μm thickness. The transparent area was formed with a thickness of 125μm by UV curing the acrylate resin. The opaque area with good thermal-conductive property was formed by UV curing the mixture of acrylate resin and carbon-black. Since carbon-black was used as a filler in the previous report where the thermal conductivity of polymers was increased to more than 20W/mK after adding graphite as a filler. [5] Figure 2 shows the cross sectional view of the thermal-conductive sheet structure fabricated in this study. Both of sample 1 and sample 2 were prepared with the same 75% fill factor, but the heights of them were manufactured differently with 100μm and 80μm, respectively.

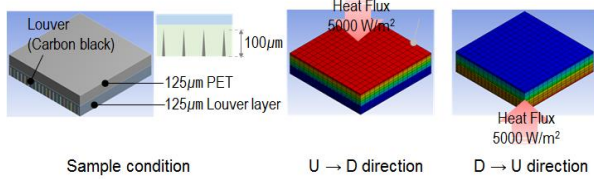


Figure 3. Measurement – Heat flow meter apparatus

Table 1. Measurement results – Sample 1

Nano-black (50%)	Heat transfer direction	Sheet thermal conductivity (z-direction)		
		Ave.	Ref.	Evaluation Value
125μm PET	-	0.4185	0.400	←
100μm Louver Total T 250μm	U → D	0.555 (0.552/0.558)	-	0.5365 (0.5335/0.5395)
	D → U	0.5315 (0.534/0.529)	-	0.513 (0.5155/0.5105)

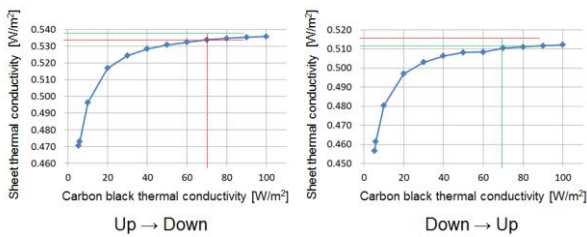


Figure 4. Estimation - Thermal conductivity of acrylate containing carbon-black

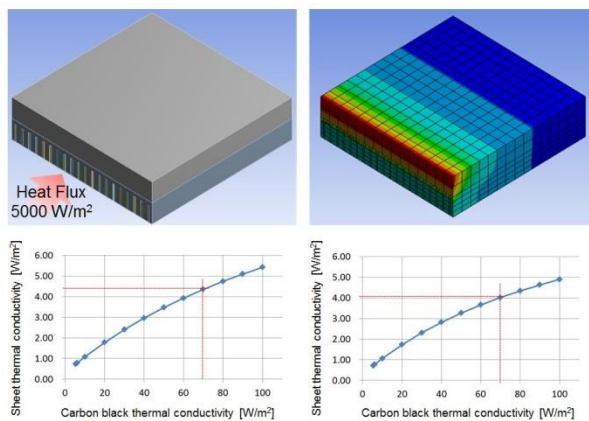


Figure 5. Estimation - Thermal conductivity of sheet

Table 2. Estimation results – Sample 1 & 2

	Louver height [μm]	Film thermal conductivity [W/mK]
Sample 1	100	4.35
Sample 2	80	4.02

2.2 Evaluation of the Fabricated Sheet

Measurement of the fabricated thermal-conductive sheet was only effective in the z direction. As shown in Figure 3, it was measured through a heat flow meter apparatus, and the results were summarized in Figure 4 and Table 1. As a result, in the case of Sample 1, the thermal conductivity of the acrylate containing carbon-black was estimated to be approximately 70W/mK. The same result was also obtained for Sample 2. However, it is not easy to measure the thermal conductivity in the louver direction directly. Therefore, we had to first estimate the thermal conductivity of acrylate made of carbon-black filler through simulation. The thermal conductivity of the acrylate containing carbon-black was then calculated by simulation and estimated as the closest value to the actual measurement result. Based on these results, the thermal conductivity in the louver direction was estimated to be more than 4.0 W/mK, as shown in Figure 5 and Table 2.

2.3 Evaluation of Transparent OLED Display Module

In order to confirm the effectiveness of the fabricated thermal-conductive sheet, additional module experiments and simulations were conducted after applying it in the OLED display module. As shown in Figure 6 and Figure 7, respectively, the experiment and simulation conditions were designed in a way that the OLED structure is simulated as simply as possible. Here, the film means the fabricated thermal conductive sheet whereas PET and OCA means PET film of 125um thickness and optical clear adhesive of 125um acrylate, respectively. For the temperature measurement, PET is placed in the film position instead of the fabricated thermal-conductive sheet, and the surface temperature

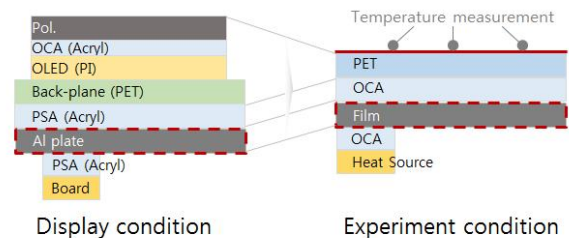


Figure 6. Experiment condition

of PET around the heat source is approximately 55°C.

Figure 8 shows the results of both the simulation and the experiment which have similar values. Therefore, it can be concluded that the thermal conductivity of fabricated sheet shows good performance to be applied in the transparent OLED displays.

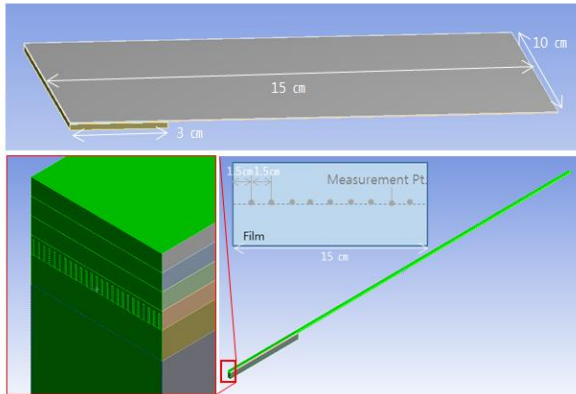


Figure 7. Simulation condition

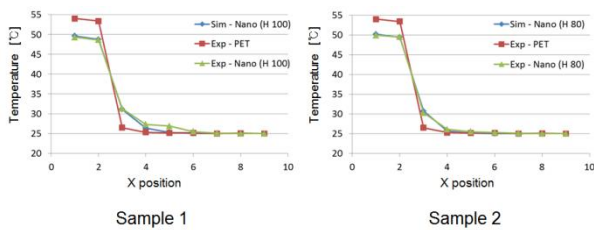


Figure 8. Experiment & Simulation result

Table 3. Thermal conductivity according to direction

Heat transfer direction		Thermal conductivity [W/mK]		※ Direction
		Sample 1	Sample 2	
x – direction (Louver direction)		4.35	4.02	
y – direction		0.313	-	
z – direction	U → D	0.5365	0.4510	
	D → U	0.5130	0.4395	

Table 4. Optimization structure

		OLED Only	Sample 1	Sample 2	Optimization
Louver Height [μm]		-	100	80	60
Experiment Luminance Contour					-
Simulation	Luminance Contour				
	Transmittance [%]	-	75	75	75
	Thermal conductivity [W/mK]	-	4.35	4.02	3.22

3 Discussions on the Display Performance

The fabricated thermal-conductive sheet will be a solution for the critical thermal problem in transparent OLED displays. Unlike the approach based on materials, the fabricated sheet shows anisotropic characteristics, as summarized in Table 3. In the louver direction, it has a value of 4.0 W/mK or more, but in the other direction it has a value of 0.6 W/mK or less. In some aspects, it could be a limitation of our proposed thermal conductive sheet since it is based in the structural design. However, the high thermal conductivity resulted in a sufficiently competitive method.

Another issue for the proposed thermal-conductive sheet is a viewing angle reduction. Table 4 indicates how the luminance contour changes when the height of the louver is altered. To make it similar to the luminance contour of OLED itself, the louver height should be lowered. In addition, as the surface area for heat transfer is reduced, the thermal conductivity also decreases. The viewing angle reduction will be a little issue in the display field where the privacy mode is required.

4 Summary

In this study, only carbon black was considered as a material of louver. It is because UV resin is the easiest way to implement louver. In the future, it is expected that research on other methods will utilize materials with higher thermal conductivity than carbon black so that structures with better performance can be derived.

The present study proposes a method utilizing a structure-based approach (rather than a material-based approach) in order to solve the local heat concentration generated in OLED. This study significantly indicates that when we utilize the structure louver on high thermal-conductive opaque materials, optically transparent and enhanced thermal-conductive properties will be easily expected. This structure has the following three characteristics, compared to transparent thermal conductive materials in transparent OLED displays.

✓ When a transmittance of 75% is achieved with a louver containing carbon black with a thermal conductivity of 70W/mK, it is possible to obtain a thermal conductivity of at least 3.0W/mK or higher in the louver direction.

✓ Since it has a thermal conductivity of 1.0W/mK or less in directions other than the louver direction, attention should be paid to the direction when applying.

✓ As the louver height increases, a high thermal conductivity can be realized, but viewing angle reduction may occur.

Through this study, the possibility was confirmed that the proposed thermal conductive sheet structure can help the thermal stability of transparent OLED displays.

References

- [1] Rui Fan. (2019). "Influence of ambient temperature on OLED lifetime and uniformity based on modified equivalent lifetime detection", *Society for Information Display*, 27, pp. 597-607.
- [2] Tokihisa Kawabata. (2013). "Optical measurements of OLED panels for light applications", *Journal of Modern Optics*, 60(14), pp. 1176-1186.
- [3] Kojiro Uetani. (2016). "Thermally conductive and optically transparent flexible films with surface-exposed nanocellulose skeletons", *Journal of Materials Chemistry*, 4, pp. 9697-9703.
- [4] Marjan Alsadat Kashfipour. (2019). "Regulating Intermolecular Chain Interaction of Biopolymer with Natural Polyol for Flexible, Optically Transparent and Thermally Conductive Hybrids", *Engineered Science Publisher*, 8, pp. 11-18.
- [5] Julia A. King. (2010). "Thermal Conductivity of Carbon-filled Polypropylene-based Resins", *Journal of Composite Materials*, 44, pp. 839-855.