PROCEEDINGS OF THE INTERNATIONAL DISPLAY WORKSHOPS, VOL.28, 2021

**OLED2-4L**

***(Late-News Paper)***

# Research on heat dissipation method of active-matrix organic-light emitting diode in automotive applications

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Keywords: Heat dissipation, organic-light emitting diode, automotive.

## ABSTRACT

*Temperature rise is a key factor affecting the performance and user experience of automotive organic-light emitting diodes. By systematically studying the heat source, heat dissipation path and stacking structure, the effective methods are sorted out with the maximum temperature rise of module significantly reduced to15 ℃ at room temperature.*

## 1 Introduction

Automotive organic-light emitting diode (OLED) aims to high brightness, long lifetime, high reliability and low temperature rise. With higher brightness, the current of the module may be larger along with higher temperature rise, which may cause shorter lifetime and worse reliability performance [1]. Namely, Temperature rise can be the key point to effect product performance and user experience in automotive applications [2].

To solve this issue, active-matrix organic-light emitting diodes (AMOLED) module with consumption specification was usually added active heat dissipation apparatus [3] or attached thermal conductive film on the back [4], but the volume of active heat dissipation apparatus is too large to be embed in ultra-slim customer assembly, and the cost of middle-size thermal conductive film is too expensive with limited improvement on heat dissipation. Based on this condition, we systematically studied heat source, heat transfer path and stacking structure to produce effective heat dissipation method in automotive AMOLED application.

## 2 Experiment

As shown in Fig.1, the experiment was conducted on 12.8 inch AMOLED module with aluminum (Al) bracket and Chip on Film (COF)/ printed circuit board (PCB) bended on the back.

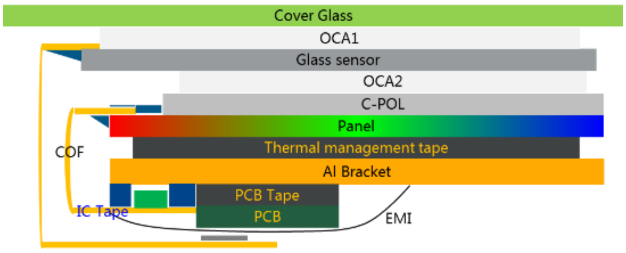


**Fig.1 Structural diagram of 12.8 inch AMOLED module**

After warm-up with full white pattern for 2 hours, the temperature of module was tested with infrared thermal imager in vertical. The maximum value of temperature rise on the module under room temperature was used to evaluate the heat dissipation effect.

### 2.1 Experimental design

Limited by the customer urgent demand of slim shape, this paper mainly study passive heat dissipation methods. Heat generated from panel, IC on COF and PCB board surrounded was transmitted over Intermediate film to outermost interface through thermal conduction, and subsequently heat on the outside was exchanged with air through thermal convection, and heat was transferred to air by infrared ray through thermal radiation simultaneously. From above heat generation and dissipation process, three improvement methods of heat source control, heat transfer path modify and structural modify can be proposed as follows shown in Fig. 2:

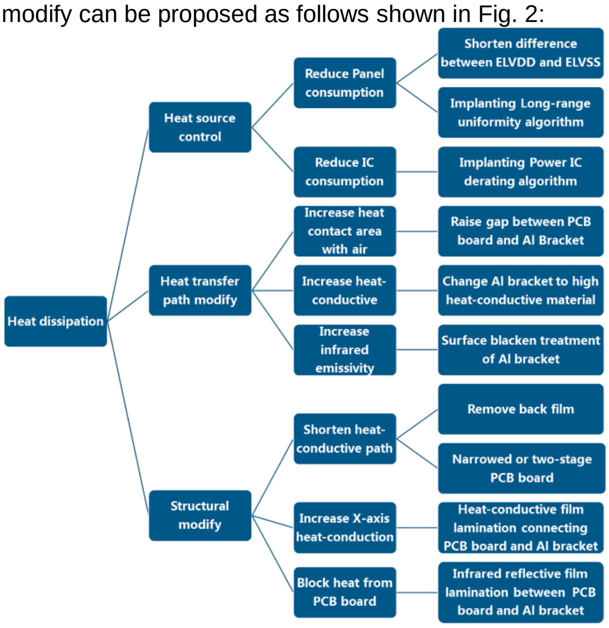


**Fig.2 Heat dissipation method summary of 12.8 inch AMOLED module.**

## 3 Results and discussion

The highest temperature rise on our 12.8 inch module in initial stage can be over 22℃ with local temperature on the surface reaching almost 50℃, which may scald hand with one touch and had undesirable impact on lifetime and reliability in different degrees. To solve such issue, we proposed improvement methods as follows:

### 3.1 Heat source control

Obviously, the main heat generators are OLED and layout lines in panel as well as IC and other electronic component in COF and PCB board. Due to the demand of high brightness in automotive module with large current, the heat source control is crucial.

Firstly, under the premise of the span voltage on OLED enough to ensure OLED working on saturated region [5], there is still a safe buffer voltage, which can generate heat. As shown in Fig.3, by measuring luminance and color coordinates of module with different ELVSS voltages when fixing ELVDD voltage, the inflection point of ELVSS voltage can be acquired, and the range of the inflection point can be obtained to finally determine ELVSS voltage after massive data collection. The module in this paper set ELVSS positive deviating for 1 V with output current almost the same, the power consumption can reduce 2 W with the highest temperature rise decline for 2℃ by this way.

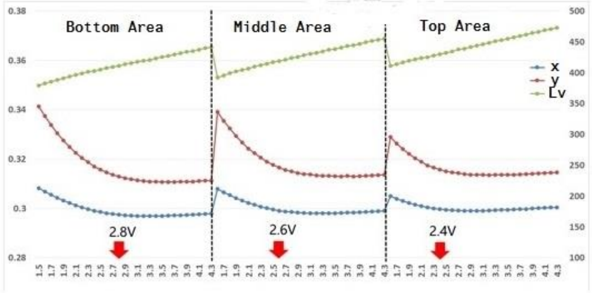


**Fig.3 Curve diagrams of luminance and color coordinates vs ELVSS voltage in OLED.**

Secondly, in terms of surrounded bypass line on panel, it is necessary to calculate the number of bonding inlet pads named ELVDD and ELVSS of each current according to the current density, and symmetrical display design with impedance matching of each bypass line is needed to avoid local heating at single port bypass line in case of uneven impedance. Fig.4a shows the temperature imaging of panel without impedance matched in inlet bypass line taken by thermal imager, it can be seen that the temperature of two inlet bypass line on the left reaches 103℃, which is much higher than that on the right, causing 10℃ temperature difference between left and right part on the panel. By symmetrical designing bypass line on the left and right side of panel, the simulated current density distribute of panel is bilateral symmetrical (Fig. 4b) with only longitudinal IR drop in-plane, and the similar measured temperature distribute was shown in Fig. 4c.

In terms of the in-plane part on panel, due to voltage drop caused by the internal metal line resistance and cathode resistance of the panel, the brightness of some areas significantly exceeds the central target brightness along with excessive current and temperature rise in panel. By introducing the brightness uniformity compensation (BUC) algorithm in the panel, the brightness of local areas can be close to the central brightness, which can not only improve the brightness uniformity in the plane, but also slightly reduce the temperature rise on panel with more symmetrical and uniform temperature distribution as shown in Fig. 4d. After IRC algorithm is turned on for the test sample used in this paper, the brightness uniformity of the panel is improved to more than 90%, and the maximum temperature rise can be reduced by about 1 ℃.

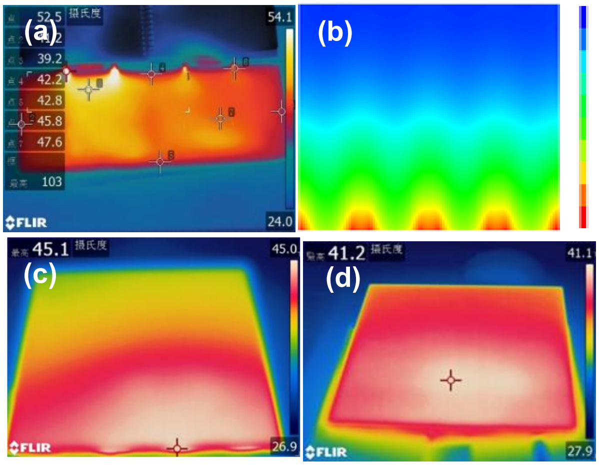


**Fig.4 Temperature imaging of panel without impedance matched (a), simulated current distribute (b) and temperature imaging (c) of panel with impedance matched, and temperature imaging of panel with BUC algorithm (d).**

Thirdly, COF / PCB bended on the back will transfer heat of the corresponding electronic components to the panel side, and prevent heat from dissipating to the coverage area, both which may cause panel temperature rise. Source IC of the test sample in this paper has serious heating with temperature more than 90 ℃. Although thick adhesive tape is used to pad up source IC from Al bracket, it can still transfer massive heat to the panel. Here we proposed adjusting the matching relationship between the opening time of data signal and gate signal (as shown in Fig. 5a) to the optimal parameters with the AVDD output waveform ripple

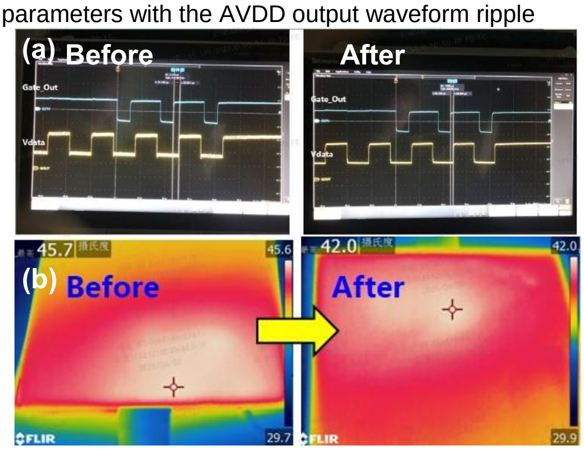


**Fig.5 Wave diagram (a) and thermal imaging (b) of 12.8 inch AMOLED module before and after SD IC timing modify.**

becoming smaller, and the logic power consumption was reduced by half, which significantly reduces the SD IC temperature to 55 ℃ and the maximum temperature rise of the panel can be reduced by 2 ~ 3 ℃ shown in Fig. 5b.

### 3.2 Heat transfer path modify

According to theory, heat transfer can be divided into three ways: heat convection, heat conduction and heat radiation [6]. This paper mainly conducted principle analysis and explanation based on simple formulas.

Thermal convection refers to the heat transfer process in which the relative displacement of particles in the fluid occurs. Its formula is $\mathrm{Q} = \mathrm{Ah}(t_s - t_f)$, in which Q refers to heat flux, A refers to surface area, $t_s$ refers to surface temperature of module, $t_f$ refers to temperature of fluid and h refers to convective heat dissipation coefficient. Since active heat dissipation scheme is not considered in our module, the main method in terms of heat convection improvement is padding PCB board from Al bracket by adding plastic column to increase the contact area of PCB board and Al bracket with air, which can promote convective transfer of heat generated from panel and PCB board to air and eventually reduce temperature rise of module. As shown in above Fig.6, the heat dissipation effect is gradually significant with the increase of pad height and the temperature rise can be significantly reduced when the pad height exceeds 6mm. however the height can only be elevated to 4mm limited by the slim assembly, the temperature rise can hardly be reduced.

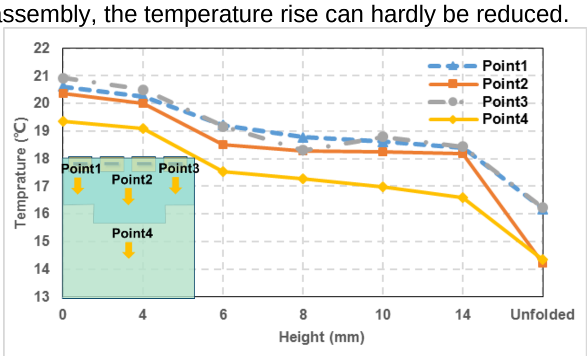


**Fig.6 Temperature rise distribute of module with different padding highness.**

Heat conduction refers to the phenomenon of energy transfer through the micro vibration, displacement and collision of molecules, atoms and electrons when there is a temperature difference between different objects. Its formula is $Q = -\lambda A\frac{dT}{dx}$, in which Q refers to heat flux, A refers to surface area, $\frac{dT}{dx}$ refers to temperature gradient and λ refers to heat conductivity. Among these parameters, one of the main factor affecting heat conduction performance is thermal conductivity. It is proposed to replace Al alloy with other material with higher thermal conductivity. Though pure copper (Cu) has advantage of high conductivity of 400 W/m.K$^{-1}$ twice than that of Al alloy, its disadvantages of low rigidity hardly achieving comparative support performance and high cost make it difficult to be applied in our module. Besides, other common materials could be selected as shown in Table. 1, the Cu alloy and Al alloy with surface Cu plating treatment have slightly lower conductivity than Al alloy, in which temperature rise of module can hardly be improved than current scheme. Thus, replacing Al alloy with above material cannot reach the target of heat dissipation improvement.

**Table.1 Heat conductivity and emissivity of different materials and temperature rise(△T) of module with corresponding materials.**

| Material | λ (W/ m.K-1) | $\varepsilon_1$ | △T (℃) |
|---|---|---|---|
| Al alloy | 163~209 | 0.02 | 15.2 |
| Pure Cu | ~400 | 0.3 | 12~13 (Estimated) |
| Cu alloy | 118~170 | 0.3 | 15.4 |
| Cu plating on Al alloy | 177~230 | 0.03 | 14.5 |
| Al alloy with Electrophoretic blacked | 163~209 | 2.0~2.4 | 13.9 |
| Al with coating blacked | 163~209 | 1.9~2.1 | 14.4 |
| Al alloy with printing blacked | 163~209 | 1.9~2.2 | 14.2 |

All objects with temperature above absolute zero can generate thermal radiation, and the higher the temperature is, the greater the total energy radiated. Its formula is $\mathrm{Q} = \varepsilon_1 A_1 \sigma F_{12}(T_1^4 - T_2^4)$, in which Q refers to heat flux, $A_1$ refers to surface area, $\varepsilon_1$ refers to emissivity, σ refers to Boltzmann parameter, $T_1$ and $T_2$ refers to temperature of radiation surface 1 and 2. One of the key factor affecting thermal radiation is emissivity, which can be improved by blackening treatment on the surface of Al bracket in this paper. The thick coating blackened material of oxidized Al on the surface block the overall heat conduction to reduce thermal conduction and thermal convection but along with improved thermal radiation. The oxidized layer produced by electrophoretic blacked method is thinner than that coating blacked layer, and also has better thermal conductivity, but one-sided blackening needs to remove locally after the whole blackening treatment, which process is complex and costly. The printing blackening process is relatively simple and friendly to pattern customization with much lighter blackening layer than the painting process. Among above blackening methods, the electrophoretic blackening treatment has a significant effect on reducing temperature rise for 1.3 ℃ shown in table 1 above.

### 3.3 Structural modify

In terms of structural modify, we proposed adding some function film or remove some unwanted film in module to improve heat dissipation performance.

Firstly, it is easy to see that the module with less film has better heat dissipation performance [7].Therefore, the removal of the back film (BF) with low thermal conductivity on the panel can shorten the heat transfer path from panel to Al bracket side, which can significantly reduce the panel temperature rise by maximum 1.7 ℃. Since BF works as prevent particle from falling to the back during transmission, the removal of BF may occasionally cause thin film encapsulation injury in practical applications, it can be avoided through improving raw materials and lamination process, and whether to introduce such scheme can be decided refers to defect occurrence rate.

Secondly, it can be found that the temperature rise of area near COF side is higher than that far away from COF. The reason is that the area near COF is covered with PCB board on the back, which block heat longitudinal transmit, resulting in inconsistency of the temperature rise in the whole panel. To solve this problem, by designing a narrowed or two-stage PCB board to keep the overall area structural consistent, the temperature rise in the area near COF can be directly reduced with more uniform temperature distribute. Among them, narrowed PCB board may need multilayer to layout large number of electronic components, which has higher design difficulty and higher cost, however, The two-stage PCB board with connector scheme is easy to realize and suitable to be carried out in practical application, thought it usually need to increase the shell space of the module assembly.

Thirdly, since the transverse thermal conductivity of graphite or graphene film or soaking plate can reach 800-3000 W/m.K$^{-1}$, the lamination of such film between PCB board and Al bracket can transfer heat from area coved by PCB board to far-end, which can significantly improve the uniformity of temperature and slightly improve the maximum temperature rise of the panel shown in Fig. 7. This scheme has obvious advantage of significant heat dissipate improvement, but the cost is too expensive in vehicle medium and large-size products, which may have weak practicability of mass production.

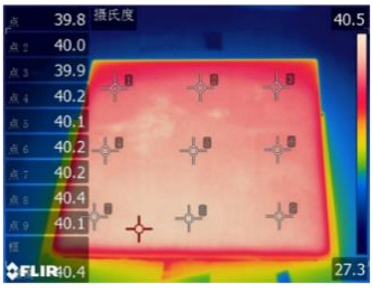


**Fig.7 Heat imaging of module with soaking plate.**

In addition, considering that the electronic components in the PCB board are also heat source, it is also necessary to design a thermal insulation structure to prevent heat source from affecting the panel. Therefore, we proposed attaching infrared reflection film between PCB board and Al bracket to reflect and radiate the heat to the outside in the form of infrared, so as to block the heat. In the actual test, the maximum temperature rise of the module with such film can be significantly reduced by 1.1 ° C.

All in all, through the experimental verification as shown in Table. 2, only three improvement schemes in terms of system or algorithm can be applied in final module with appropriate cost and few structural changes, and there are still six schemes validated can be selected with the weakness of cost and process risk.

**Table.2 Summary of temperature rise and practicability of mass production in different heat dissipation methods.**

| Methods | Temperature rise improve (℃) | Practicability of mass production |
|---|---|---|
| Designing a narrowed or two-stage PCB board | 3-5 | Key point |
| Implanting power IC derating algorithm | 2~3 | Effective and applied |
| Shorten difference between ELVDD and ELVSS | 2 | Effective and applied |
| Remove back film | 1.7 | Weak protection to TFE |
| Surface blacken treatment of Al bracket | 1.3 | Effective but costly |
| Infrared reflective film lamination between PCB board and Al bracket | 1.1 | Effective but costly |
| Implanting Long-range uniformity algorithm | 1 | Effective and applied |
| Heat-conductive film lamination between PCB board and Al bracket | 0.8 | Costly |
| Change Al bracket to high heat-conductive material | 0.7 | Costly and low effect |
| Raise gap between PCB board and Al Bracket | 0.7 | Limited by the height of the assembly |

## 4 Conclusions

In this study, we proposed three countermeasures of heat source control, heat dissipation path and structural modify to reduce temperature rise in automotive AMOLED modules. Several improvement schemes can be applied in final module with temperature rise of such module significantly reduced to below 15 ℃. And the key point to temperature rise issue is heat dissipation management from the source and the design of panel bypass line, PCB board and module assembly shell.

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