Research on Heat Dissipation Design of Automotive High-Brightness Display with u-LED

Zuojia Wang, Jun Yang, Hailong Pan, Fancheng Liu, Guowei Zha, Jianfeng Yuan
***TCL China Star Optoelectronics Technology Co., Ltd, Wuhan, Hubei, China**

Abstract

This paper introduces the thermal coupling problem between pixels when LED chips are used in highlight display. The heat dissipation analysis of vehicle highlight display under different conditions is studied by using Icepak simulation software. It provides a solution direction for the heat dissipation design of the vehicle highlight display module.

Author Keywords

Vehicle high brightness display ; pixel thermal coupling ; thermal simulation research ; heat dissipation method

1. Introduction (Background of MLED Thermal Management)

Micro LED(MLED), with its characteristics of high brightness, low power consumption, and fast response speed, meets the requirements of high resolution, high brightness, and energy efficiency. It is considered a promising candidate to replace LCD and OLED as the mainstream technology for next-generation displays. In recent years, MLED has shown diversified development in areas such as commercial displays, televisions, automotive displays, and smartwatches. However, during its development, Micro LED faces numerous challenges. These include the immaturity of mass transfer technology, low transfer yield, and high costs. Among these challenges, thermal management has become a critical issue that cannot be overlooked.

At present, the COG display scheme is to fix the MLED chip on the glass. Limited by the current technical ability, the power consumption of the glass substrate is usually about 50 ~ 60 %, which leads to a high heating of the substrate under high brightness. Due to the characteristics of MLED chips, the panel temperature needs to be controlled at about 40 °C to ensure its best luminous efficiency. Therefore, how to better deal with the heat dissipation of the substrate is an urgent problem to be solved.

Taking COG (Chip on Glass) as an example, the MLED architecture consists of three layers from top to bottom: the encapsulation layer, the LED layer, and the glass substrate (including array circuits). Due to the low thermal conductivity of conventional encapsulation materials and glass substrates, the heat generated by LEDs accumulates, resulting in high temperatures. Under high-brightness conditions, the display panel temperature can exceed 100°C, significantly affecting the luminous efficiency of the LEDs. For instance, at an ambient temperature of 50°C, the brightness of red chips decreases to 80%, and the attenuation becomes more severe as the temperature rises.

Conventional thermal solutions are typically designed based on the full power consumption scenario (maximum brightness in a full-white image), employing heat dissipation measures such as heat spreaders, fins, and fans. However, this approach increases the thickness, cost, and size of the thermal management system. Our research indicates that different product forms and application scenarios exhibit considerable variations in display content. For example, projectors tend to have a higher proportion of full-white images, while TVs have relatively fewer. In automotive applications such as dashboards and HUDs, displays primarily consist of simple lines and localized images to prevent complex visuals from distracting the driver and compromising safety.

The pixel-level LED control in MLED direct displays enables an innovative approach to thermal management through UI-based heat dissipation. This method not only reduces the cost of thermal management but also minimizes the size of the cooling system, making it a feasible solution tailored to specific application scenarios. This paper uses automotive HUD and transparent window displays as examples to investigate heat dissipation under UI interfaces with the aid of Icepak thermal simulation software.

2. UI Interface Thermal Simulation Analysis

In automotive display applications, the primary scenarios include high-brightness windshield projections, transparent windows, and exterior displays, as well as non-high-brightness displays such as interior dashboards and entertainment systems. Taking the head-up display (HUD), which has the highest brightness requirements, as an example, the thermal management thickness of the module can be significantly reduced when only considering the UI design of the application scenario. A comparison is shown in Figure 1.

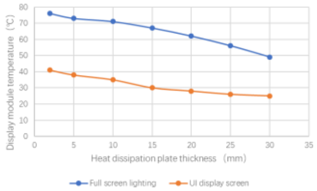


Figure 1: Comparison of Thermal Management Designs Across Different Scenarios

Under the same brightness, the power consumption required to display the all-white screen and the UI interface pattern is very different, which will lead to a difference in heat dissipation thickness. Even if the pixel power density is the same, due to the different shape of the pattern and the heat transfer path of the lit pixel, the maximum temperature of the screen will be different. The simulation data shown in Figure 1 is derived based on the thermal simulation process outlined in Figure 2.

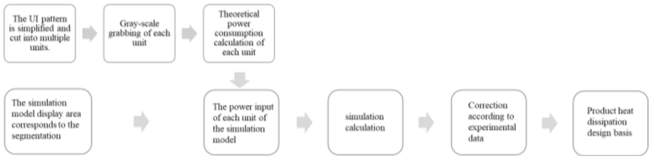
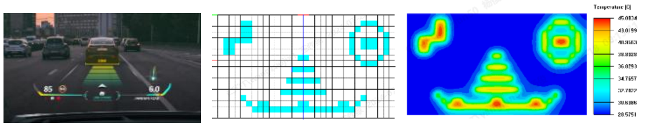


Figure 2: Thermal Simulation Process for UI Display

For a specific HUD pattern, considering that additional navigation and entertainment information is displayed in the non-driving field of view on the windshield, the simulation model increases the displayed information, bringing the illuminated pixel ratio to 15%. The following illustrates the UI pattern reference (Figure 3-a), the UI simulation model segmentation (Figure 3-b), and the simulation results (Figure 3-c).

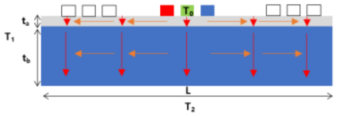


(a) UI Reference (b) Simulation Model Segmentation (c) Simulation Results

Figure 3: UI Display Simulation Process

Theoretically, the more accurate the approximate fine temperature simulation of the unit segmentation, but it is accompanied by a huge amount of calculation and a long simulation time. It is impossible to quickly guide the design of the heat dissipation scheme in the product design stage, so it is necessary to explore the minimum segmentation unit. Taking the P0.2 MLED high-brightness display substrate with a substrate thickness of 0.4mm as an example, the thermal conductivity of the TFT is taken as $\lambda_a = 2\mathrm{W} / \mathrm{m} \cdot \mathrm{k}$, and the thermal conductivity of the substrate is taken as $\lambda_b = 1\mathrm{W} / \mathrm{m} \cdot \mathrm{k}$. The calculation shows that L is approximately equal to twice the pixel spacing, that is, in a 3 × 3 pixel unit centered on the illuminated pixel, the horizontal and downward thermal resistances are equal ($R_1 = R_2$; $T_1 = T_2$). The calculation is shown in Figure 4.

ISSN 0097-996X/25/5601-0677-$1.00 © 2025



$$\frac{1}{R_1} = \frac{1}{\frac{L/2}{\lambda_a * L * t_a}} + \frac{1}{\frac{L/2}{\lambda_b * L * t_b}}$$

$$R_2 = \frac{t}{\lambda * S} = \frac{t_a}{\lambda_a * L^2} + \frac{t_b}{\lambda_b * L^2}$$

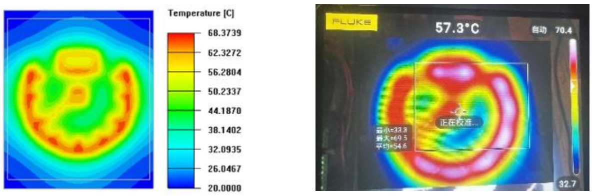
(a) Pixel Heat Transfer Path (b) Heat Spreading Unit Calculation

Figure 4: Pixel Thermal Coupling Analysis

The problematic issue is that in actual UI patterns, the illuminated pixel areas are continuous, leading to more severe thermal coupling effects between pixels. It is urgently necessary to reduce the thermal resistance on the back of the display to minimize lateral heat transfer, thereby reducing its impact on adjacent pixels. Combined with the actual working scene and product temperature accuracy requirements, as well as the previous simulation & experimental verification, this paper divides the display area into 5mm × 5mm units for temperature simulation of different application scenarios.

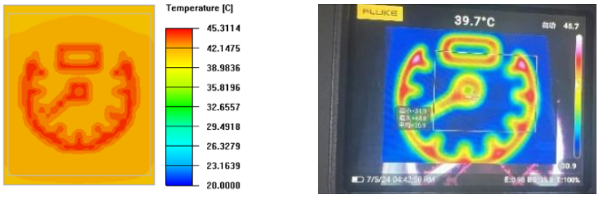
3. Thermal Analysis of HUD Module

HUD display applications require that the display content on the windshield can still be seen clearly when the outdoor sunlight is direct, which requires MLED to have a higher display brightness. At present, the brightness of MLED can reach about 80,000 nits, and the higher brightness will inevitably bring high heat. Moreover, due to the low thermal conductivity of the substrate glass, if there is no soaking plate when displaying the UI, the heat will accumulate and cannot be dissipated, resulting in high temperature. Below is a comparison experiment conducted on a 6-inch MLED product with a heat spreader under the same current input or not.



(a) Simulation Results **(b) Experimental Testing**

Figure 5: Comparison of Simulation and Experiment Without Heat Spreader Structure



(a) Simulation Results **(b) Experimental Testing**

Figure 6: Comparison of Simulation and Experiment With Heat Spreader Structure

The results show that adding a heat spreader significantly reduces the maximum temperature in the display area. This is because the heat dissipation structure on the back of the non-display area transfers most of the heat. However, the maximum temperature rise still reaches 25.7°C.

In actual automotive display scenarios, particularly during summer when the cabin temperature can reach 60°C, starting the HUD display under such conditions could result in the display module temperature rising to a maximum of 85.7°C. In this case, the junction temperature of the LED chips would be even higher, leading to a significant decline in luminous efficiency. Therefore, it is essential to lower the temperature of the display module before the HUD operates.

In addition to relying on the thermal conduction pathway formed by coupling the display module with the vehicle frame, it is also recommended to incorporate active cooling methods for rapid heat dissipation of the display module. For instance, a combination of fans and heat sink fins can be used to remove heat from the display module by utilizing the cooler air outside the car or inside the cabin after the air conditioning is turned on. Figure 7 illustrates the structure of the HUD display module combined with fins and a fan.

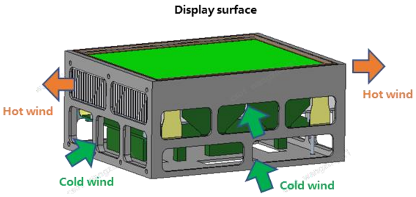
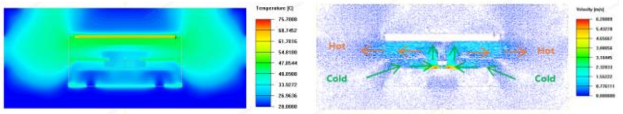


Figure 7: Display Module Structure and Airflow Design

Through software simulation analysis of the PCB and fan placement, the airflow path and overall structure are optimized as follows.



(a) Cross-sectional Temperature Distribution (b) Cross-sectional Airflow Distribution

Figure 8: Simulation Results of Full-Screen Peak Brightness Temperature for the Display Module

The analysis results indicate that the fan drives air from the cabin or the underside of the vehicle upward through the heat sink fins, enabling convective heat transfer and transferring the heat released by the module upward. Even when the entire screen reaches peak brightness under a full-white image, the maximum temperature rise can be controlled within 55°C. For standard automotive information display interfaces, the maximum temperature rise is kept within 15°C, meeting the requirements of most application scenarios.

It is reasonable to believe that with a matched overall heat dissipation channel design integrated with the vehicle, the temperature rise of the Micro LED display module can be further reduced.

4. Thermal Analysis of Transparent Displays

In display scenarios with limited space for heat dissipation, the heat transfer paths are constrained, leading to greater fluctuations in temperature simulation errors based on total power consumption. Taking transparent displays as an example, when the maximum screen temperature is limited, the power consumption that can be sustained is much lower compared to models equipped with heat dissipation devices. However, the radiative power consumption of both models is similar. This can be explained through the radiation formula, which shows that the radiative power emitted by the screen to the external environment depends only on the screen temperature and the characteristics of the screen assembly.

$$Q_{\text{net}} = \varepsilon A_s \sigma \left(T_w^4 - T_\infty^4\right)$$

ε :Emissivity (radiation rate)

σ: Stefan-Boltzmann constant, 5.67×10^{-8}W/(m$^2 \cdot$ K^4)

As: Surface area, m^2

*T*w and *T*∞: Temperatures of the radiative surface and the environment, unit: K.

Therefore, in high-brightness display scenarios without active cooling methods, radiative heat dissipation accounts for a significant proportion. It is necessary to conduct radiation heat transfer studies on the thermal simulation model of the display. Here, the simulation model was optimized by comparing different radiation models and surface radiation parameters of materials.

Temperature tests were conducted for simple white block patterns illuminated in the display area without a heat dissipation structure. The analysis included the maximum temperatures under varying illuminated window ratios and different power consumption levels.

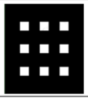
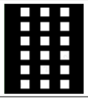
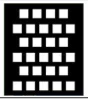
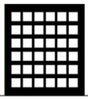
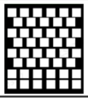
	Experimental records				Simulation result	Difference
Simple UI pattern	I（A）	P(W)	power density（W/m2）	Maximum temperature（°C）		
10% 	0.1	0.4	278	37.3	33.7	-3.6
	0.2	1.2	821	48.8	45.7	-3.1
	0.3	2.1	1444	59.6	58.4	-1.2
	0.5	3.8	2557	83.2	78.6	-4.6
20% 	0.2	1.0	332	37.6	35.3	-2.3
	0.5	3.1	1034	53.8	51.5	-2.3
	0.6	4.0	1339	59.5	58.1	-1.4
	0.9	6.9	2353	80.3	78.8	-1.5
30% 	0.5	2.5	560	44.2	42.3	-1.9
	0.6	3.5	791	50.1	48.1	-2
	0.8	5.2	1171	59.1	57.6	-1.5
	1.1	8.1	1822	73.7	74.0	0.3
40% 	0.7	3.9	660	49.1	46.4	-2.7
	0.8	4.7	802	53.9	50.3	-3.6
	1.0	6.6	1117	61.2	59.9	-1.3
50% 	0.4	1.8	248	38.1	35.5	-2.6
	0.7	3.5	468	45.4	42.4	-3
	0.9	5.3	715	52.2	50.0	-2.2

Figure 9: Thermal Simulation and Measured Data Without Heat Dissipation Structure

As shown in the table above, the simulated predicted temperatures have an average error of less than 3°C compared to the subsequent experimental data, verifying the accuracy of the simulation model.

In practical automotive applications, transparent displays are typically encapsulated within large-sized cover glass (CG), as shown in Figure 10. A substantial amount of heat is dissipated to other regions through conduction, reducing local temperature peaks.

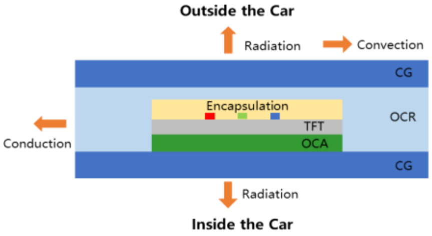
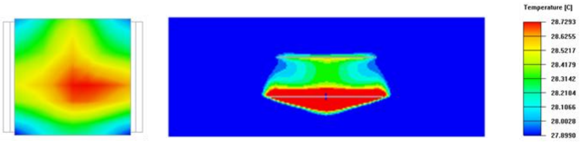
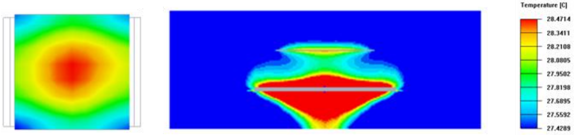


Figure 10: Schematic Diagram of Transparent Display Module Encapsulation

To better align with the application requirements of real automotive scenarios, subsequent simulation analyses must consider the impact of the encapsulation structure on heat conduction. Factors such as the thermal conductivity of the encapsulation materials, the heat capacity of the large-sized CG, and the heat diffusion pathways to surrounding structures can significantly affect thermal management performance.



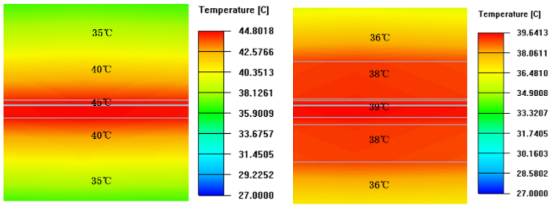
(a) Without Encapsulation



(b) With Encapsulation

Figure 11: Comparison of Radiation Conditions With and Without Module Encapsulation

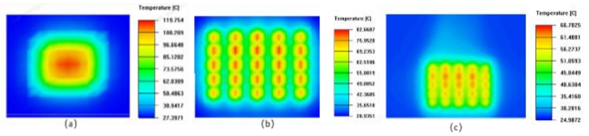
As shown in Figure 11, under conditions without encapsulation, heat is primarily concentrated near the heat source area of the screen, with a limited dissipation range and higher temperature peaks. This situation may lead to a thermal concentration effect, reducing the local performance of the screen or affecting the long-term reliability of the transparent display.



(a) Without Encapsulation AIR-MOD-AIR (b) With Encapsulation AIR-MOD-AIR

Figure 12: Cross-Sectional Temperature Contour of Radiation Thickness With and Without Cover Glass Encapsulation

As shown in Figure 12, after adding MOD encapsulation, the total radiation remains unchanged under the same power consumption. However, the heat conduction area increases, enhancing efficiency, and the module temperature is significantly reduced by 10%.



(a) Single Screen Pure White Display (b) Single Screen UI Display (c) UI Display with Window Encapsulation

Figure 13: Temperature Simulation Comparison of Display Modules Under Different Conditions

As shown in Figure 13, adding window glass encapsulation and using UI display effectively addresses the heat dissipation issue of automotive transparent displays, significantly reducing the module temperature. Future plans include conducting experiments with window glass encapsulation featuring different surface emissivities and encapsulation using high-thermal-conductivity transparent materials to further lower the display module temperature.

5. Discussion

The thermal simulation process for display modules under specific UI interfaces is complex and requires secondary development on the simulation platform to simplify the workflow. Under the same power density, it is also necessary to analyze the distribution of the UI patterns to conduct targeted thermal management research for MicroLED products in specific application scenarios, providing a theoretical basis for structural simplification.

The thermal solution for the display module must be designed to integrate with the terminal's thermal management system, ensuring an overall matched design while considering the spatial layout of the terminal product to select an appropriate cooling structure. This study, through thermal analysis of the display module, suggests that high-brightness MicroLED displays can achieve targeted module structural optimization based on actual display content.

6. Conclusion

This study first analyzed the issue of thermal coupling between pixels when LED chips are used in high-brightness displays. It then proposed a thermal management solution for automotive displays under UI interfaces, which involves first implementing heat spreading within the display module and then transferring heat using the vehicle's cooling system, significantly reducing the module thickness.

Additionally, for transparent display applications with limited cooling conditions, a heat dissipation solution was proposed using heat conduction through the car windows and enhancing the emissivity of encapsulation materials. Both approaches provide valuable insights for the thermal design of high-brightness display modules in automotive applications.

After the optimization of the simulation model and the correction of the measured model, this case can achieve the simulation error within 5 °C ; at the same time, using the heat dissipation thickness of the UI, the thickness of the module can be reduced by 6 times compared to the full white state.

7. References

1. LIU Huiyan ,TIE Qingmu, WANG Zheng. Research on Heat Dissipation Technology of Highly Reliable High-brightness Display [J]. Optoelectronic Technology.2022,03-0235-06.
2. Peng K, Guoliang X, Sen W. Structural and Thermal Design of a Modular Electronic Case [J]. New Technology & New Process (CN); 2023(04):29-32.
3. Yiyi W, Jie W, Xiaosong Z. Heat dissipation performance analysis of high-power LED liquid-cooled cold plate [J]. Science Technology and Engineering(CN), 2023, 23(27): 11632-11638.
4. Qiu Dujin，Liu Peng，Zhang Xiaoyu. Simulation and Verification of Passive Heat Dissipation Scheme for HUD TFT Panel [J]. Electromechanical Engineering technology (CN); 2021,50(08):192-196.