

75-inch LCD Displays with AM MiniLED Local Dimming Backlight Units on Glass

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ABSTRACT

We developed AM miniLED local dimming backlight systems on glass for 75-inch LCD displays, with each consisting of 5184 localizing dimming zones. The 75-inch display achieves a high dynamic contrast ratio of 1,000,000 : 1 and high brightness of more than 1000nits. This backlight system grants the LCD display with HDR performance, which is comparable to those of Dual-cells and OLEDs, by making the dark state real black. In addition, the system exhibit advantages such as low fabrication cost, long life time and more energy-efficient.

1 INTRODUCTION

Although the traditional LCD displays with a contrast ratio of about 5000 : 1 has prevailed in the TV market for almost twenty years, recent demand of the high-end TV market for display with a high dynamic contrast ratio of 1,000,000 : 1 has been increasing. Organic light emitting diode displays (OLEDs) first arrived at the market in the year of 2013 to meet the demands. However, even in 2019 there is still a large gap existing between the price of an OLED and a LCD TV. The OLEDs [1] suffer from disadvantages including relatively short life time and low brightness. Recently, a new LCD technology, dual-cell, which combines two LCD panels with a traditional backlight with one of the two panels works as a pixel-level localizing dimming system, was presented and demonstrated to achieve a high contrast. But the technique of combining the two panels is complex and the low transmittance of the dual-cell will make the power consumption high.

MiniLEDs, a technology that uses direct-lit local dimming backlight units to achieve HDR with traditional LCD panels, have attracted attentions of both consumers and manufacturers. They can outperform dual-cells and OLEDs in other aspects such as life-time, brightness and energy efficiency. The mini-LED displays available in the market are usually passive-matrix (PM) and have a few hundreds of zones of LEDs and their LEDs are directly soldered on PCB boards. However, miniLED displays with only a few hundreds of LD zones suffer from severe halo effect and the cost of their fabrication using PCB boards is relatively high. Therefore, we have developed an active-

matrix (AM) miniLED local dimming backlight system with more than 5000 LD zones to dramatically reduce the halo effect and improve display quality while lowering the cost by fabricating it on glass.

2 RESULTS

The 75-inch LCD display with the miniLED local dimming backlight system was successfully built-up. It is consisted of miniLED backlight, a QD film, an optical film and LCD panel (Fig.1). The local dimming backlight system on glass with ultra-high numbers of zones grants the LCD with properties including HDR, high peak brightness, suppressed halo effect, low fabrication cost and low power consumption. The realization of the superior display qualities and properties rely on the innovation of technologies including backplane design and fabrication, module construction, and driver solutions, which will be discussed in the following sections.

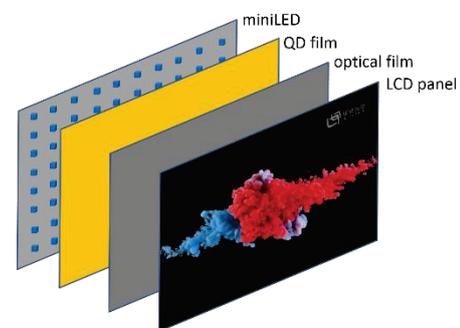


Fig.1 illustration of the 75-inch LCD display.

2.1 Backplane technology

While the miniLED display available in the market are basically all PM systems, we employ AM miniLED system with 2T1C pixel model in the backlight unit. The number of the local dimming zones, which is 5184 with each zone consisting of 4 LEDs, is much more higher than that of the ones in the market (a few hundreds). The purpose of making a miniLED display with an ultra high zone number is to improve the display quality especially to reduce the halo effect. And an AM system is a more economical way to make this product.

2.1.1 Large LD zone number to reduce halo effect

Halo effect is always a common issue for miniLED display [2]. Since the zone number of the backlight system is much smaller than the number of pixels of the front panel, halos always appear when part of the panel is at dark state but the corresponding region of backlight is illuminated. There are actually two parts contributing to the effect: one (halo₁) is because that the size of the zone is larger than the image displayed on the LCD panel; the other (halo₂) is due to light leakage from the bright zone to the dark zone. As demonstrated in Fig.2, after the modulation of the backlight and the LCD panel, there are light leakage of both halo₁ and halo₂. Although several methods including high contrast ratio of LCD panels and modification of the light expansion of LEDs have been proposed to reduce the halo effect, increasing the LD zone number is still necessary way to further alleviate the effect. Therefore, the display quality can be further improved using the ultra-large number of LD zones.

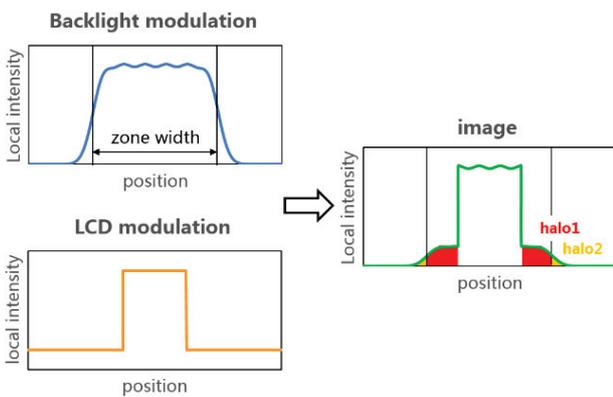


Fig.2 the origin of the halo effect: halo₁ is because that a zone size is much larger than that of a pixel, halo₂ is because of the light leakage from the bright zone to the adjacent dark zone.

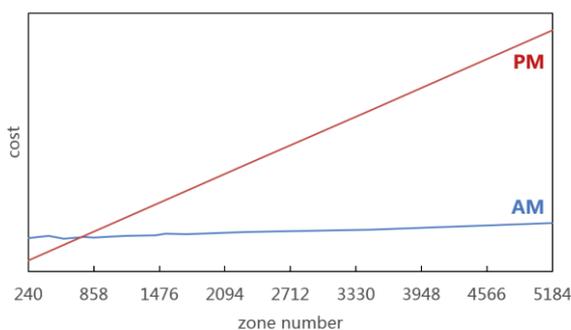


Fig.3 comparison of the cost of PM and AM miniLEDs

2.1.2 AM-miniLED system for low fabrication cost

AM and PM miniLED systems are both feasible for the driving solution, but a AM miniLED system is the only option when it comes to a lower cost of fabrication. The relationship between the cost and the zone numbers of AM and PM are compared in Fig.3. The result indicates that the cost of a AM miniLED system is 80% lower than that of

a PM system when the zone number is as large as 5184. Because a large zone number means more IC chips and larger PCB boards for PM, the cost is dramatically increased. But for AM, it does not require complex and costly driving solutions.

2.1.3 Pixel design

In the 2T1C pixel model [3] (as shown in Fig.4), the driving transistor (T1) is connected in serial with 4 LEDs, directly controlling the ON and OFF of the LED while the scan transistor (T2) is to pass the Data signal to the driving transistor. We have two strategies for the two transistors: one is that both T1 and T2 are a-Si thin-film transistors (TFTs) fabricated on glass, the other is that T1 is a metal-oxide-semiconductor field-effect transistor (MOSFET) and T2 is a TFT. The latter strategy is better than the former at reliability because a MOSFET is more stable than an a-Si TFT during operation.

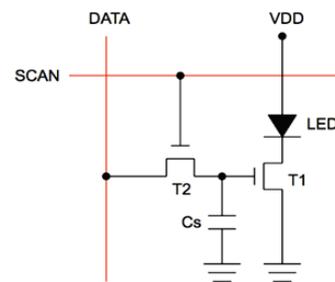


Fig.4 structure of the 2T1C pixel model

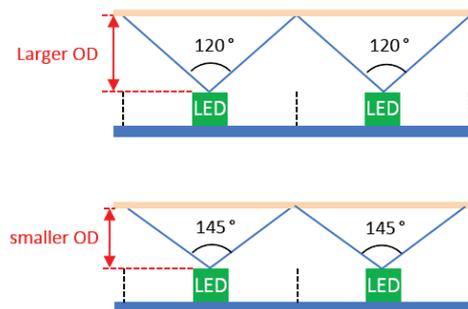


Fig.5 illustration of the relationship between optical distance and LED light emission angle

Four LEDs are included in each pixel (zone) to extend the lifetime of LEDs and reducing the optical distance (OD). The operation current for 4 LEDs in one zone is much lower than that of one LED per zone. Operation under large current will accelerate the degradation of the LEDs. Therefore, the design (4 LEDs per zone) which enables operation under smaller current is preferred. In addition, higher density of LEDs is also desirable to obtain a smaller OD, so that the profile of the module can be thin. Since light is emitted by the LEDs at a certain angle, the OD has to be large enough to allow the light expansion to overlap before the light of LEDs reaching the optical film, in order to obtain a uniform optical property. As demonstrated in Fig.5, the light emission

angle is further tailored to 145 degree compared to 120 degree for the traditional miniLEDs so that the profile can be further thinned.

2.1.4 Fabrication compatibility with a traditional array process

The fabrication process of the AM miniLED backlight systems includes four steps: array, cell, SMT and bonding processes. The array process follows a standard 4-mask channel-etch process. The cell process only includes a single cutting process, at which the glass substrates are cut into pieces of 21.2 inch chips. The SMT process is to weld the LEDs on the glass substrates with solder (Fig.6(left)). Finally, the chips are bonded to PCBs with COF packages. Fig.6(right) shows the result of lighting test after a miniLED chip is fabricated.

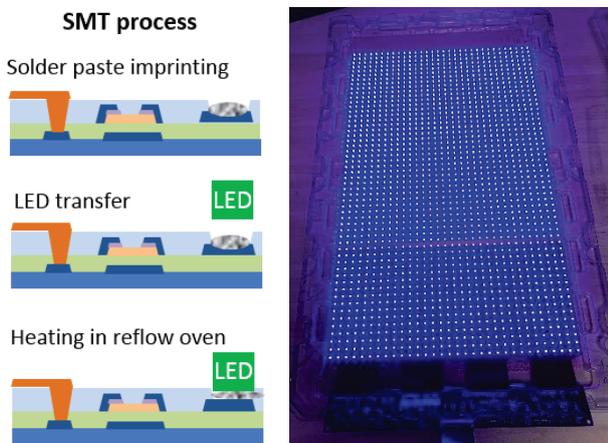


Fig.6 (left) fabrication steps of the SMT process; (right) lighting test result of a bonded miniLED chip.

2.2 Module construction

After the fabrication of 21.2 inch chips, a 75-inch LCD module is constructed by 12 chips (2 rows and 6 columns) in either direct type or all-in-one type. The difference between these two types is the direction towards which the PCB of the upper chips hang. The direct type is relative easy to assemble with the PCBs of the upper chips hang upwards and those of the lower chips hang downwards. However, the all-in-one type is generally more attractive to consumers because of its thin profile, which is attributed to hanging the PCBs of the upper chips downwards.

The glass substrates should be handled with extra care because they are relatively fragile. Unlike the traditional miniLED backlight made with PCB boards, the glass substrates should not be fixed on the shell by screws but can be fixed by tapes. In addition, because glass is a thermal insulator and the design of re-enforcement is not beneficial for heat dissipation, the temperature of the light bar should be higher than the one of the PCB based backlight. Therefore, two major concerns for the module consisting of glass substrates are whether it can endure a critical mechanical stress without breakage and whether

heat can be efficiently dissipated.

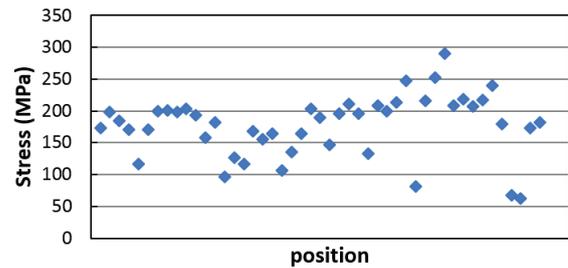


Fig.7 test result of the stress at different positions required to break the glass using 4-Point-Bending method

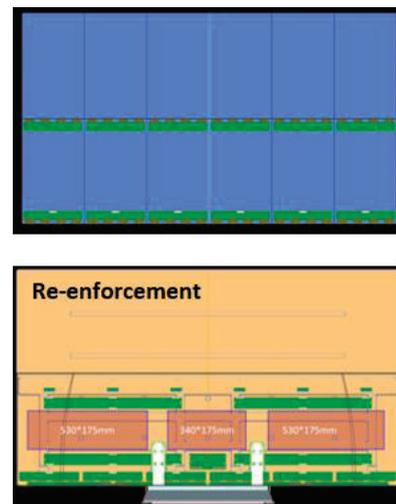


Fig.8 demonstration of (top) the placement of 12 chips and (bottom) re-enforcement structure for all-in-one type moduel

The stress distribution of the one-in-all module at the most extreme situation was simulated. When the module is carried by only two hands at two diagonal corners, the maximum stress applied on glass is 43MPa, as shown in Fig.7. The minimum required stress to break a glass substrate was also tested using 4-Point-Bending method, which indicates that the minimum value is 63MPa. Therefore, we conclude that the possibility of glass breakage during module consutruction and transporation should be low.

Temperatures of different parts of our module and a traditional miniLED module were simulated and compared. There are not much difference in the temperature of the front panels and the back cases. However, for the light bar, the temperature of our miniLED module is increased by 20 degree, reaching 61 degree. This is because that the light bar is not in contact with any of other part of the module and the surrounded air is poor in thermal conductivity, making it difficult to dissipate the heat. Fortunetly, 61 degree is lower than

the maximum LED operation temperature (70 degree). So, we the display can function normally.

2.3 Driver solution

Our AM miniLED driving method for ultra large numbers of LD zones is shown in Fig.9 and compared with the conventional one for PM miniLED with only a few hundreds of LD zones. The conventional method suffers from delay and reliability issues because of its serial connection. The AM driving method outputs data for panel and backlight in parallel from FPGA, therefore its speed of signal transmission is high and suitable for large numbers of LD zones.

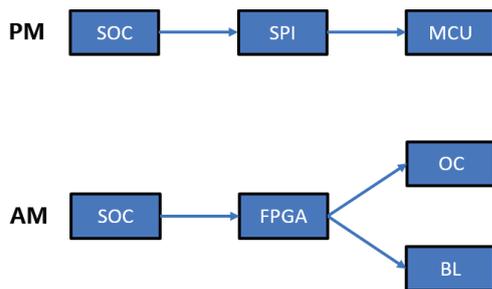


Fig.9 Driver solutions of PM and AM miniLEDs

2.3.1 LD algorithms

Fig.10 shows the framework of the local dimming algorithms we used to realized the HDR performance. The backlight algorithm is divided into 4 parts: brightness calculation, brightness enhancement, spatial filter and time filter. The brightness calculation module calculate the brightness of each zone by taking into account of the brightness of the image displayed on the panel. Then the brightness is enhanced to further increase the contrast. A gaussian filter is applied to smooth the brightness profile and avoid abrupt change in the brightness, making the displayed scene more natural. A time filter is to reduce the flicker effect. After the above processing steps, the backlight signal is finally produced. In addition, the backlight signal is passed into a light expansion module and the image signal for the front panel is processed by pixel compensation to improve the iamge quality.

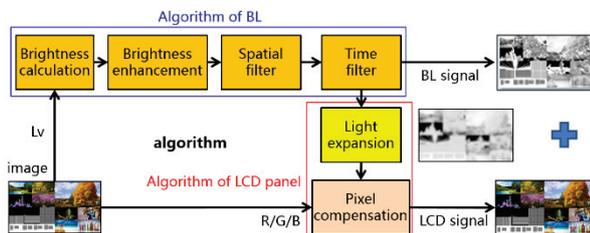


Fig.10 the framework of local dimming algorithm

2.3.2 Algorithms for Halo effect reduction

Conventionally, the brightness of the LD zone is merely determined by the gray scales of the pixels located at the zone. Improvement in algorithms can be done to reduce

halo effect by taking both the gray scales of the pixels and the area of an image at the corresponding LD zone. Therefore, the brightness is lower when the area ratio of the image displayed on panel to that of the LD zone is smaller the brightness is lower, dramatically reducing the halo effect. But a side effect could be that the border of the image will be dark.

3 Achieving HDR performance

Finally, the 75 inch AM miniLED display was assembled and demonstrated to achieve HDR with an alleviated halo effect, as shown in Fig.11.



Fig.11 Demo of the 75 inch display with the AM miniLED backlight system on glass and a 4K LCD panel

4 CONCLUSIONS

The 75 inch AM-miniLED backlight system with ultra large number of LD zones, which enable the LCD panel to exhibit HDR performance, has been sucessfully fabricated on glass. Compared to the conventional PM miniLED on PCB, our AM-miniLED system is lower in the fabrication cost. Thanks to the large number of LD zones, the halo effect is also dramatically reduced.

REFERENCES

- [1] Oh, C.-H., Shin, H.-J., Nam, W.-J., Ahn, B.-C., Cha, S.-Y., and Yeo, S.-D., "Technological Progress and Commercialization of OLED TV." SID Symposium Digest of Technical Paper, 44(1), pp. 239-242 (2013).
- [2] G. Tan, Y. Huang, M.-C. Li, S.-L. Lee, and S.-T. Wu, "High dynamic range liquid crystal displays with a mini-LED backlight" Optics Express, Vol. 26, No. 13, pp. 16572-16584 (2018).
- [3] S. Ono, K. Miwa, Y. Maekawa, and T. Tsujimura, "Vt compensation circuit for AM OLED displays composed of two TFTs and one capacitor" IEEE TRANSACTIONS ON ELECTRON DEVICES, Vol. 54, No. 3, pp. 467(2007).