Active Matrix Driving mini-LED Device

Chin-Lung Ting[1], Chung-Kuang Wei[1], Ker-Yih Kao[1], Li-Wei Mau[1], Ho-Tien Chen[1], Minoru Shibazaki[2],

[1]Innolux Corporation, No.3, Sec. 1, Huanxi Rd., Tainan City, Southern Taiwan Science Park, 74147, Taiwan
[2]Innolux Japan Co., Ltd., 5th Floor, Seishin-minami, Nishi-ku, Kobe, 651-2242, Japan
Keywords: mini-LED, active matrix driving, LCD backlight, public information display

ABSTRACT

We have developed a glass- or flexible substrate-based active matrix (AM) driving mini-LED device. The AM driving mini-LED device controls each mini-LED element precisely with thin film transistor (TFT), and can be applied to public information display (PID) and backlight (BL) of liquid crystal display (LCD), improving the optical performance of dynamic range, contrast ratio (CR), color purity and viewing angle performance of the display.

1 INTRODUCTION

Light emitting diodes (LED) displays have been used for entertainment digital signage and PID application in baseball stadiums, concert halls, and other public places. It is relative easy to achieve a larger size monitor with the LED display and the brightness is quite high compared with other devices. So we can see the display images even from a long distance and outdoors under sunlight. But when observed from a shorter distance, the image quality is very poor because of low pixel density. As the LED chip size and the control drivers are so large, it is difficult to make the display with high pixel density.

In recent years, a compact size LED such as mini-LED [1] element was introduced and was utilized as display pixel elements to replace the current large size LED. The mini-LED device is expected to be the next generation display because of its high dynamic range, high pixel density, environmental durability, long lifetime, and other favorable characteristics.

For the early stage of mini-LED development, we have driven the mini-LED elements with passive matrix (PM) driving method, because the photolithography process of the electrode on the substrate is quite simple and cost-effective. Besides, the high pixel density and the high resolution were not requested at that moment, since PM driving method was good enough to drive the mini-LED display at that time.

Recently, however, higher image quality displays with higher resolution, higher pixel density, wider dynamic range, and so on, have been requested. We have developed a high quality mini-LED device using AM driving method. This device can control each mini-LED element precisely. Furthermore, we can install the mini-LED elements on the glass or flexible substrate with a driving circuit, so it is relatively easy to make a large display with more than several hundred inches in diagonal size for PID by tiling the small mini-LED unit devices. Accordingly, we can utilize the mini-LED device in various sizes - from small size to large size displays - and in various shapes of displays and applications.

In this paper, we report the benefits of this AM driving mini-LED device and introduce some applications of this device.

2 Challenges of PM driving mini-LED

2.1 Circuit in PM driving mini-LED

When PM driving method for the mini-LED displays is used, the control ICs for PM driving can only drive limited number of mini-LED elements, and thus a large number of control ICs are required to drive all the mini-LED elements in the display. Accordingly, the size of printed circuit board assembly (PCBA) becomes very large, as shown in Fig.1, and the PCBA process becomes complicated (e.g. multi-layer printed process). Consequently, the total cost of processes and materials become very expensive.

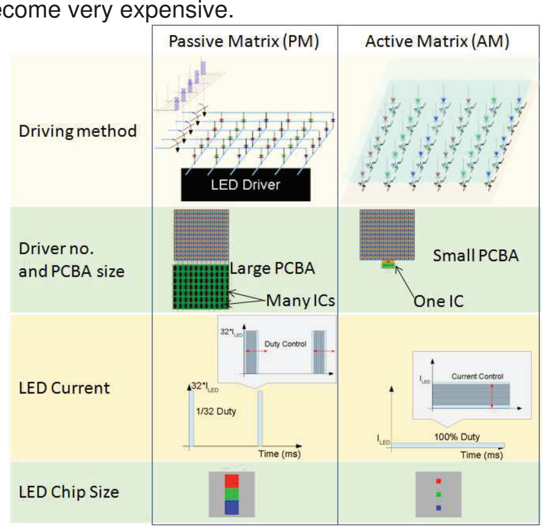


Fig.1 Difference between AM and PM driving

2.2 Optical performance in PM driving mini-LED

To achieve the gray scales in PM driving mini-LED, a pulse width modulation (PWM) driving can be used. Since the IC controls the brightness of multiple mini-LEDs by time-multiplexing for PM driving, the emission time of each mini-LED element is divided by the multiplexing number and the gray scales. As a result, the maximum LED current must increase proportionally to get the same brightness as hold type device. Generally, the efficiency of LED becomes lower at high current density. Hence the LED efficiency of PM driving is worse than that of the hold type display. In order to improve the efficiency of LED at high current density, we need to select a larger size mini-LED element as shown in Fig.1. But the cost increases at the same time and the pixel density may be lower.

A further problem is PWM minimum pulse width. There are two main issues to be solved for PM driving that AM driving does not have. One is gamma curve, and the other is light and dark lines when taking a picture of mini-LED by camera. PWM driving can only produce linear gamma (=1) and needs a redundant gray scale with extra bits to fit the gamma value of 2.2. Even assuming 14 bits linear grayscale supported by IC, we cannot achieve the brightness at low gray scales in 8 bit gamma 2.2 as shown in Fig.2. In addition, the extra bits narrows the PWM pulse width only 15ns in estimated with 60Hz refresh, 14 bits and 32 time-multiplexing as shown in Fig.1. Besides, to prevent the bright and dark line when taking a picture of the PM mini-LED PID, it has been proposed to increase the fresh rate to 10 times of the shutter speed (2000Hz for 1/200 shutter speed) [2]. This causes further narrow pulse width (~480ps). This is the toughest challenge, coming from LED current scheme of PM driving as shown in Fig.1. Besides, we need a large number of ICs to control whole mini-LEDs. Also, IC output difference accelerates the non-uniformity as shown in Fig.3 [3].

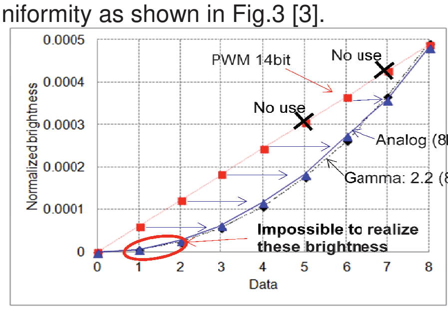


Fig.2 Low gray scales in PM driving

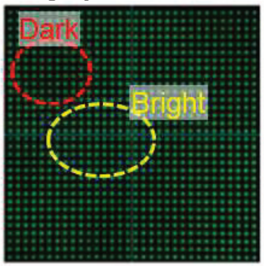
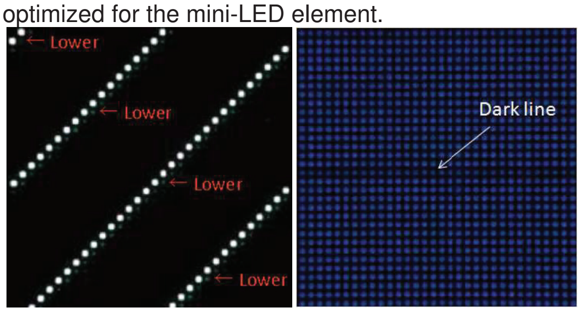


Fig.3 Non-uniformity at low gray scale of PM driving

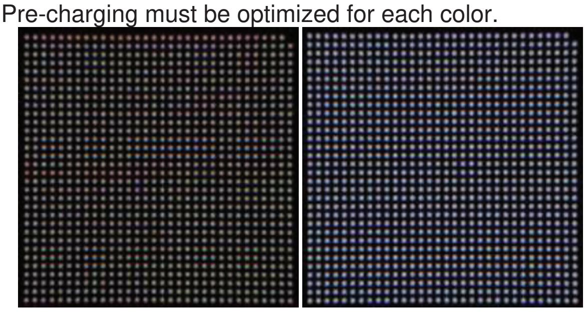
Another challenge of time-multiplexing of PM driving is parasitic capacitance which exists in the anode and the cathode lines [3]. The remaining charge in the capacitance causes unexpected lighting and visibility in lower and upper adjacent pixels of the lit-on pixels (i.e. ghosting effect) as shown in Fig.4 (a), and the capacitance can be additional loading for the driving which causes low brightness as shown in Fig.4 (b), if the driving is not optimized for the mini-LED element.



(a) Unexpected lighting (b) Unexpected dark line

Fig.4 Ghost and dark line issues in PM driving

On the other hand, pre-charging is well-known as a countermeasure for the lower ghosting effect, but it brings a side effect of color shifting as shown in Fig.5. Pre-charging must be optimized for each color.



(a) Color shifted image (b) Correct image

Fig.5 Gray scale color shift issue in PM driving

2.3 Pixel pitch in PM driving mini-LED

Because of the use of larger size mini-LED for the better LED efficiency, it is difficult to make a panel with high pixel density. Figure 6 shows a conceptual diagram of a display size and a viewing distance [1]. In case we view the display with low density pixel close to the display, we can recognize the mini-LED element itself easily if the pixels pitch is not small enough. Then the display image creates a granular feeling. The display with high pixel density and high resolution is required for powerful and realistic images.

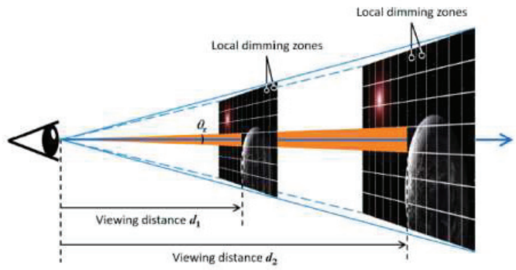


Fig.6 Conceptual diagram of pixel density

2.4 Summary of the challenges related to PM driving mini-LED

From the discussion above, PM driving mini-LED device is not suitable for a high quality display because many ICs and expensive PCBA are needed, driving up total cost and the power consumption, and the optical performance could be quite poor due to the difficulties of controlling driving signals which cause Mura issue. Moreover it is more difficult to achieve high pixel density because of the larger size mini-LED element for high LED efficiency.

3 Advantage of AM driving mini-LED

In order to overcome the challenges of PM driving mini-LED device, we have developed the AM driving method. Two types of mini-LED elements are available: package type and bare chip type. The package type is bonded on the substrate by a surface mounted technology (SMT) and the bare chip type by chip on board (COB). We use the low temperature poly silicon (LTPS) TFT to control each mini-LED element using a glass or flexible substrate. Figure 7 shows a photo of mini-LED array on the glass substrate.

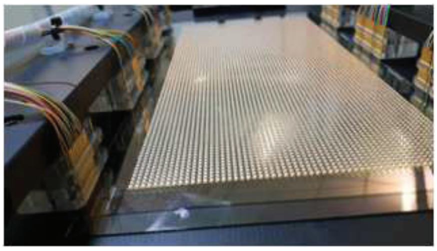


Fig.7 mini-LED on LTPS TFT glass substrate

The package type mini-LED is mainly used for PID or LCD backlight for TV and automotive displays. The bare chip type mini-LED is used for the backlight of LCD for smartphones because of cost and thickness benefits.

The driving system controls more than millions of pixels with one driving IC by controlling the TFTs that are arranged in a matrix form. And then, even though the pixel number increases to some degree, the number of ICs does not increase. We have optimized the driving system and the processes for mini-LED device, for example, the maximum electric current and the maximum voltage tolerance, among others. As a result, we don't need to use a large size PCBA like PM driving mini-LED device as shown in Fig.8. Since we can reduce the total IC numbers and PCBA size for high quality display, the total cost, including for process and material, could be more reasonable compared to that of PM driving mini-LED displays.

Fig. 8 Driving IC and PCBA for AM driving

In order to control the brightness of each mini-LED element, an analog control can be used for AM driving method. We control the electric current for each mini-LED element and can achieve any kind of gray scale, so it is easy to control the gamma properties as shown in Fig.4. We can achieve even low gray scales precisely. Besides, we can apply the electric current all the time to all of the mini-LED elements, thus reducing the maximum current. Accordingly, we can select small size of mini-LED element and the cost is lower than that of big size for PM driving mini-LED.

From the above discussion, the AM driving mini-LED device is much superior to the PM driving device in optical performance, the power consumption, and the total cost, as shown in Table 1.

Table 1 Comparison between PM and AM driving

	PM mini-LED	AM mini-LED
Backplane cost	**Low**	High
IC numbers	Huge	**Less**
PCBA size	Large	**Small**
Cost of driving board	High	**Low**
Grayscale	PWM (digital)	**Current control (analog)**
Gamma adjustment	Effective bits are reduced	**Embedded in driver IC**
Maximum current	High	**Low**
LED efficiency	Poor	**Good**
LED size	Large (for better LED efficiency)	**Small**
LED cost	Expensive	**Cheap**

4 Application of AM driving mini-LED device

4.1 Backlight for LCDs

One of the applications of AM driving mini-LED is backlight unit of LCDs. Figure 9 shows the structure of backlight unit. We use a rear cover with heat sink to dissipate the heat under the mini-LED. The diffuser plate and optical film are placed on top of the mini-LED device for uniform brightness. Figure 10 shows a 65-inch VA mode LCD with mini-LED backlight. Table 2 shows a specification of the display.

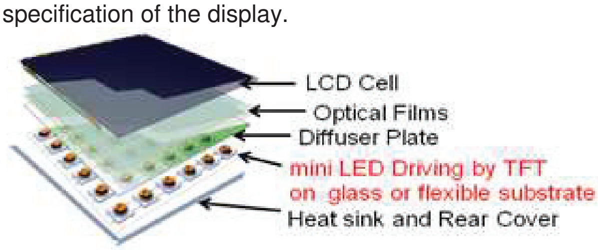


Fig.9 Structure of backlight unit using mini-LED

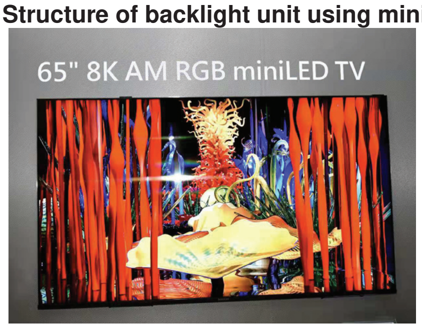


Fig.10 65" VA LCD with mini-LED backlight

Table 2 Specification of 65" VA LCD

Display size	65inch
LC mode	VA
Panel resolution	7,680 x 4,320
Peak brightness	1,000nits
Contrast ratio	1,000,000 : 1
Color saturation	127% NTSC (97% BT.2020)
mini-LED Backplane	LTPS on glass substrate
Dimming zone	9,600

Owing to the precise control of each mini-LED, we could achieve a very fine dimming area and a wide dynamic range. Accordingly, we could reduce the halo effect and the contrast ratio improves to more than 1,000,000:1. The maximum brightness of the panel becomes more than 1,000 nits. Besides, we could control the mini-LEDs with each primary color for TV application that contribute to the high color gamut as well.

Viewing angle performance of the VA mode LCD device can be improved. Generally speaking, the viewing angle dependence of middle gray scale of LCD is poor because liquid crystal molecules tilt up in middle level and then the viewing angle dependence of retardation value changes from different view positions. So, basically when the tilt angle of liquid crystal molecules is close to 0 or 90 degrees, the viewing angle dependence is smaller. When combined with dimming BL to assign the gray scales to mini-LED BL, the tilt angle of liquid crystal molecule can be smaller or larger than that of conventional backlight, and then the viewing angle performance improves accordingly.

4.2 PID application

We have applied AM mini-LED for the large size PID with high image quality. We can enlarge the display system by tiling the mini-LED sub-modules without any boundary or the limitation of tiling number. The resolution of one sub-module is 120 x 135 pixels, and one cabinet consists of 8 mini-LED sub-modules which add up to the resolution of 480 x 270 pixels. Currently, the pixel pitch of mini-LED PID is 1.27mm which is state-of-the-art of the industry today. The pitch of AM mini-LED can be further reduced in the near future, achieving a level which is very difficult for PM mini-LED.

Figure 11 shows a 330" AM mini-LED PID with 144 (12x12) cabinets and table 3 is a specification. As shown in the picture, we can enlarge the display to taller than adult height without any boundary between the cabinets or the bright and dark line when taking a picture.

We made the mini-LED array on the flexible substrate as well and we can apply it to the curved or flexible PID as shown in Fig.12.

5 Summary

Several decades ago, LCD came along for monitor and TV applications thanks to its lightweight and slim size. In the beginning, LCD was controlled by PM driving (STN), which was later replaced by AM driving. Eventually, AM driving LCD replaced the cathode ray tube (CRT) display.

History will repeat. Now that we have developed the AM driving mini-LED device which will replace the PM driving method. The new device can control each mini-LED element with smaller number of ICs. Accordingly, we can achieve high quality display with low cost and apply it for a lot of applications.

As illustrated above, we strongly believe that AM driving mini-LED is the next generation of displays.

Fig.11 330" AM mini-LED PIDs

Table 3 Specification of 330" mini-LED PID

Display size	330 inch
Resolution	5,760 x 3,240
Cabinet number	12 x 12
Max. brightness	600nits
Contrast ratio	1,000,000 : 1
Color saturation	115% NTSC

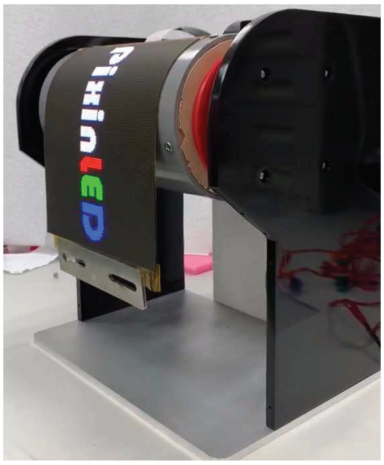


Fig.12 Flexible AM mini-LED device

REFERENCES

[1] Tingzhu Wu, et al, "Mini-LED and Micro-LED: Promising Candidates for the Next Generation Display Technology", Appl. Sci. 2018.8.1557

[2] Ping-Kai Huang, "10X Refresh Rate Theorem of LED Display", Technical article of Macroblock, Inc.

[3] Chung-Ta Tsai, "Fine Pitch LED Display, Possible Problems and Driver IC Solutions", Technical article of Macroblock, Inc.