Investigation of Temperature-dependent Behaviors of Mini/Micro-LEDs

Zhaojun Liu*[1], Minggang Liu[2], Yong Fan[2], Jiayu Lee[2], Bo Lu[1], Hao-Chung Kuo[3], Xiaowei Sun[1]

[1] Department of Electrical and Electronic Engineering, Southern University of Science and Technology, Shenzhen, China
[2]Shenzhen China Star Optoelectronics Technology Co., Ltd (CSOT) , Shenzhen, China
[3]Department of Photonics and Institute of Electro-Optical Engineering, College of Electrical and Computer Engineering, National Chiao Tung University, Hsinchu, Taiwan

Keywords: Micro-LED Display; Mini-LEDs; Temperature-dependent;

ABSTRACT
Micro-LED display consist of arrays of Micro-LEDs and driving backplane with bonding technologies. As the size of LED pixel get smaller, the amount of LED chips becomes a huge number. The thermal issue of Mini/Micro-LEDs needs to be considered carefully. We report a 32×32 flexible Mini-LEDs array with driving current of 10mA under applied bias of 2.6V. The result of testing temperature distribution in different brightness shows that the Mini-LED array satisfy the requirement of thermal stability.

1 INTRODUCTION

Micro-LED display is a quite new technology which has developed only about a decade and been attracting tremendous attention in recent years. It was regarded as a great candidate for many applications, such as solid-state lighting, display, wearable devices, AR/VR, communication, detector and sensor. Our group have reported Backlight-unit-free (BLU-free) Micro-LED projector by optical synthesis in 2012 and 1700 PPI Micro-LED display in 2014 Compound Semiconductor Integrated Circuit Symposium [1][2]. Micro-LEDs are also very potential for visible light communications (VLC) and position system because of the fast response time and high modulation bandwidth, which has been reported in 2016, supporting 1.25-Mb/s for a bit error rate <10−5 up to >500cm distance with a lens [3]. Besides, the superior intrinsic properties of III-nitride material also enable Micro-LEDs work as sensors, biomedical devices, photodetectors, and solar cells and so on. Design and fabrication of high-quality Micro-LED device with superior stability and reliability is the key for high quality micro-displays. Nowadays, an increasing number of companies and research institutes paid their effort to this hot topic, therefore more and more improved technology were reported in many field such as epitaxy, fabrication, full color realization, mass transferring, system integration and pixel repairing.

On Display Week 2019, there were many Micro-LED prototypes demonstrated on I-Zone which caught much more interests from both academic institutions and industries. Many products were also exhibited and got much attention during the display week, such as Micro-LED transparent display with LTPS driving, Micro-LED transparent display with by TFT driving, Micro-LED full-color display with QDs. Besides, BOE, TCL, CTOS, TianMa and many companies shared their novel mini-LED products, which also showed great potential in the future display field.

In recent work, we reviewed the development of Micro-LED which attracted increasing attention recently, share our work about how to get high quality Micro-LEDs and the its applications for displays and beyond. In addition, we achieved Micro-LED devices with good electrical performance and high reliability under several different extreme environment with different size and structure. The corresponding size-effect, edge effect and optical performance optimization were also systematically discussed and analyzed.

As LED chips become smaller and smaller, the number of LED chips will increase dramatically. As a result, heat problems become serious and cannot be ignored. Increasing temperature will reduce the luminous efficiency of Micro-LED, leading to the raise in thermal resistance and a red shift of spectral line. In this report, we mainly focus on the effect of the wavelength shift of LED which is caused by the band gap decreasing of the material. Many papers have reported the effect red shift caused by temperature changing. However, limited reports mentioned thermal stability issues on flexible transparent LED array. In this paper, we discussed the investigation of thermal issues of Mini-LED displays and find out whether the temperature will influence the emission wavelength.

2 EXPERIMENT

The Mini-LED array on a flexible and transparent polyethylene terephthalate (PET) substrate was implemented. The chip unit consist of GaN epitaxy wafer and driving circuit with passive matrix driving scheme. Flip-chip technology was used for bonding as shown in figure 1 to make 1024 Mini-LEDs could be electrically connected to a corresponding driving unit on the circuit board.

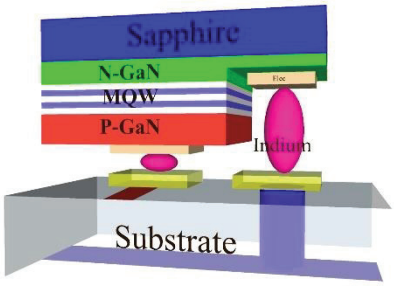


Figure 1. Schematic diagram of Flip-chip technology

The pixel pitch of the Mini-LED array was 500um×150um, and the resolution was 32 × 32. As shown in figure 2, the row lines will be sequentially scanned which is the scan signal. The specific column lines will be addressed to provide a constant sink current for each pixel of the Mini-LED array [4][5]. In this design, the brightness will be controlled by the duty ratio.

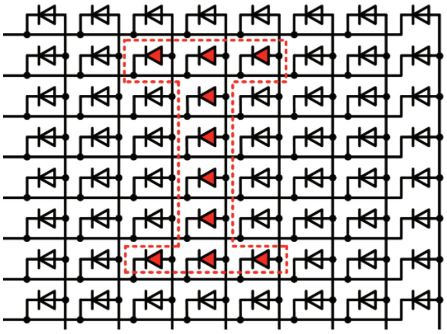
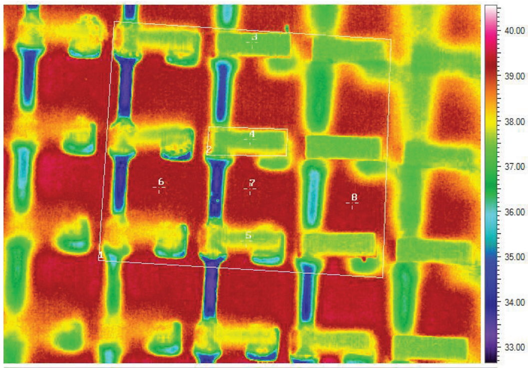


Figure 2. Schematic of the system

The electroluminescent spectra from the mini-LEDs and temperature distribution were measured at different brightness. Thus, the thermal stability was analyzed at each brightness. Meanwhile, temperature uniformity was also investigated under different brightness state. Thermal imaging microscope was used to measure temperature of the surface of the mini-LEDs at different brightness. In details, the handheld thermal imager was placed at 10 cm away from the Mini-LEDs to obtain the temperature distribution by taking the thermal image. Detailed temperature data was calculated by MATLAB.

3 RESULTS



#	Name	Hi Lim	Low Lim	Emiss	Area	Max	Min	Mean
1		500.0	-40.0	1.00	121,205	39.70	33.34	38.16
2		500.0	-40.0	1.00	4,070	39.02	36.84	37.75
3		500.0	-40.0	1.00	1	37.30	37.30	37.30
4		500.0	-40.0	1.00	1	37.40	37.40	37.40
5		500.0	-40.0	1.00	1	37.79	37.79	37.79
6		500.0	-40.0	1.00	1	39.32	39.32	39.32
7		500.0	-40.0	1.00	1	39.23	39.23	39.23
8		500.0	-40.0	1.00	1	39.39	39.39	39.39

Figure 3. Schematic of the system

Figure 3 shows the temperature distribution of Mini-LED array in highest brightness which is over 5000 nits. When the brightness was tuned from highest to lowest, the wavelength spectra was accordingly changed. The difference was hardly observed by human eyes but can be caught by spectrograph.

According the literature, the color difference that human eye can resolve is 0.005 [6]. As the temperature increases, the light intensity, wavelength, and FWHM (full width of half maximum) of the LEDs changed. Therefore, it is necessary to test the temperature uniformity of the LED array. The band gap decreases with the temperature rising, leading to the wavelength shift, which have been studied in the past [7]. The peak wavelength, the FWHM, and the peak value of the LED spectral also changed with temperature as show in formula (1) [8]

$$\begin{cases} \lambda_{0,T} = \lambda_{0,25} + k_1(T-25) \\ \triangle\lambda_{0.5,T} = \triangle\lambda_{0.5,25} + k_2(T-25) \\ I_T = I_{25} \cdot k_3(T-25) + I_{25} \end{cases} \quad (1)$$

The relationship between the spectra and temperature is shown in figure 4. When the color difference is smaller than the range that can be resolved by the human eye, the change has no effect on the perception, which is required to less than 0.005.

However, for higher temperatures such as 45°C, 65°C, 85°C and others, it is clear that the Mini-LED array cannot reach these temperatures for testing, so the unmeasured temperature is substituted into the formula (1) to get the peak value, peak intensity and FWHM. That means temperature difference should less than 9°C to meet the requirements of high quality display applications.

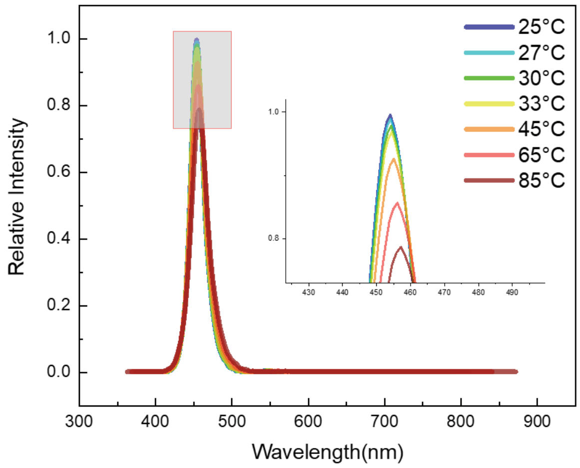


Figure 4. Wavelength spectra with different temperature

4 CONCLUSIONS

This paper describes the fabrication of flexible, transparent Mini-LED array. The detailed fabrication process was introduced. The temperature-dependent behavior of the array such as spectra in different brightness were measured, and the result shows that this array is with sufficient thermal stability and be suitable for high quality displays.

ACKNOWLEDGEMENT

The authors would like to thank Prof. Kei May Lau and Prof. Hoi Sing Kwok and Ms. Ke Zhang of ECE department of HKUST. This work was supported by Guangdong Key Project (2019B010925001), Shenzhen Peacock Project Innovation Team (No. KQTD20170810110313773).

REFERENCES

[1]. Z. Liu, K. Zhang, Y. Liu, S. Yan, H. S. Kwok, J. Deen, X. Sun, “Fully Multi-Functional GaN-based Micro-LEDs for 2500 PPI Micro-displays , Temperature Sensing , Light Energy Harvesting , and Light Detection,” in IEDM Tech. Dig., pp. 871–874, (2018).

[2]. W. C. Chong, and K. M. Lau, and et al., “1700 pixels per inch (PPI) passive-matrix micro- LED display powered by ASIC” no. OCTOBER, pp. 2–6, (2014).

[3]. Li, Xianbo, et al. "Design and characterization of active matrix LED microdisplays with embedded visible light communication transmitter." Journal of Lightwave Technology, vol. 34, no. 14, pp. 3449-3457, (2016).

[4]. Markov, L. K., et al. "Comparison of the properties of AlGaInN light-emitting diode chips of vertical and flip-chip design using silicon as the a submount." Semiconductors, vol. 47, no. 3, pp. 409-414, (2013).

[5]. Das, Naresh Chandra, et al. "Flip Chip Bonding of 68 × 68 MWIR LED Arrays." IEEE Transactions on Electronics Packaging Manufacturing, vol. 32, no. 1, pp. 9-13, (2009).

[6]. Perduijn, Armand, et al. "43.2: Light Output Feedback Solution for RGB LED Backlight Applications." SID Symposium Digest of Technical Papers, vol. 34, no. 1, (2003).

[7]. Allen, Philip B., and Jean Paul Nery. "Low-temperature semiconductor band-gap thermal shifts: T 4 shifts from ordinary acoustic and T 2 from piezoacoustic coupling." Physical Review B, vol. 95, no. 3, p. 035211, (2017).

[8]. Man, Kwong, and Ian Ashdown. "Accurate colorimetric feedback for RGB LED clusters." Sixth International Conference on Solid State Lighting. Vol. 6337, p. 633702. International Society for Optics and Photonics, (2006).