# Investigation of High Performance and Fine-pitch GaN-based Micro-LEDs

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**ABSTRACT**

*Micro-LEDs have become the focus of display research due to their outstanding characteristics in brightness, lifetime, resolution, and efficiency. The research of small size and fine-pitch Micro-LED has attracted full attention. In this paper, we review the progress of GaN-based Micro-LEDs with small size and fine pitch. Besides, high performance Micro-LED arrays, which have 6um*6.5um pixel size and 9.5um*9.5um pixel size will also be reported. This research is an essential breakthrough for fine-pitch GaN-based LEDs.*

## 1 INTRODUCTION

Micro-LED can meet the personalized needs of advanced applications, such as mobile phones, wearable watches, virtual/augmented reality, and micro-projection due to its fast response speed, high luminous efficiency, low energy consumption, and small size, which instrument and ultra-high definition display. Therefore, it is regarded as the cornerstone of next-generation display technology and has received more and more attention [1-3].

In the last decade, the broad application prospects of Micro-LED have attracted many manufacturers. Sony introduced the first 55-inch full high-definition (HD) Micro-LED TV panel with a resolution of 1920×1080 in 2012, including 6 million individual Micro-LEDs. Samsung launched the world's first consumer modular Micro-LED 146-inch TV in 2018, called "The Wall". In 2019, the latest Micro-LED display from Canadian startup VueReal can achieve ultra-high resolution of 30,000 PPI and ultra-high brightness of 100,000 nits, which strengthens AR/VR display applications.

In the academic field, the research on Micro-LED has also been more than ten years. In 2006, the University of Hong Kong's Science and Technology team used passive drive and flip-chip welding technology to make Micro-LED displays.

The microarray was released by the Z. Gong's team in 2008 is still driven by a passive matrix and integrated with flip-chip welding technology. This team made a blue Micro-LED array (470nm) and UV micro-LED array (370nm), and successfully prove the feasibility of quantum color mode by stimulating the green and red dots in UV LED array [4].

In 2009, Z. J. Liu's team at the Hong Kong University of Science and Technology used a UV micro-LED array to excite red, green, and blue phosphors to obtain a full-color micro-LED display chip [5]. In 2010, the team prepared a 360 PPI Micro-LED display chip using red, green, and blue LED epitaxial wafers and integrated the three chips to realize the world's first full-color Micro-LED projector with no backlight [6].

In 2018, Micro-LED micro displays with 5000 pixels per inch (PPI) were reported by Jade Bird Display [7].

The size and pitch of Micro-LED determine PPI. The smaller the pixel pitch and size, the higher the PPI and the more luxurious the picture's details. Here, we report on Micro-LEDs arrays that have 6um*6.5um size with 2um pitch and 9.5um*9.5um size with 3um pitch, which is suitable for Head-Mounted Displays (HMD), Augmented Reality(AR) and Virtual Reality(VR), and ultra-high-definition for large-screen TVs. The display is a breakthrough in the small size and exceptional pitch of Micro-LED.

## 2 EXPERIMENT and ANALYSIS

We have fabricated Micro-LEDs array with 6um*6.5um size with 2um pitch and 9.5um*9.5um size with 3um pitch. The fabrication process is showing in Figure1, Micro-LEDs are fabricated on the sapphire substrate, which has ten Multiple Quantum Wells (MQW), as showing in Figure1(a). Using $SiO_2$ as a hard mask for photolithography and Inductively Coupled Plasma (ICP) etching as showing in Figure1(b).

Then, ITO is deposited on the surface of P-GaN as the current spreading layer (CSL), as showing in Figure1(c). Perform rapid thermal annealing (RTA) to achieve ohmic contact between p-GaN and CSL. Ti/Al/Ti/Au is deposited as electrodes by electron beam evaporation, as showing in Figure1(d). Use the Keysight B1500A analyzer to analyze current-voltage characteristics.

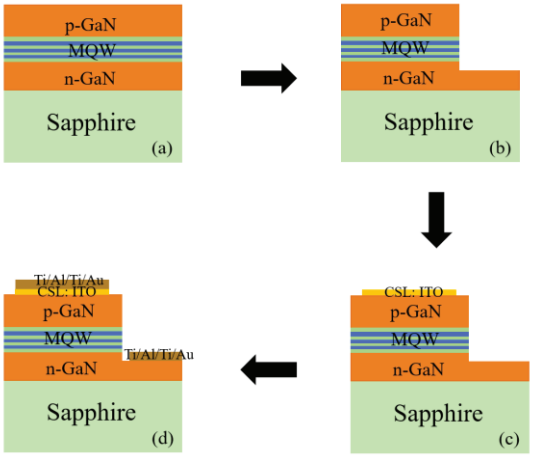


**Fig.1 Fabrication process**

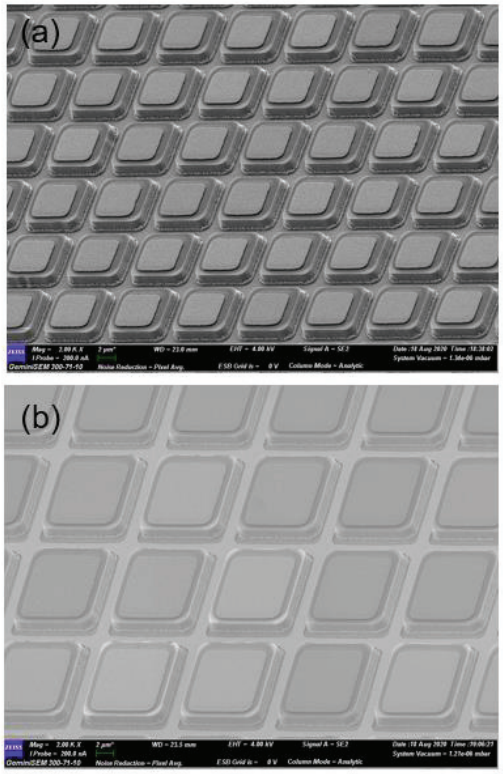


**Fig.2 (a)6um*6.5um size with 2um pitch. (b)9.5um*9.5um size with 3um pitch. Micro-LED array.**

The fabricated Micro-LED array is shown in Figure 2. Figure 2(a) shows Micro-LED array with a size of 6um*6.5um, while Figure 2(b) shows Micro-LED array with a size of 9.5um*9.5um. Since passivation has not been done yet, the sidewalls appear roughly, which will have some impact on the electrical and optical performance. We plan to deposit a $SiO_2$ layer for passivation by plasma-enhanced chemical vapor deposition (PECVD), and the pattern is by reactive ion etching (RIE). Finally, open the contact hole and evaporate indium as a pad. In order to transfer to a printed circuit board (PCB) for wire bonding. After all the fabrication processes are done, it can be directly combined with the driving panel for display. The Micro-LED arrays we have reported are tiny in size and pitch, which means that the display array has ultra-high PPI. It has excellent applications in wearable near-eye display devices such as VR/AR. At the same time, it is a breakthrough for HD display.

The linear characteristics of I-V (current-voltage) and J-V (current density-voltage) in the semi-log form are plotted in Figure 3. The diode ideality factor of each size device can be extracted from the I-V curve. The ideality factor of 6 microns is 1.6, and that of 10 microns is 1.8. The low ideal value of GaN-based LEDs shows that our devices exhibit excellent performance in theory. In the JV semi-log curve, the forward voltage ($V_F$) of 1 A/cm$^2$ and 10 A/cm$^2$ can be derived as 2.15 V and 2.34 V. With the shrinking of Micro-LEDs, smaller-sized Micro-LEDs Can withstand higher current density under the same voltage. Compared with OLED [8] and QLED [9], Micro-LED has better display capabilities.

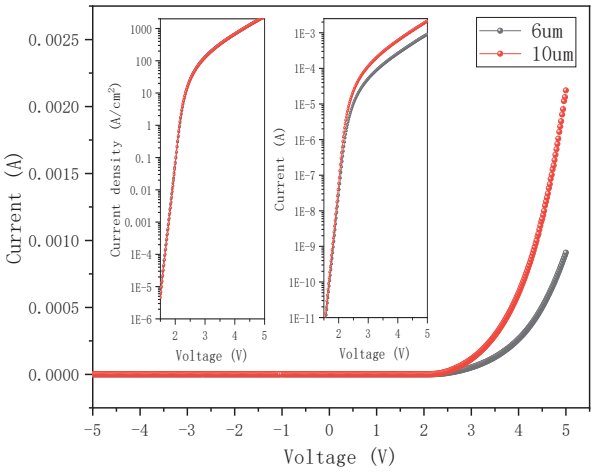


**Fig.3 The current-voltage semi-log curve with current density-voltage semi-log curve inset of device size with 6*6.5um$^2$ and 9.5*9.5um$^2$.**

## 3 CONCLUSIONS

It is essential to investigate the small size and fine pitch Micro-LED. We report Micro-LEDs arrays that have 6um*6.5um size with 2um pitch and 9.5um*9.5um size with 3um pitch. According to the electrical characteristics, the small-sized Micro-LED shows an excellent ideality factor and low forward display voltage. This research is a breakthrough in the small size and fine-pitch of Micro-LED, playing a significant role in near-eye display and ultra-high-definition display of large-screen TVs.

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