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OLED, MiniLED, MicroLED and QNED: The Battle for the Next Generation of Televisions

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ABSTRACT

OLED was once thought to be a sure winner for the next generation of high end TVs. However LCD keeps improving and closing the performance gap, and new technologies are emerging. Among them, miniLED, microLED and QNED have raised a lot of attention as potential OLED alternatives for TV applications.

1 INTRODUCTION

OLED was once thought to be the sure winner in the high-end TV market, but LCD is increasingly efficient at competing in this segment as well. Technologies such as quantum dot (QD) films, dual cell, Full Array Local Dimming (FALD) and miniLED significantly improve LCD performance while leveraging the existing LCD manufacturing infrastructure and requiring little to no additional capital expenditure (capex). The performance gap between LCD and OLED shrank while white OLED (WOLED) failed to reduce the cost gap. As a result, OLED is facing increased competition from LCD in the high-end segments, forcing LG to reduce WOLED panel prices for the first time in years.

Meanwhile, new display technologies and architectures are emerging. Those include inkjet-printed OLED, electroluminescent QDs, QD-OLED, microLED, QNED. Samsung Display has closed most of its LCD fabs but pledged to invest up to US$11B in new technologies, including $8.4B in capital expenditure for new fabs.

2 MiniLED

2.1 Benefits

Full Array Local dimming (FALD) is an efficient way to improve LCD contrast and reduce blooming (halo) effect for bright objects displayed on a dark background, such as planet and stars in a dark sky, fireworks, candle lights etc (Fig. 1).

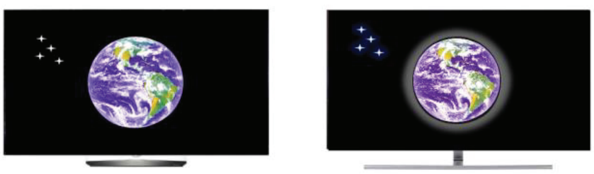

Fig. 1 Impact of local-level dimming: OLED (left) vs. LCD (right).

By increasing the number of zones to more than 5000 and the number of LEDs top more than 10,000, miniLED backlight further improve contrast and blooming reduction to a level where for more viewers, the experience in image quality is close to or indistinguishable to that of OLED [1]. In addition, miniLED reduce power consumption by up to 50% compared to traditional LCD and enable brightness level significantly better than OLED.

2.2 Architecture

The design of a miniLED backlight involves complex tradeoffs between performance, cost and aspect (thickness). LED sizes and numbers will impact brightness, thickness, contrast, cost and manufacturability. The choice of a substrate is also driven by cost manufacturability and the size of the LED: As the size of the die decreases, the gap between the n- and p- bonding pads decreases. This requires more stringent PCB specifications: flatness, roughness etc. to ensure precise lithography and die placement (Fig. 2).

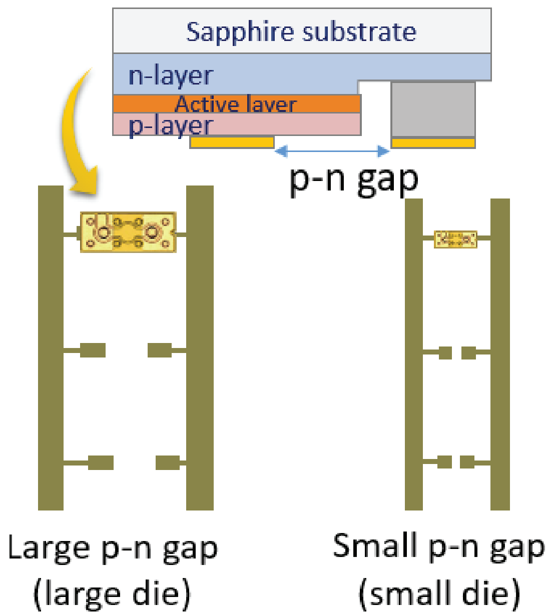

Fig. 2 Reduction of miniLED die size and p-n gap

The assembly of more than 10,000 miniLED is also time consuming and costly. Standard LED chip bonders fail to deliver sufficient placement accuracy and throughput. New generations of tools are therefore require. High precision chip bonder also usually operate over relatively small stage areas. As TV size increases and now routinely reach 65”, 75” or above. The miniLED backlight must be assembled in modules tiled together. With PCBs, electrical connections are routed through the board to the backside where the drivers and other components are located. The board can have multiple layers to allow complex routing of the signals and enable seamless, gap-free assembly. For glass boards, module stitching becomes an issue as the signal needs to be routed to the edge of the glass boards using flexible edge connectors bonded at the surface of the glass (Fig. 3)

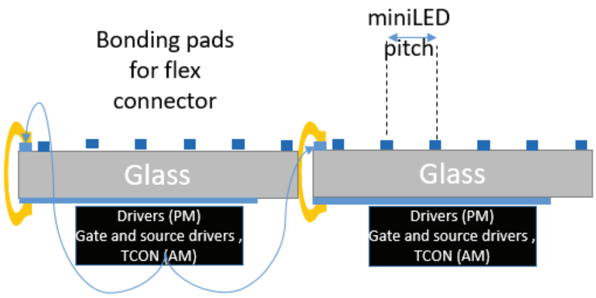

Fig. 3 Tiling of glass-based miniLED backlight modules

Via holes (AKA “TGV” for Through Glass Vias) remain prohibitively expensive.

As the miniLED pitch decreases, the area available for bonding and bending the flexible connector without creating a pitch discontinuity decreases.

Flex connector is currently the preferred option although some panel makers have developed edge connectors deposited directly on the edges of the glass.

2.3 Driving

Passive Matrix (PM) is the standard for LCD FALD BLU. It is well suited for displays with low numbers of zones.

As the number of zones increases above a few thousands, the performance of PM driving decreases (ghosting) and the number of drivers increases, leading to a rise in costs.

Active matrix miniLED backlight driving can be implemented by using a glass based Thin Film Transistor (TFT) backplane. The high currents required to drive the LED chips however requires specific TFT design, with large channels for the drive transistors. Alternatively, the TFT can provide the switch transistor only while the drive transistor is provided as a discrete MOSFET circuit assembled in the same way the miniLED chips are. The concept of “minidriver” where the full driving and compensation transistors and capacitors are provided by a discrete CMOS circuit is also explored (fig. 4).

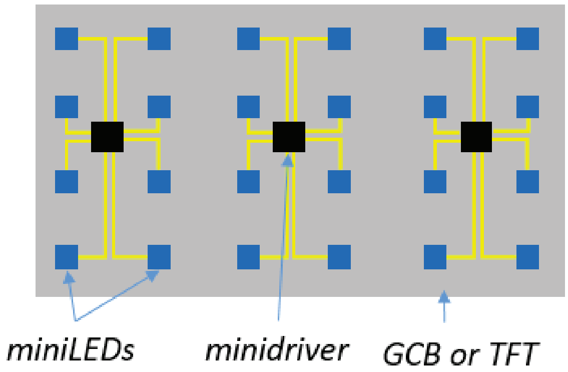

Fig. 4 Tiling of glass-based miniLED backlight modules

3 MicroLED

3.1 Overview

Micro LED displays use individual, small inorganic LED chips as the sub-pixels. Unlike OLEDs, inorganic LEDs require high processing temperatures (>1,000°C) and can’t be “grown” and patterned directly atop the transistor matrix. Therefore, the microLED chips are manufactured separately on 4” to 12” wafers before singulation, transfer and assembly onto the display substrate and/or backplane. This can be done from individual red, green and blue LED chips (Fig. 5), or using blue chips combined with red and green color converters such as quantum dots.

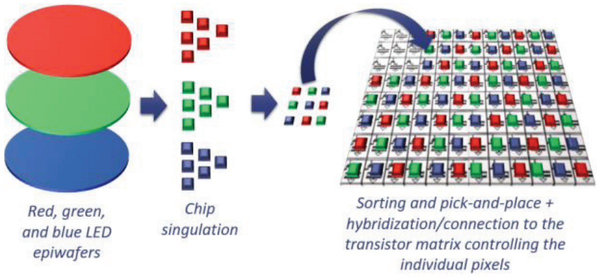

Fig. 5 Basic concept of microLED displays

3.2 Benefits

As a self-emissive technology, microLEDs retain all the benefits of OLED: pixel-level dimming, wide viewing angle etc. It could also deliver much higher brightness and, being a robust, inorganic material, microLEDs are stable and durable, eliminating risk of image burn it and the need for complex, expensive encapsulation.

For TV applications specifically, microLED also offer a unique characteristic: because they don’t require sealing like LCD or encapsulation like OLED, microLED can be made 100% bezeless. This unable modular designs, where seamless tiling of microLED modules allows the building of displays of arbitrarily large sizes (Fig. 6)

Such modular design improve manufacturing yield (only defective modules are rejected, rather than the full display) and could significantly reduce the cost of large displays as well as simplifying the logistic of shipping, delivering and installing "jumbo" TVs in sizes above 100".

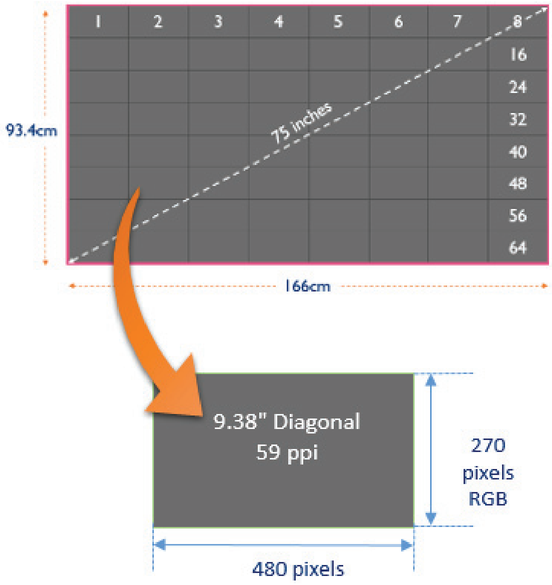

Fig. 6 Concept of a modular 75" microLED TV

3.3 Challenges

The challenges of microLED displays have been discussed extensively [2], [3]. They include assembly, microLED efficiency at small sizes, beam shaping, driving, yield management and repair etc.

The tiling of microLED modules brings additional challenges. The modules must be bezel-less, the stitching & assembly absolutely flawless both mechanically and in terms of calibration of each individual tile (color, brightness, contrast…). Signal and power must be routed to the pixels from the back of the module, either via plated Through Glass Vias ("TGV") or the edges of each module. (Fig. 7).

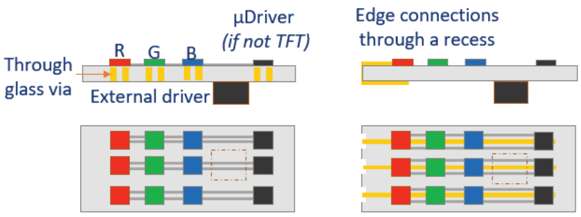

Fig. 7 Signal routing for microLED modules

Various technologies and architectures are being explored in order enable signal routing from the front to the back of the modules. Those include TGVs, wrap around electrodes, flexible TFT backplanes or vias created through the frontplane. In this latter architecture, the driver ICS sit on the top of the structure and requires that a bottom emission display structure be used.

4 QNED

4.1 Overview

The term "QNED" stands for "Quantum Nano-Emitting Diodes" or "Quantum Nanorod Emitting diodes". QNEDs have been developed jointly by Kookmin University, PSI Corp and Samsung. QNEDs consists in small LED "rods", typically 2-3 μm length, 0.5 μm diameter self-assembled in a pixel bank. Rod-shape μLEDs are grown, harvested, coated with a surfactant to avoid aggregation and dispersed into a solvent. The μLED "solution" is deposited by inkjet printing on the TFT backplane by inkjet printing. Pixels are separated by dams. Electrodes on the pixel bank are used to apply an asymmetric AC voltage (typical 0-30V at 950 kHz). This create a force that aligns the rods perpendicular to the electrodes. The solvent is then evaporated and the connecting electrodes are deposited. Optional scattering particles and color conversion is added (Fig. 8)

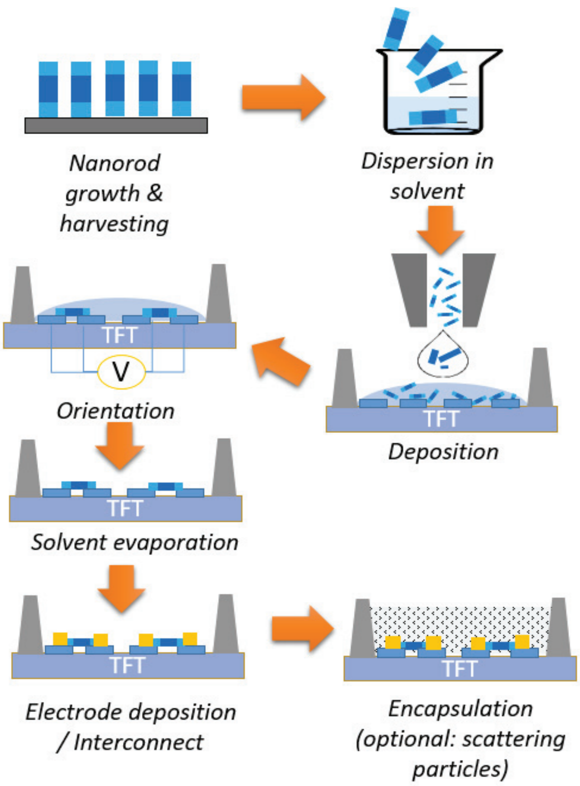

Fig. 8 Overview of the QNED process

4.2 Potential Benefits

The QNED display structure and manufacturing process are similar to that of QD-OLED. QNED could solve some of the major challenges associated with QD-

OLED by replacing the fragile, low efficiency, blue-OLED material multi-stack with a robust, long lifetime high efficiency inorganic “coat” of QNEDs. The technology could lift many of the major roadblocks that are still preventing adoption and volume manufacturing: Standard µLEDs require multiple technology and manufacturing breakthroughs for transfer and assembly as well as yield management, repair.

QNED are self-assembled using Inkjet Printing (IJP). IJP is already used in mass production for OLED thin film encapsulation. Many companies are working on IJP for RGB OLED subpixels. Samsung will be using it to deposit the patterned QD conversion layer in its QD-OLED scheduled to ramp up by late 2021. Each QNED pixel contains10x to a few 10’s of QNEDs. This built-in redundancy eliminates the yield management and repair-related µLED conundrum (Fig. 9)

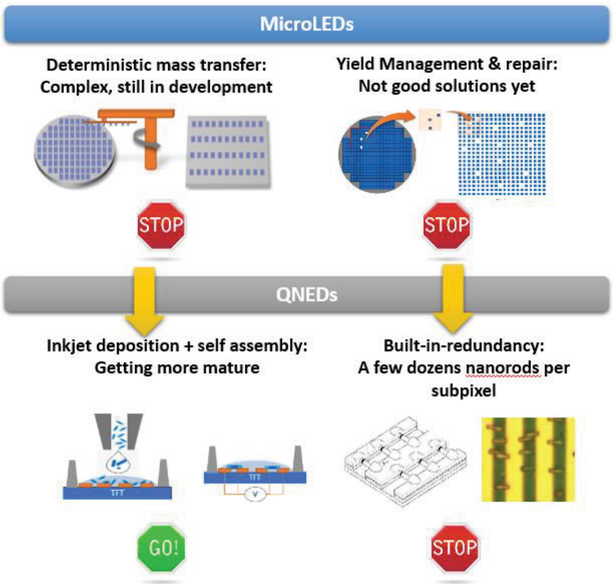

Fig. 9 How QNED could solve some major microLED challenges

4.3 Challenges

Just like MicroLED or QD-OLED, QNED technology has not yet been proven in volume manufacturing. Many potential challenges could still prove to be major roadblocks. To deliver good performance and brightness, the external efficiency (EQE) of the nanorods should be at least equivalent to current commercial blue OLED materials, i.e. > 6%. Since they can be driven much harder than OLED, they could deliver much higher brightness even with similar efficiency.

But the nanorods are vertically etched through the epitaxial layers. Just like for standard µLED, etching creates subsurface damage that can significantly reduce internal efficiency [4]. The inkjet printing deposition of solid, µ-sized nanorod LEDs could pose various challenges such as clogging of the printer nozzles, aggregation, non-uniform repartition in the pixel bank (“coffee ring” effect), etc. The process must also guaranty that enough QNEDs light up in each pixel and that pixel/pixel variations are within a range that can be compensated for with driving. Typically, only 60-80% of the QNEDs operate after assembly. QNED oriented in the wrong direction won’t produce light. If AC driving is used, all LED light up but remain off for half the cycle. For cost reasons, the number of QNEDs per subpixel can’t exceed a few 10’s so it must be ensured that this will lead to enough rods lighting up in each pixel to meet brightness requirement

5 CONCLUSIONS

The TV industry is a crossroad with LCD strongly dominating but commoditizing, there is little opportunity for differentiation left. Panel makers must therefore make, multi-billion dollar bets on next technologies. MiniLED leverage on existing LCD infrastructure. They require little investment and transfer the value of the panel from the LC module to the backlight. MicroLED are more disruptive and offer unique abilities such as modular displays or any arbitrary sizes. However, major manufacturing roadblocks remain. QNEDs could open a third path between OLED and microLED by resolving some of the major challenges associated with both technologies. However, they are not yet proven in volume manufacturing and some fundamental challenges remain.

At the same time, OLED remain a moving target with cost and performance improving on a regular basis. Most panel makers are actively working on inkjet –printed RGB OLED and electroluminescent QD which, if successful could also win the battle for the next generations of high end TVs.

REFERENCES

[1] David M. Hoffman Natalie Stepien Wei Xiong, “The Role of Local Dimming Density, Native Panel Contrast, and Glare Sources in the Visual Quality of HDR Displays”, SID Symposium Digest of Technical Papers, Volume 47, Issue 1, pp. 802-805 (2016)

[2] Eric H. Virey, Nicolas Baron, “Status and Prospect of microLED Displays”. SID Symposium Digest of Technical Papers, Volume 49, Issue 1, pp. 593-596 (2018)

[3] Eric H. Virey, Nicolas Baron, Zine Bouhamri, “Overlooked challenges for microLED Displays”. SID Symposium Digest of Technical Papers, Volume 50, Issue 1, pp. 129-132 (2019)

[4] Anis Daami, François Olivier, Ludovic Dupré, Franck Henry and François Templier, "Electro-optical size-dependence investigation in GaN micro-LED devices”, SID Symposium Digest of Technical Papers, Volume 49, Issue 1, pp. 790-793 (2018)