Revolutionary MAX OLED^{TM} Solution for Next-Generation OLED Displays

Yu-Hsin Lin*, Dieter Haas**, Ji-Young Choung, Chung-Chia Chen*, Sheng-Wen Wang*, Jungmin Lee**, Wen-Hao Wu**, Jae-Wook Jeong***, Takashi Anjiki****, Si-Kyoung Kim***, Indrajit Lahiri*****

***Applied Materials Taiwan, Ltd., Hsinchu, Taiwan**
****Applied Materials, Inc., Santa Clara, USA**
*****Applied Materials Korea, Ltd., Pyeongtaek, Korea**
******Applied Materials GmbH & Co. KG, Alzenau, Germany**

Abstract

A revolutionary OLED patterning technology, the MAX OLED Solution, will be introduced, featuring a patented pixel architecture, novel process flow, and integrated system solutions. This breakthrough is expected to enhance OLED displays by making them brighter, longer-lasting, and more energy-efficient, thereby enabling a wider range of applications.

Author Keywords

OLED patterning; overhang; evaporator; thin film encapsulation.

1. Introduction

OLED technology has become integral to smartwatch and smartphone displays due to its superior image quality and flexibility [1]. However, the current RGB OLED patterning process, which relies on Fine Metal Mask (FMM) technology, presents several challenges. The necessity for a pixel definition layer (PDL) gap of over 17µm between subpixels limits the aperture ratio to approximately 30% for smartphone displays. Fig. 1 shows the main challenges leading to large PDL. Additionally, the global cathode contact structure, a common cathode contacting to metal bus-line at panel border area, causes significant IR drop. To overcome side effects from IR drop, a buffer voltage is added to prevent non-uniform brightness, leading to higher power consumption, which is a major drawback for larger displays. The high cost of ownership associated with FMM infrastructure, coupled with the need for a large source-to-substrate distance to minimize heat load to mask sheet, results in low material utilization and, therefore, high material costs per display.

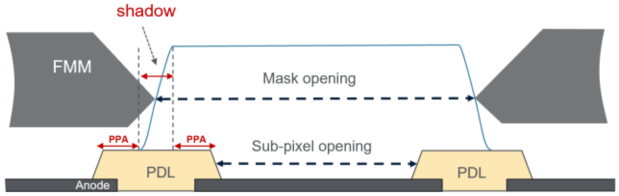

Figure 1. pixel placement accuracy (PPA) comes from misalignment between FMM opening and subpixel opening, shadow comes from FMM step height and gap between FMM and substrate. PDL > 2x PPA + shadow.

Photolithography patterning, commonly used in TFT and semiconductor processes, is considered to be a potential solution for RGB OLED patterning. However, OLED materials are highly sensitive and can be damaged by air and moisture during the lithography process. While some researchers have attempted to use special materials to protect OLEDs during this process, they have yet to achieve successful outcomes.

2. Introducing the MAX OLED^{TM} Solution

This article introduces the revolutionary MAX OLED solution, designed to address these issues. The MAX OLED solution features a novel pixel architecture, new process flow, and integrated system solutions. The novel pixel architecture includes a proprietary overhang structure, a precisely angle-controlled deposited OLED layer stack, and a pixelated encapsulation to protect sensitive OLED materials in each subpixel. The new process flow leverages mature photolithography patterning processes, incorporating extensive process know-how and integrated material solutions. To fabricate this advanced pixel architecture, integrated system solutions have been developed, including a precise angle-controlled OLED evaporator and an industry-leading thin-film encapsulation (TFE) CVD system optimized for MAX OLED.

By utilizing photolithography, the MAX OLED solution is expected to double the aperture ratio compared to the FMM process, significantly enhancing pixel brightness, resolution, and display longevity. The precise angle-controlled evaporator allows for wider cathode deposition than organic layers, enabling local cathode-contact with overhang metal structure which fundamentally eliminates the IR drop issue. For IT applications, this solution is anticipated to reduce power consumption by 30% for a single OLED device, comparable to tandem OLED devices fabricated using the FMM process.

3. Pixel architecture and process flow

The overhang structure is formed by conductive materials with a roof structure extending laterally past a body structure using a standard TFT backplane process. The first color OLED layer stack and TFE are then deposited, followed by photolithography and etching processes for patterning the first color subpixel. This process is repeated for the second and third colors, and finally, a global encapsulation is formed to complete the OLED display manufacturing process. In this process flow, TFE deposition immediately after OLED stack deposition is required to protect the sensitive OLED layer stack during photolithography and etching processes. Figure 2 shows an example of the overhang structure on PDL fabricated by the standard backplane process. Figure 3 illustrates the full-color patterning process sequence.

Since the OLED stack for each color is deposited separately, OLED device performance can be individually optimized for each color due to no common layer. Even TFE can be fine-tuned individually to optimize light out-coupling for each color. The overhang plays a crucial role in MAX OLED technology. Since OLED evaporation is a line-of-sight deposition due to the long mean free path, OLED layers will be discontinuous under the overhang structure. TFE, a conformal deposition film, will protect the OLED stack from multiple patterning processes and moisture.

ISSN 0097-996X/25/5601-0121-$1.00 © 2025

Figure 2. overhang formation with standard backplane process

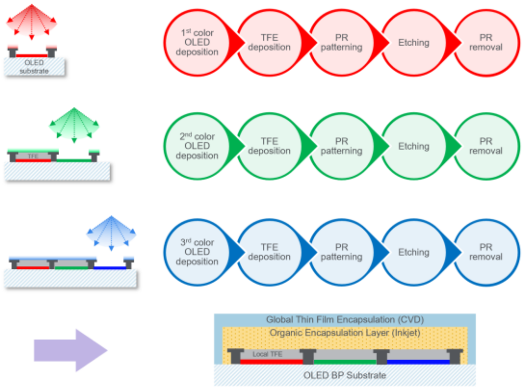

Figure 3. full-color patterning process flow

4. Integrated system solutions

To fabricate this advanced pixel architecture, integrated system solutions have been developed, including a precise angle-controlled OLED evaporator and an industry-leading thin-film encapsulation CVD system optimized for MAX OLED. Figure 4 shows the MAX OLED evaporator system, and Figure 5 depicts the thin-film encapsulation system.

In this OLED evaporator system, a linear metal source has been developed with precise deposition angle control capability to deposit the cathode layer, contacting the conductive overhang structure. This enables a local cathode contact structure, eliminating IR drop and thereby reducing power consumption. Furthermore, a micro-contamination control methodology and device have been developed and integrated into this evaporator system, proving to extend OLED device lifetime by approximately two times compared to conventional evaporator systems without this methodology and device.

It is well known that flexible OLED technology has been enabled by Applied Materials' TFE CVD system [2]. This system has been further optimized for MAX OLED technology to provide subpixel-level protection during multiple patterning processes.

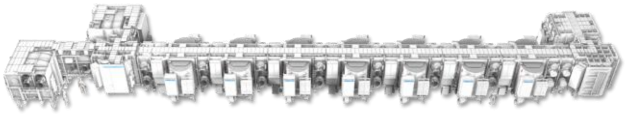

Figure 4. MAX OLED evaporator system

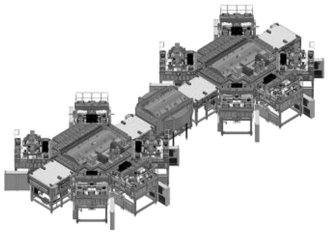

Figure 5. Thin film encapsulation system

5. Improving OLED display performance

By utilizing photolithography and etching processes, the challenges related to the FMM process will be eliminated; no FMM shadow, no FMM misalignment, no FMM thermal expansion and no FMM sagging. Therefore, pixel placement accuracy can be significantly improved. Figure 6 shows that the aperture ratio can be doubled by MAX OLED technology, where PDL has been reduced from 17-22µm to 8-10µm. With a twofold increase in aperture ratio and micro-contamination control technology, this technology is expected to achieve over three times better brightness. If such high brightness is not required, then over five times the OLED panel lifetime can be achieved compared to FMM OLED.

As PDL can be reduced down to the 8µm level, high pixel density up to 2,000 pixels per inch (ppi) becomes possible, enabling many new applications. One example is virtual reality (VR) display applications based on glass substrates. Figure 7 shows an example of pixel density increase using MAX OLED technology.

Since local cathode contact structure is enabled by MAX OLED technology, the buffer voltage used for containing IR drop can be eliminated. Fig. 8 shows the power consumption can be reduced by 33% for a 15.6-inch notebook PC display, 47% for a 34-inch monitor display if FMM can be made to produce 34-inch display.

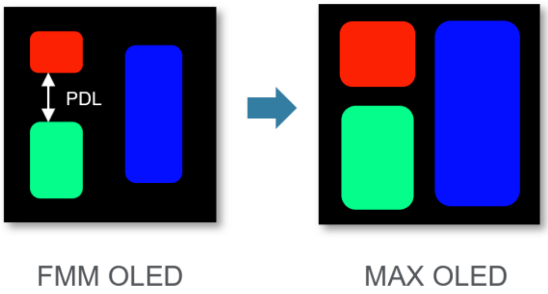

Figure 6. aperture ratio comparision

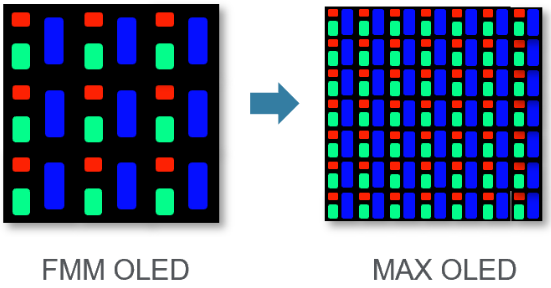

Figure 7. pixel density comparison

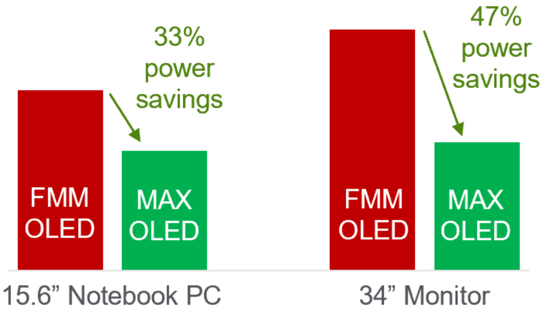

Figure 8. power consumption comparision

6. Enabling time to market

Typically, the lead time for an FMM for a newly designed OLED product is about 3 to 4 months. If a redesign is required to solve any issues during the development phase, an additional 3 to 4 months of lead time is needed. This makes the new product development cycle very long. Since the photolithography process is used for OLED patterning in MAX OLED technology, the new product development cycle will be much shorter, requiring just 3 to 4 weeks of photo mask lead time. Additionally, photo masks are much less expensive than FMMs, allowing many new products to be developed in parallel in a production line.

In addition to lead time and cost benefits, multiple products and designs can be arranged on a substrate thanks to photolithography-based MAX OLED patterning. Figure 9 shows an example of this concept: a 16-inch product with 6 different designs, an 8-inch product with 4 different designs, and a 32-inch product with 4 different designs. With this approach, multiple products and designs can be developed and validated in a single device fabrication lot. With all these benefits, time to market can be significantly reduced, disrupting the current pace of new OLED product and technology development.

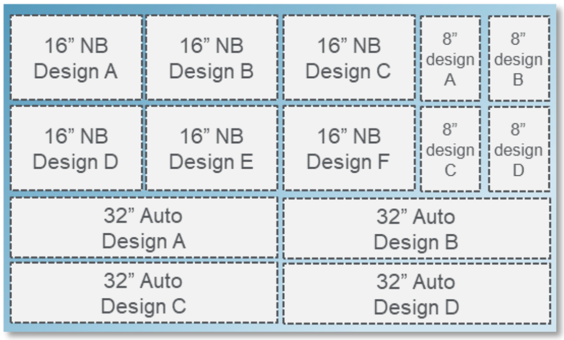

Figure 9. Multiple products and designs on a substrate

7. Driving cost reduction

In conventional OLED evaporator systems for FMM OLED, a long source-to-substrate (TS) distance of around 500mm is used for FMM layers, such as expensive RGB emission materials, to reduce heat load to the FMM and improve PPA. The MAX OLED evaporator system, however, is a vertical evaporator with a compact source design to minimize heat load, enabling a short TS distance of 230mm. With this short TS distance design, OLED material costs can be significantly reduced, achieving about twice the material utilization.

In FMM OLED, mask tension and welding onto a mask frame is a standard process for FMM preparation. The tension force applied to the mask induces wrinkles and deformation, resulting in non-uniformities and larger gap between the mask sheet and substrate. This leads to significant shadow dimension variation. Non-uniform brightness, and color mixing will be observed, ultimately reducing yield in production. To overcome this issue, a dummy mask opening pattern surrounding the active area is typically used to prevent wrinkles and deformation in the active area. However, this reduces glass utilization, increasing manufacturing costs per display. For MAX OLED, such a dummy area is not required, improving glass utilization. Furthermore, multi-product in a mother glass (MMG), widely used in LCD factories, can be applied to MAX OLED to further improve glass utilization.

Figure 10. low glass utilization for FMM OLED

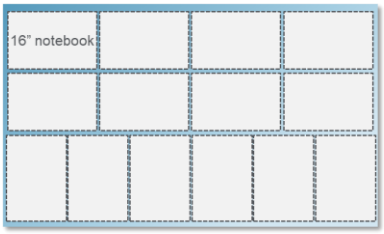

Figure 11. high glass utilization for MAX OLED

8. Empowering novel applications

Virtual reality (VR) has been regarded as the next big thing. A high-resolution display is required to provide an immersive user experience for enjoying the VR world. LCD technology has high potential to reach high resolution but offers lower image quality, while OLED provides good image quality but faces challenges in achieving high resolution. To overcome this, an interim solution, WOLED+CF (color filter), is adopted to achieve the required resolution, though it sacrifices other performance aspects [3]. As described in the previous section, MAX OLED technology utilizing the photolithography process has the potential to reach 2,000 ppi RGB OLED on glass substrate. For wafer-based semiconductor processes, it is expected to reach over 3,000 ppi. Achieving 6,000 ppi may be possible with higher resolution lithography technology.

Transparent OLED is a well-known example of novel applications for OLED displays [4]. To achieve high transmittance, cathode patterning is typically required to increase transmission in the transparent area. However, using FMM to pattern the cathode is costly due to the difficulty of cleaning the deposited cathode on the mask sheet for reuse. With MAX OLED, the transparent area will be free of cathode and organic layers as a result of lithography patterning, making high-transmittance transparent OLED displays easier to produce.

In recent years, sensor integration inside or under OLED displays has been gaining more attention. One example is the under-panel camera (UPC) display. In UPC applications, much lower resolution in the camera area is adopted to increase transmittance. However, this results in reduced image quality and a noticeable difference. With MAX OLED, thanks to the small PDL, a high transmittance area can be designed similar to the transparent display, allowing for less resolution reduction or even no reduction. This enables a much better UPC area without sacrificing display quality.

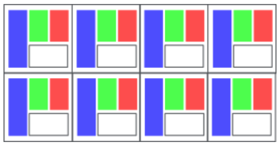

Figure 12. 4th subpixel can be used for UPC or sensor integration

9. Conclusion

The MAX OLED solution represents a significant advancement in OLED display technology, addressing critical limitations of current RGB OLED patterning processes. By leveraging an advanced pixel architecture, innovative process flow, and integrated system solutions, this technology enhances the aperture ratio, brightness, resolution, and longevity of OLED displays. The precise angle-controlled deposition and pixelated encapsulation techniques protect sensitive OLED materials, while the local cathode contact design reduces power consumption by eliminating IR drop issue. These improvements make the MAX OLED solution a promising candidate for next-generation OLED displays, offering brighter, more energy-efficient, and longer-lasting performance suitable for a wide range of applications.

10. References

1. Lin Y-H, Lee M-T, Huang A-T: Booming Flexible Applications Enabled by AMOLED Technologies, SID Digest of Technical Papers vol. 48, issue 1, page 29-32, 2017.
2. Nominanda H, Wu W-H, Chen J-R, Choi SY: Large Area Thin Film Encapsulation from Bendable to Rollable and Foldable, SID Digest of Technical Papers vol. 49, issue 1, page 1103-1105, 2018
3. Chen C-C, Lee M-T, Shen S-M, Wen Z-X, Fu J-J, Lin Y-H: Novel approaches to realize high-resolution AMOLED display, Journal of the Society for Information Display, vol. 23, issue 6, page 240-245, 2015.
4. Lin Y-H, Chen P-Y, Chen K-K, Jen K-R, Lu H-H, Liu C-H, Hong H-J: Highly Transparent AMOLED for Augmented Reality Applications, SID Digest of Technical Papers vol. 49, issue 1, page 621-623, 2018.