ViP™ Technology for Mask Less OLED: Mass Production Readiness and Future Applications on Gen 8.6 Lines

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Abstract
OLED has achieved broad adoption in small-size applications, while its expansion toward medium- and large-size displays is emerging as the next growth engine. Conventional fine metal mask (FMM) processes, however, encounter scalability and cost limitations for larger substrates. Visionox intelligent Pixelization (ViP™) stands out as a promising lithographic OLED process eliminating metal masks and enabling high-uniformity patterning across Gen 6 and Gen 8.6 substrates.

Author Keywords
Gen 8.6; mask less OLED; photolithography patterning.

1. Introduction
OLED technology has become a dominant force in the display industry, especially in the small and medium-size market. Since its conceptual inception in 1987, AMOLED has evolved significantly, moving from experimental prototypes to full-scale mass production (MP) and achieving ubiquitous adoption in small mobile devices. Today, the industry's focus is shifting towards scaling OLED technology for medium and large-size applications[1]. This trend is evidenced by the adoption of OLED panels in medium-size products by leading brands, as well as the rapid expansion of manufacturing capabilities for larger products by display enterprises worldwidely. Several enterprises, including Visionox, have established Gen 8.6 high-generation production lines dedicated to medium-to-large size display manufacturing. Although fine metal mask (FMM) technology is well-established on Gen 6 lines, its application on Gen 8.6 lines stills faces certain challenges. These challenges arises because the horizontal evaporation method causes the FMM to undergo sagging deformation. Consequently, this leads to significant pixel deposition misalignment at the center of the mask, potentially resulting in color mixing defects. This phenomenon is particularly severe in large-size FMMs used in high-generation lines, thereby restricting the application of OLEDs in large-size products.

Driven by these factors and the inherent defects associated with FMM[2,3], the industry has pursued multiple maskless OLED alternatives, such as IJP-OLED, QD-OLED, WOLED, and lithographic OLEDs. Since 2023, Visionox has developed the unique ViP™ technology based on photolithography. By preserving deposition quality to guarantee device integrity while eliminating FMM-related patterning restrictions, ViP™ highlights the significant capability of photolithography to upgrade OLED performance. Our previous publications have detailed the numerous advantages of ViP™, such as low power consumption, extended lifetime, high aperture ratio, and environmental reliability[4,5]. These technical advancements have laid a solid foundation for mass production. Consequently, this paper elaborates on the readiness of ViP™ for mass production and its application in Gen 8.6 lines, with a specific focus on technical R&D and process capability optimization.。

2. ViP™ Evaluation Platform
In order to evaluate the mass production feasibility and performance metrics of ViP™ technology, Visionox has established diverse verification platforms spanning from smartphone and smartwatch to notebook applications (Table 1 and Figure 1). These prototypes were engineered and manufactured at Visionox's Gen 6 plant in Hefei, China, utilizing a specialized evaporator designed for ViP™ processes (mother glass dimensions: 1850 × 1500 mm; half glass dimensions: 925 × 1500 mm).

Table 1. Specifications of new ViP™ evaluation platforms

Item	Parameters			
	ViP™-04	**ViP™-05**	**ViP™-06**	**ViP™-07**
Active area size	6.x inches	1.x inches	14.x inches	16.x inches
Pixel density	~460 ppi	~310 ppi	~260 ppi	~283 ppi
Substrate	Flexible (PI)			Glass
Min. PDL gap*	14 um			
Pixel aperture ratio	~35%	~39%	~43%	~34%

*Min. PDL gap: the narrower PDL gap in X or Y direction.

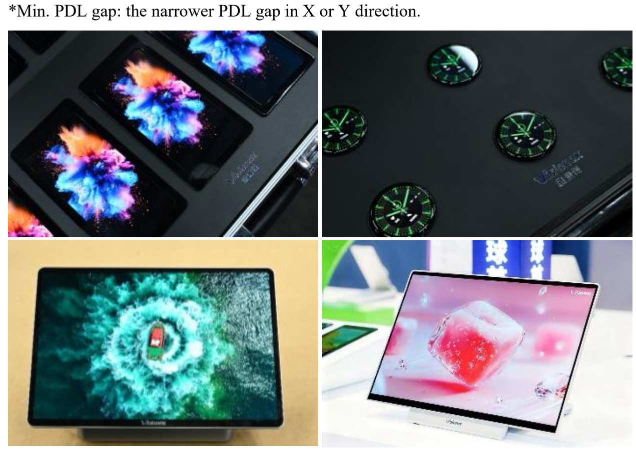

Figure 1. AMOLED display made by ViP™ for Watch, Phone and Notebook Applications

3. Results and Discussion
3.1 Design Capability Optimization: In terms of display performance, ViP™ technology offers multiple advantages due to the 2D mesh-like isolation structure positioned between adjacent sub-pixels. Regarding manufacturing, ViP™ overcomes the limitations of FMM, enabling superior performance across small-

to-medium display products. The following sections will elaborate on the technical advancements and product performance enhancements achieved by ViP™.

3.1.1 OLED device: In the conventional fabrication process for OLED devices, which relies on a fine metal mask (FMM), common layers such as the hole transport layer (HTL) and the electron transport layer (ETL) for red (R), green (G), and blue (B) sub-pixels are typically designed with identical materials and thicknesses. Consequently, any process fluctuations will induce variations of the same magnitude and direction across the common layers of all RGB devices.

The issue becomes more pronounced with the non-common layers, as their deposition is entirely dependent on the FMM. During prolonged evaporation processes, material and thermal accumulation can build up on the FMM. This not only causes changes in the size of the pixel apertures but also leads to both horizontal and vertical misalignments. Such shifts degrade the pixel position accuracy (PPA), resulting in color mixing defects. Furthermore, they alter the actual thickness of the film deposited within the pixel area, ultimately causing color non-uniformity (mura) in the final product.

In contrast, Visionox intelligent Pixelization (ViP™) technology fundamentally overcomes these inherent process challenges associated with FMM by eliminating its use and adopting an independent micro-cavity structure for each of the RGB sub-pixels. The specific advantages are as follows:

Firstly, ViP™ technology enables precise process control tailored to a specific light color by leveraging the differential sensitivity of RGB pixels to film thickness variations. For instance, blue-light devices, due to their shorter wavelength, require a much thinner optical micro-cavity than red and green pixels, making them exceptionally sensitive to thickness fluctuations. In traditional FMM-based devices, the constraints of the common-layer design preclude any independent tuning of critical layers within the blue sub-pixel. The ViP™ process, however, allows for targeted control over the key layers that define the micro-cavity length in blue pixels, thereby enhancing the film thickness stability and mitigating fluctuations in efficiency and luminance decay. Moreover, the independent micro-cavity architecture offers an additional optimization pathway when process improvements are limited: the thickness of highly sensitive layers can be reduced while proportionally increasing the thickness of less sensitive layers, maintaining the original cavity length and further improving overall process stability.

Secondly, the elimination of the FMM entirely removes issues of PPA deviation and inter-pixel thickness variations caused by material and thermal accumulation during deposition. Additionally, this maskless design significantly shortens the distance between the evaporation source (nozzle) and the substrate. This not only improves the utilization rate of organic materials but also allows for lower evaporation temperatures. A lower temperature suppresses thermal build-up within the crucible material during deposition, preventing evaporation rate fluctuations and thus ensuring a highly stable deposition rate for all film layers throughout the entire evaporation cycle.

3.1.2 High transmittance: Under-display cameras and sensors have emerged as a key solution in modern mobile design. To maximize the performance of these components - such as recognition accuracy and fingerprint sensor latency - high panel transmittance is essential. Figure 2 compares the layer structures of conventional FMM and ViP™ technologies. While FMM-based designs retain multiple layers (e.g., the cathode) that obstruct light within the high-transmittance zone, ViP™ allows for the photolithographic removal of these redundant layers. This process requires no additional masks or costs, thereby enabling ViP™ to deliver significantly higher light throughput for under-display functions.

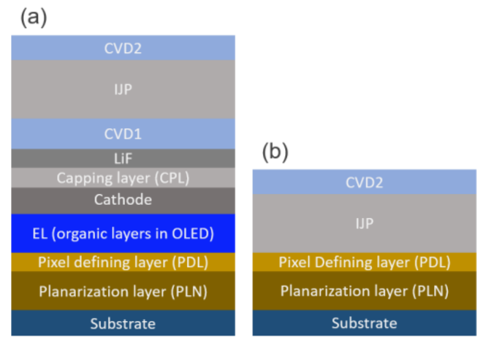

Figure 2. Layers stack-up of (a) FMM and (b) ViP™ in high-transmittance zone[5]

Measurements were conducted on twelve samples selected from various locations across the mother glass (1850 × 1500 mm; half glass: 925 × 1500 mm). As illustrated in Figure 3, the results exhibit excellent transmittance uniformity, confirming the process's viability for mass production.

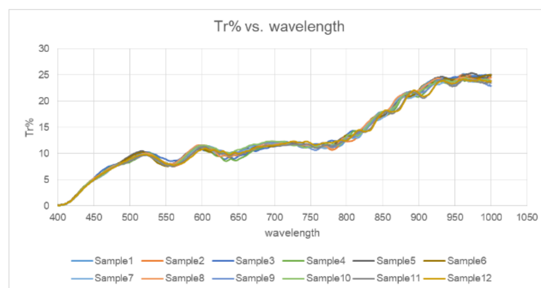

Figure 3. Layers stack-up of (a) FMM and (b) ViP™ in high-transmittance zone

3.2 Process Capability Optimization

In response to the defects observed in mass-produced ViP™ devices, the following systematic process improvements were formulated.

Cathode Overlap Optimization: The uniformity of film coverage in the electrode overlap area was enhanced by tuning the thin-film deposition angle. Optimizing the deposition angle effectively ensures consistency in the cathode overlap region, reduces contact resistance, and enhances display quality. This approach effectively mitigates the occurrence of defects.

Cleaning Equipment and Process Upgrade: New surface cleaning equipment was adopted alongside composite cleaning agents to treat the electrode overlap interface. While conventional methods tend to leave chemical residues that degrade interface quality, this new equipment-reagent combination ensures efficient residue removal and optimal surface cleanliness.

Dry Etching Process Upgrade: Next-generation dry etching tools were adopted to improve uniformity and device stability. While traditional equipment is susceptible to local over-etching, under-etching, and dielectric residues, all of which compromise substrate quality, the new equipment enhances both etching precision and residue removal efficiency. This significantly improved etching uniformity and reduced defects.

Wet Etching Process Improvements: Wet etching equipment was upgraded to improve selectivity and precision. Higher selectivity ensures precise process control, eliminating structural defects caused by over-etching. Additionally, optimized tip dimensions increased the effective overlap area, reducing dark spot risks caused by unstable overlap resistance.

Dielectric Layer Overlap Optimization: The dielectric deposition scheme was reconfigured to improve multi-layer stack stability. Since improper overlap parameters heighten the risk of delamination, the optimized scheme was implemented to enhance structural integrity and minimize overlap-associated defects.

On the basis of the above improvements, these comprehensive measures enable the precise management of dark spot defects. By significantly improving process stability and product yield, we establish a robust technical foundation for ensuring high-quality delivery in mass production

3.3 Mass Production Readiness: Building upon prior design and process studies, Visionox has identified key strategies to address the technical challenges associated with ViP™. The feasibility and mass production validation of this technology are intrinsically linked to its deviations from conventional FMM methods across product design, processing, equipment, and materials. Figure 4 illustrates the significant divergences between FMM and ViP™ development in these four dimensions.

Generally, ViP™ imposes no additional requirements on the TFT backplane, global thin-film encapsulation, on-cell touch, or module assembly compared to FMM OLEDs. Crucially, it eliminates several high-cost, yield-limiting factors inherent to FMM, such as mask-related processes and common OLED layers. The unique technical requirements of ViP™ are primarily concentrated in the metal isolator structure, the pixel etching process, and specialized evaporation equipment. Consequently, the technical challenges are confined to specific domains, and MP readiness is achieved by resolving these targeted issues.

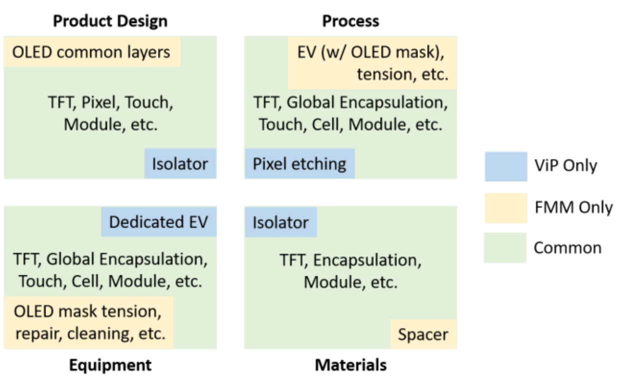

Figure 4. OLED display key points comparison (FMM vs. ViP™, in terms of product design, process, equipment, and materials) [5]

3.3.1 MP product verification: Visionox has successfully developed multiple ViP™ products intended for mass production (MP). Current measurement results demonstrate that the process capability has already met key specifications for MP requirements. Driven by substantial progress in design optimization and key process control, the display demonstrates superior luminance and color uniformity, even in medium-size products (Figure 5).

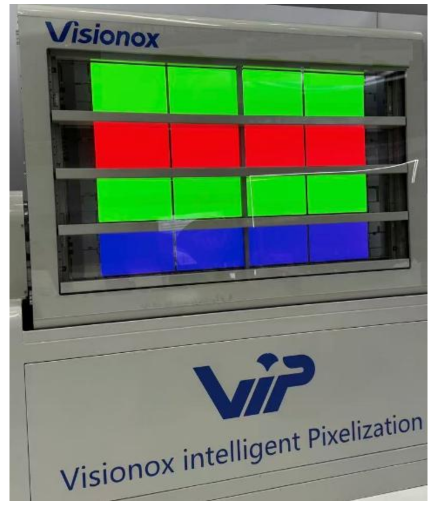

Figure 5. Half glass light-on result of a mid-size ViP™ display (ViP™-06 in Table 1)

3.3.2 Future application on G8.6 production line

Construction of Visionox's Gen 8.6 AMOLED production line commenced in Hefei in September 2024, and the facility was successfully topped in August 2025(Figure 6). This milestone marks the transition of ViP™ technology into a new phase of large-scale mass production.

Figure 6. Visionox ViP™ Gen8.6 production line

Driven by continuous process improvements and the ongoing evolution of ViP™ technology, combined with the mature manufacturing capabilities of Visionox's Gen 8.6 line, we are positioned to manufacture a diverse range of products. These include smartphones, automotive displays, tablets, notebooks, and monitors. Consequently, the mass production and commercial shipment of ViP™ products from the Gen 8.6 line are on the horizen.

4. Summary and Outlook

With successful verification completed on Gen 6 platforms, ViP™ technology has achieved mass production readiness. The topping-out of the Gen 8.6 line in August 2025 signals the commencement of a new era for large-scale OLED manufacturing. Leveraging these advancements, Visionox is poised to initiate the high-volume supply of ViP™ panels for all-size applications, meeting the market's growing demand for high performance and medium-to-large size OLED displays.

5. Acknowledgments

This work was supported by the National Key Research and Development Program of China (Grant No. 2024YFB3612102 and 2024YFB3612103).

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