Technical and Industrialization Progress on ViP OLED Display Technology

CC Lee*, Yiming Xiao*, Zhendong Ding*, Yongqiang Du*, Xuejing Zhu*, Zengqiang Xia*, Hui Li*, Yuan Yao*, Zhengkui Dong*, Bowen Yang*, Zhao Zu*, Haohan Zhang*, Pengle Dang*, Yucheng Liu*, Ying Shen, Xiujian Zhu**, Zhaoji Peng**, Deqiang Zhang****

*Hefei Visionox Technology Co., Ltd., Hefei, Anhui, China

**Visionox Technology Inc., Kunshan, Jiangsu, China

Abstract

ViP (Visionox Intelligent Pixelization) Technology represents a revolutionary advancement in RGB OLED patterning, eliminating the need for conventional OLED masks. Since its introduction in May 2023, the technology has made remarkable strides toward commercialization. This paper highlights the latest achievements in display performance and the progress made in preparing ViP Technology for mass production.

Author Keywords

ViP; OLED; metal mask-less; FMM-free; photolithography patterning.

1. Introduction

With the rapid growth of the display industry, active-matrix organic light-emitting diode (AMOLED) technology has become a leading display solution for consumer electronics due to its outstanding performance [1-2]. Among the various R/G/B sub-pixel patterning methods for AMOLED displays, the fine metal mask (FMM) evaporation process remains the most widely used, particularly in AMOLED devices such as smartphones, smartwatches, tablets, and laptops. However, this process faces several inherent limitations, including constraints on pixel aperture size, inefficient utilization of electroluminescent (EL) materials, and high manufacturing costs, etc.

To tackle the challenges posed by FMM technology, Visionox Technology Inc. introduced ViP (Visionox Intelligent Pixelization) technology. This innovative approach eliminates the need for FMM or other metal masks in the OLED evaporation process, instead employing photolithography for sub-pixel patterning. According to published studies [3-4], ViP offers multiple advantages, such as improved view angle performance, superior image quality at low grayscale levels, higher pixel density (PPI), increased aperture ratios, and reduced manufacturing costs, etc.

This paper will delve deeper into the benefits of ViP, highlighting its intrinsic advantages in the patterning process and its unique metallic isolator structure compared to FMM technology. Additionally, the paper will discuss the verification of ViP's feasibility for mass production, along with further data to support these findings.

2. ViP Verification Platform

To evaluate the ViP technology for mass production and especially its optical, power saving, lifetime, and reliability performance, Visionox developed multiple verification platforms including mobile phone, smartwatch, and notebook (as in Table 1) besides the previously reported ViP prototypes [3-4]. These products are designed and manufactured in Visionox Gen.6 Hefei Fab (V3) with dedicated evaporator for ViP technology. (Mother glass size=1850*1500 mm; Half glass size=925*1500 mm).

Table 1. Specifications of New ViP Evaluation Platforms

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

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

3. Results and Discussion

3.1 Performance improvement: one of the most noteworthy technical advantages of ViP is the higher aperture ratio than FMM OLED products. The 2D isolator network structure between adjacent sub-pixels also brings benefits in power consumption and image quality. Below is the detailed discussion.

3.1.1 Long OLED lifetime: due to the constraint from FMM manufacture, the PDL gap of commonly used FMM OLED products is hard to be further reduced. In ViP technology, the OLED mask is not required, and thus the PDL gap is mainly dependent on photomask's process precision, which is higher than FMM. Therefore, a much lower PDL gap of ViP products than the mass-produced OLED displays in the market can be easily achieved. Visionox has developed a wearable product based on both FMM and ViP designs (ViP-05 in Table 1), and the obvious difference in PDL gap leads to significant aperture ratio difference. The lifetime measurement result shows that ViP has a tremendous lifetime advantage over FMM. The benefit comes from the aperture ratio advantage of ViP (approximately 2 times of FMM in this case), and can be further improved with evolution of photolithography equipment, process capability, and related materials (photoresist, etc.).

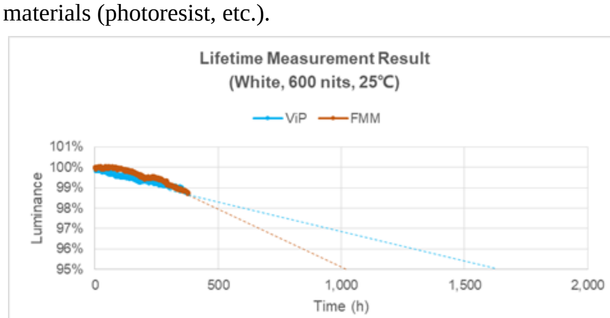

Figure 1. Lifetime measurement results (FMM vs. ViP)

3.1.2 Low power consumption: power saving is now becoming one of the major trend of portable electronic devices evolution. In conventional FMM OLED products, the OLED

ISSN 0097-996X/25/5601-0350-$1.00 © 2025

cathode is a common layer shared by all the sub-pixels. Because the cathode layer is thin, it shows a relatively high resistance, and the voltage-drop (IR Drop) in the active area is substantial (in large size displays), which leads to high power consumption.

In ViP product design, the special metal isolator structure serves as an auxiliary cathode, and cuts the cathode layer into sub-pixel level segments (Figure 2). The relatively thick metal isolator network significantly reduces the ELVSS IR-drop in the whole AA, and thus reduces the power consumption. These benefit shows more advantage in larger displays, helping promote the OLED display development in IT products (tablets, laptops, monitors, TVs, etc.).

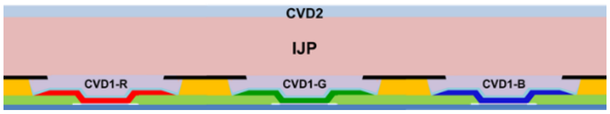

Figure 2. ViP isolator structure: cross-sectional view

Besides the power simulation results shown previously based on smartphone-sized and IT displays, Visionox has also produced 14.x” laptop ViP display, and the according EL power measurement result along with simulation result of five other laptop/monitor sizes is shown below in Figure 3. Generally, as the display increases to a relatively large size, the ELVSS IR-drop in the conventional FMM OLED display’s planar cathode also increases significantly. But the simulation and measurement result shows that the ViP EL power saving is better as the display becomes larger. This benefit mainly comes from the reduced ELVSS IR-drop brought by the unique sub-pixel level auxiliary cathode (metal isolator) in ViP display, providing a promising solution to the power saving of growing mid- and large-sized OLED display market in the future.

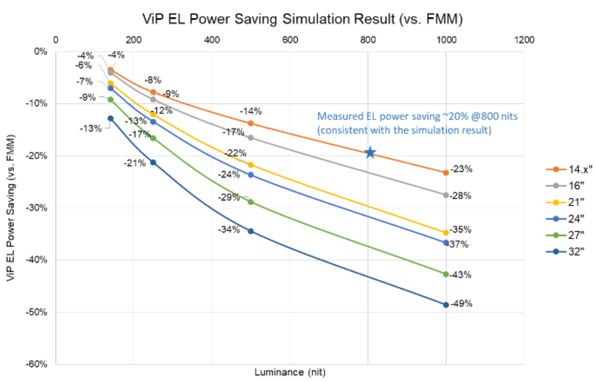

Figure 3. EL power consumption (FMM vs. ViP)

3.1.3 Better image quality at low grayscales: In FMM AMOLED products, the common layers (e.g. hole injection layer, HIL) are shared by all sub-pixels, which provides lateral paths for current leakage between adjacent sub-pixels [5]. The lateral current will lead to a luminance drop (luminance lower than the designed level) or color shift (due to the parasitic emission), which is more severe at low grayscales, leading to visual mura or insufficient brightness. For ViP, the EL common layers no longer exist as all the OLED layers are separated to sub-pixel level by isolator structure. Thus the ViP structure ensures that all charges entering the sub-pixel anode also go through all the OLED layers with no current leakage. Therefore, all the charges contribute to OLED light emission, substantially improving the current utilization at low grayscales. The measurement result (Table 2) show a serious luminance drop and color shift in FMM products, while in ViP, the luminance and color accuracy are more stable at low grayscales, even in a smaller PDL gap down to 14 um. The below measurement result will be updated based on mid-size ViP products in the full paper.

Table 2. Luminance drop and lateral leakage-caused color shift measurement result

Tech (PDL gap)	Luminance Drop Avg.			Lateral Leakage-Caused Color Shift (u’v’)		
	R	G	B	R	G	B
FMM + Single OLED (22 um)	74%	78%	98%	<0.004	0.0165	<0.004
ViP + Single OLED (22 um)	98%	104%	100%	<0.004	<0.004	<0.004
ViP + Tandem OLED (14 um)	102%	102%	103%	<0.004	<0.004	<0.004

3.1.4 High-ppi AMOLED products possibility: as mentioned in 3.1.1, one of the most noteworthy progress of AMOLED displays brought by ViP is the narrower PDL gap. Besides the lifetime and high-luminance advantages, ViP shows a potential of AMOLED’s application in high-ppi products (near-eye display for example) with the help of narrow PDL gap. A relationship between PDL gap and PPI in Real-RGB (S-Stripe) and Pentile pixel arrangement is shown below in Figure 4.

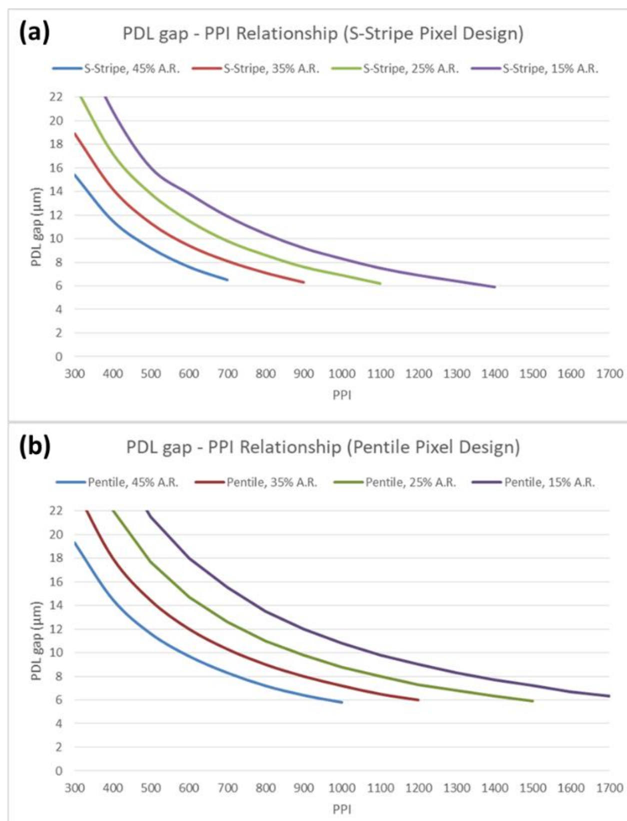

Figure 4. PDL gap - PPI relationship of (a) S-Stripe pixel design, and (b) Pentile pixel design

As Figure 4 shows, for both Real-RGB and Pentile pixel design, pixel density (PPI) is highly dependent on PDL gap and pixel aperture ratio. For example, if PDL gap can be narrowed down to 10 μm while keeping the aperture ratio 25%, the pixel density can reach about 700 and 900 ppi with Real-RGB and Pentile respectively. More aggressively, if PDL gap can achieve 6 μm while keeping the aperture ratio 15%, the pixel density can realize as high as 1400 and 1700 ppi with Real-RGB and Pentile respectively. Therefore, the key to high-ppi AMOLED display lies in narrow PDL gap and better OLED device (lifetime is long enough even with small aperture ratio). With photolithography patterning of pixel, ViP provides a solution to narrow PDL gap. So far, Visionox has validated the feasibility of multiple PDL gaps under 18 μm on actual products (Figure 5), proving the high-ppi capability of ViP technology.

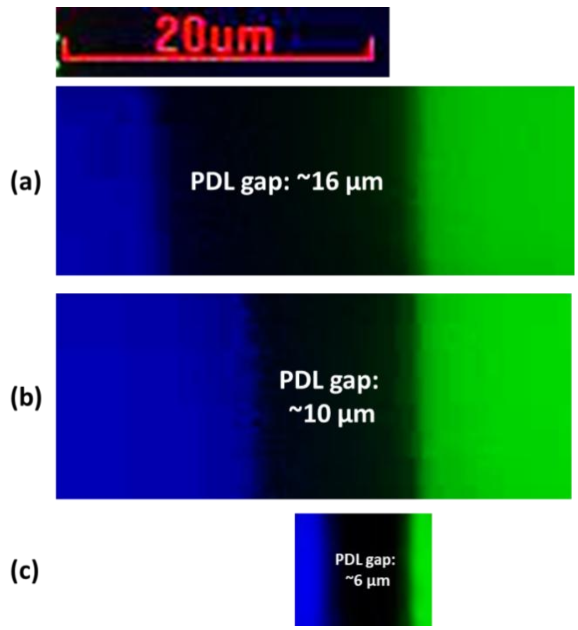

Figure 5. Optical microscope photos of different PDL gaps in ViP products

3.2 Mass production progress on ViP technology: To realize the mass production (MP) of ViP, Visionox is currently developing the integration of new equipment, process, and MP products design. The verification result provides data support for the commercialization of ViP technology.

3.2.1 MP manufacturing readiness and planning: Since the report of ViP technology in SID DW 2024 [4], Visionox has completed more ViP products development, including mobile phone, smartwatch, and notebook displays. For now, Visionox has finished the MP preparation for ViP on multiple product forms, and will mass-produce ViP products soon.

3.2.2 MP process readiness

Visionox has recognized multiple directions to identify and control the key factors to overcome ViP's technical challenges. With the help of characterization methods, the parameters' variation under the current process capability can be confirmed, and process margin can also be thereby recognized to determine the directions of process improvement. Through the process capability optimization of photolithography, the evaporation source, and different isolator structures for different products, better process control is achieved, providing a better process window for the mass production of ViP products.

3.2.3 MP product verification

Visionox has so far completed multiple ViP MP products development. More verification results will be shared in future oral reports and papers. The current measurement result shows that the process capability has already fulfilled some key specs of MP products. With the huge progress on design optimization and key process control of ViP, the light-on effect shows better luminance and color uniformity even in mid-size displays (Figure 6).

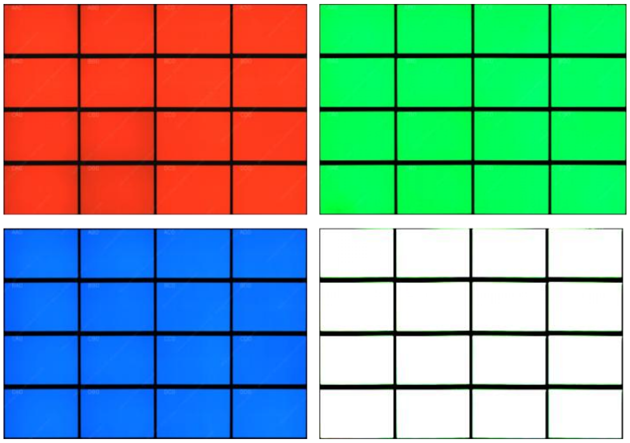

Figure 6. Half glass light-on result of a mid-size ViP product (ViP-06 in Table 1)

3.2.4 Compatibility with high-generation production line

The soaring demand for high-PPI and large-size OLED displays is leading the development of high generation OLED lines (Gen 8.6 for example). Yet it also brings some potential challenges. The PPI of FMM OLED products is strongly dependent on the PPI of FMM stick. The highest MP PPI of FMM is generally limited to ＜600 ppi with the manufacturing method of chemical etching process. Other manufacturing methods such as electroforming and laser ablation for FMM have been implemented to reach higher PPI (e.g. 800 ppi), although the key characteristics need to be further improved. As mentioned in 3.1.1, ViP technology has huge advantages on high PPI, because the precision is only limited by the resolution of photo mask, which is higher than FMM.

FMM slot size accuracy and pixel position accuracy are very important for OLED production, and it is believed that the increasing length and width of FMM sticks will lead to a decrease in size and position accuracy. Waviness, weakened rigidity, thickness variation, and PPA (pixel position accuracy) shift induced by FMM deformation are typical challenges for G8.6 FMM technology, while these problems can be easily solved by ViP technology without OLED mask.

Therefore, it can be reasonably deduced that ViP technology is more advantageous on high-PPI and large-size applications, which can meet the requirements from high generation OLED lines.

4. Summary and Outlook

The Visionox intelligent Pixelization (ViP) technology has been evaluated on several verification platforms including mobile phone, smartwatch, and notebook displays. By eliminating the constraints from FMM and other related process, ViP offers many benefits compared to the conventional FMM technology, and thus releases the full potential of AMOLED display. This paper discusses the ViP's advantages over FMM technology, including longer OLED lifetime, lower power consumption, better image quality at low grayscales, and better compatibility with high-generation OLED production lines. Currently, Visionox has completed the preparation for ViP production line and MP capability, and will continuously improve ViP's competitiveness in mass production.

5. References

1. Lee J-H, Chen C-H, Lee P-H, Lin H-Y, Leung M-K, Chiu T-L, et al. Blue organic light-emitting diodes: current status, challenges, and future outlook. J Mater Chem C Mater Opt Electron Devices [Internet]. 2019;7(20):5874–88. Available from: https://pubs.rsc.org/en/content/articlelanding/2021/xx/c9tc00204a/unauth
2. Huang Y, Hsiang E-L, Deng M-Y, Wu S-T. Mini-LED, Micro-LED and OLED displays: present status and future perspectives. Light Sci Appl [Internet]. 2020;9(1):105. Available from: https://www.nature.com/articles/s41377-020-0341-9
3. Xiao Y, Ni L, Fu Y, Yuan Y, Zhang H, Zhu X, et al. 17-2: Development of Visionox intelligent Pixelization (ViP) Technology in AMOLED Applications. SID Symposium Digest of Technical Papers. 2023;54(1):205-208. Available from: https://sid.onlinelibrary.wiley.com/doi/abs/10.1002/sdtp.16526
4. Xiao, Y., Ding, Z., Dong, Z., Xia, Z., Yao, Y., Yang, B, et al. (2024, June). 69-1: Recent Progress in High‐Performance AMOLED Display with ViP Technology. SID Symposium Digest of Technical Papers. 2024;55(1):946-949. Available from: https://sid.onlinelibrary.wiley.com/doi/abs/10.1002/sdtp.17691
5. Penninck L, Diethelm M, Altazin S, Hiestand R, Kirsch C, Ruhstaller B. Modelling crosstalk through common semiconductor layers in AMOLED displays: Modelling crosstalk in AMOLED displays. J Soc Inf Disp [Internet]. 2018;26(9):546–54. Available from: https://sid.onlinelibrary.wiley.com/doi/abs/10.1002/jsid.671