

3D-Stretched OLED Display Based on Island-Bridge Structure

Hao Hang, Yangyang Wang, Lei An, Jinyan Huang, Yang Liu, Chunxiao Gu, Xianjiang Xiong, Huihui Meng, Zheng Li, Yongfeng Zhao, Zhimin Yan and Wangfeng Xi

Visionox Technology Inc., China

Abstract

The display industry is increasingly focusing on the future development of displays with free-form deformability, and in recent years, 3D-stretched displays have garnered significant attention. In this paper, we have successfully developed a 3D-stretched OLED display with stretching rate exceeding 15% by meticulously designing the island-bridge structure, enhancing the encapsulation properties, and investigating the 3D-shape formation process.

Author Keywords

3D-stretched display; OLED; island-bridge structure.

1. Introduction

In the burgeoning era of the metaverse and artificial intelligence, the demand for sophisticated human-computer interaction is escalating. This surge is driving the need for flexible displays that can adapt to various forms and functions. The ultimate form of flexible display is the arbitrary-shaped display, which can be realized with the help of stretchable display technology [1].

Stretchable technology can be categorized into two main types based on the underlying mechanism: intrinsic stretching and structural stretching. The key distinction lies in the underlying mechanism: intrinsic stretching aims to develop each individual component, such as the thin film transistor (TFT), light-emitter, and encapsulation, to be inherently stretchable; structural stretching, on the other hand, focuses on the overall device architecture, utilizing design strategies like the island-bridge configuration to impart stretchability without requiring each sub-component to be stretchable. This structural approach has demonstrated promising progress towards practical stretchable display technologies. Many prototypes based on island-bridge structure have been exhibited since 2017, which indicates that the structural stretching technology is a promising path to realize stretchable display [2]-[4].

Without the demand for stretchability in luminescent units, the two main kind of light-emitting devices used on stretchable display are primarily the organic light-emitting diode (OLED) and the micro-LED. OLED, with its potential for higher yield rates and lower costs, has gained significant attention and is leading the charge in stretchable display development. However, despite the promise of OLED-based stretchable displays, there are critical challenges that must be addressed. The inherent contradiction between stretchability and pixel density (PPI) is a significant hurdle. In the island-bridge structure, a higher proportion of the island section is conducive to achieving a high PPI, but concurrently, a reduced proportion of the bridge section can lead to a decrease in stretchability. Additionally, the reliability of single-pixel independent encapsulation is dominating to ensure the longevity and performance of the display under various conditions. Moreover, manufacturing 3D-curved panels presents a complex set of challenges that must be overcome.

In this article, we are discussing the strategies to tackle the

challenges outlined earlier, applying them to the advancement of stretchable displays. We have successfully achieved a maximum stretch ratio of over 15% for a 3D display panel, which

demonstrates consistent performance even after being subjected to 60 °C and 90% relative humidity for up to 240 hours.

2. Results and Discussions

2.1 Island-bridge Structure Design

In order to obtain stretchable OLED panels, low-temperature polycrystalline silicon (LTPS) TFT array with island-bridge structure should be designed and produced in the first place. As shown in Figure 1, the island section of the island-bridge structure contains the pixel driving circuit and the OLED devices, which are rigid and do not deform during the stretching of the panel; the bridge section contains the conductive interconnects and the through hole between the interconnects, where the shapes are changing during the stretching of the panel.

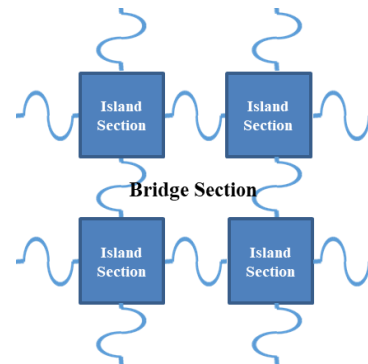


Figure 1. Schematic diagram of island-bridge structure

One island section and one connected bridge section compose the smallest repeating unit of the stretchable region for the panel. If the dimension of the island section along the stretching direction is a and the dimension of the bridge section is b , when stretching, the dimension of the island section remains as a , and the dimension of the bridge section changes to $b + \Delta b$. Therefore, the stretching rate of the bridge ($S_b\%$), as formula (1) and the overall stretching rate ($S_a\%$) of the panel is as formula (2):

$$S_b \% = \frac{\Delta b}{b} \quad (1)$$

$$S_a \% = \frac{\Delta b}{a+b} = \frac{b}{a+b} \times S_b \% \quad (2)$$

It can be observed that, with all other factors held constant, the panel's stretching rate can reach its maximum when a is smaller, or b and $S_b\%$ are larger. This suggests that in the design of the island-bridge structure, to ensure the panel has a higher stretching rate, we should:

1. Make the island section as small as possible.
2. Make the bridge section as large as possible.
3. Enhance the stretchability of the bridge interconnect.

However, the dimensions of island section and bridge section are limited by the pixel size and the PPI of the display panel. Therefore, the main path to improve the stretchability of the display panel is designing more stretchable interconnect structure in the confined space. By implementing these design considerations, we utilized simulation tools to evaluate the island bridge design and successfully obtained several typical structures with sufficient stretching capabilities.

We initially constructed an island bridge structure backplane based on a 2T1C pixel driving circuit, incorporating two bridge interconnects between adjacent islands. The design options for the shape of each interconnect are quite extensive, encompassing both C-shaped and S-shaped configurations, which can accommodate a stretching rate over 15%, as illustrated in Figure 2(a). However, the brightness uniformity of such a display panel is very poor. To further enhance the performance of the display panel, we upgraded the pixel driving circuit to a 7T1C structure with four interconnects between adjacent islands, imposing additional restrictions on their design shapes. Through more meticulous design, we ultimately achieved a stretching rate over 15% while improving the brightness uniformity of the display panel from less than 60% to over 80%, as shown in Figure 2(b).

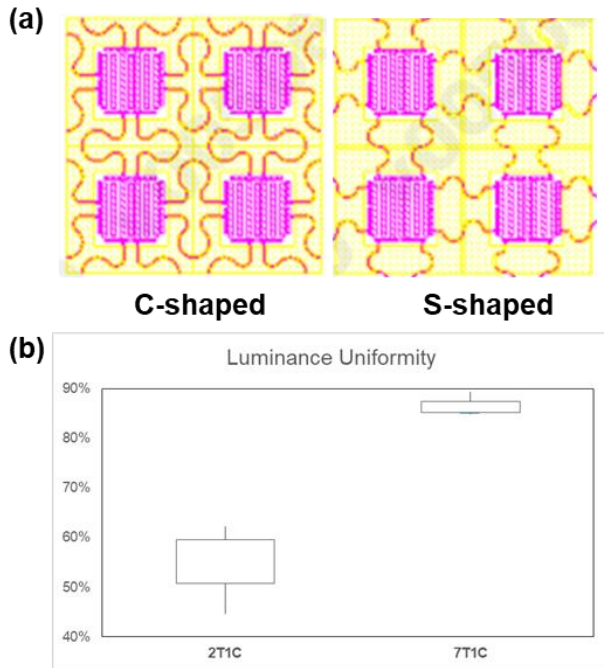


Figure 2. (a) Schematic diagram of C-shaped and S-shaped interconnects; (b) Boxplots of luminance uniformity for display panel based on 2T1C and 7T1C structures.

2.2 Single-pixel Independent Encapsulation

For conventional OLED display panels, multilayered thin film encapsulation (TFE) covering the whole surface of active area is typically employed. However, as for stretchable OLED display panels, the rigidity nature of TFE poses a challenge for stretching. As a result, a single-pixel independent encapsulation structure

needs to be developed. This approach involves encapsulating only the OLED devices in the island section, without any inextensible encapsulation film layers in the bridge section, as shown in Figure 3.

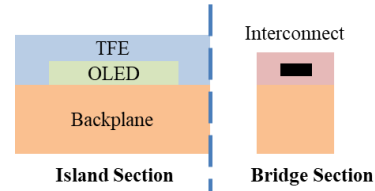


Figure 3. Schematic diagram of single-pixel independent encapsulation

To construct this structure, the following process is followed: After the vacuum evaporation of OLED layers, SiNx or SiOx is deposited on the OLED devices. This is then followed by a photo process to pattern and remove the inorganic encapsulation layers outside the island section.

The resulting single-pixel encapsulation structure effectively protects the OLED devices from the erosive effects of water and oxygen. This has been certified by 60°C/90% thermal humidity storage (THS) reliability test, which is exhibited in Figure 4. We monitored the status of the display cell after 120h THS and 240h THS, and no new defects have been found when comparing with the status before the reliability test.

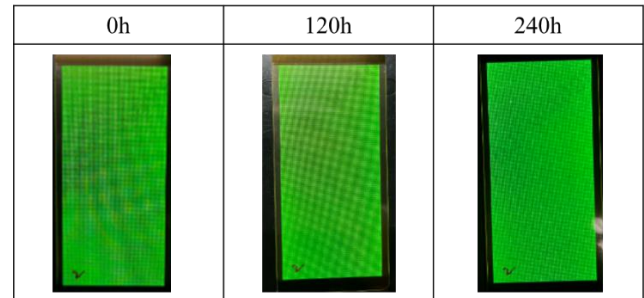


Figure 4. Reliability test results of THS.

2.3 3D-Shape formation

The future use of curved display screens in robots and smart homes depends on the essential ability to integrate stretchable light-emitting cells into 3D-shaped modules featuring non-Gaussian curved surfaces. A common approach is 3D lamination, which is already utilized in the production of curved screen mobile phones. However, there are still no mature 3D cover plates existing for displays with entire 3D shape, and the current lamination process is not suitable for non-Gaussian curved surfaces. Conversely, using thermoplastic polymers as cover plates allows for the initial creation of flat display module, which can then be transformed into 3D shapes through heat distortion, making it more suitable for the forming of 3D shapes. Hong and colleagues have successfully employed this method to develop a prototype of a 3D irregular-shaped OLED display [4].

Among the many commercially available thermoplastic polymer materials, we have selected one with a visible light transmittance greater than 85% and a glass transition temperature between 80~100°C for the cover plate material. The choice of glass transition temperature is crucial, if the temperature is too high, the deformation process would demand excessive heat, leading to the

failure of the OLED devices. Conversely, if the temperature is too low, the resulting panel would be vulnerable to deformation at high temperature. We first laminated this cover plate material to both sides of the panel with optically clear adhesive (OCA), then placed it in a semi-elliptical jig that had been preheated. By creating a pressure difference between the upper and lower jigs, we achieved the shape-forming. After cooling and setting, we obtained a 3D-stretched module, as shown in Figure 5(a).

Figure 5(b) exhibits the mechanical simulation results of the 3D-curved stretching, indicating that in the semi-elliptical state we designed, the stretching rate across different locations on the panel varies significantly, with the highest stretching rate approaching 15%, which is less than the design stretching rate sustained by our island-bridge structure. We also measured the actual stretching rate at different locations of the panel, with the maximum stretching rate being approximately 15%, which is consistent with the simulation results. The island-bridge structure did not experience stretch failure after stretching.

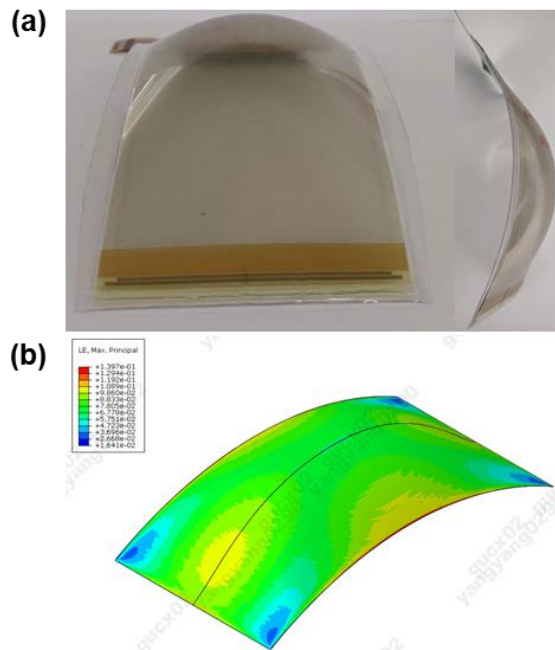


Figure 5. (a) Photograph of 3D-stretched module; (b) mechanical simulation results of the 3D-curved stretching.

2.4 3D-stretched OLED display prototype

As shown in Figure 6, our 3D-stretched OLED display prototype can exhibit complex picture or video on the 3D-curved surface for a long time. We believe that the 3D-stretched display will see future applications in domains such as robotics and smart homes, where the immersive effects of curved displays can enable the next generation of human-machine interaction.



Figure 6. Photograph of 3D-stretched OLED display prototype.

3. Conclusion

In this paper, we have designed a stable island-bridge structure, developed an inorganic single-pixel independent encapsulation structure, and applied a 3D shaping process based on the glass transition of thermoplastic polymer materials. Ultimately, a 3D-stretched OLED display prototype with a stretching rate of over 15% has been achieved, which can maintain stable performance for 240 hours under 60°C and 90% humidity conditions. With the advancement of materials, improvement in design, and optimization of processes, the future of 3D curved displays with more complex shapes and higher display performance is promising.

4. References

1. Kim DW, Kim SW, Lee G, Yoon J, Kim S, Hong JH, Jo SC, Jeong U. Fabrication of practical deformable displays: advances and challenges. *Light: Science & Applications*. 2023, 12(1): 61.
2. Choi HJ, Jeong JH, Kang MG, Kim DH. 9.1-inch stretchable AMOLED display based on LTPS technology. *SID Symposium Digest of Technical Papers*. 2017, 50(1): 1144-1147.
3. Hong JH, Kim S, Lee J, Yoon J, Kim S, Kim Y. 74 - 1: Invited Paper: Highly Stretchable and Shrinkable AMOLED for Free Deformation. *SID Symposium Digest of Technical Papers*. 2023, 54(1): 1041-1044.
4. Wang H, Wang B, Wang C, et al. P-170: Structure Optimization of Stretchable AMOLED based on LTPS TFT. *SID Symposium Digest of Technical Papers*. 2024, 55(1): 2033-2035.