Deformed Helix Ferroelectric Liquid Crystal Based 3µm-pitch Micro Display for VR/AR Displays

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Abstract
A glass-based micro-display with pixel size (<3µm) has been fabricated and verified in this work using deformed helix ferroelectric liquid crystal. High contrast (over 600:1), fast response time (< 400µs) and continuous gray scale within 5V driving voltage are achieved in the prototype .

Keywords
Ferroelectric liquid crystal; fast response; fringe field effect; VR/AR; high PPI display; micro-display

1. Introduction
In the past few years, the liquid crystal (LC) based active devices have been widely used in both display and photonics industry, such as Liquid crystal on silicon (LCoS), and active matrix liquid crystal display (AMLCD). However, the slow response time (>4ms) [1] and serious crosstalk under uneven electric field distribution make the nematic LC (NLC) limited the pixel density of LCD to be smaller than 1500ppi (pixel per inch) [2]. What's more, the OLED display and µ-LED display become more and more important to the market. But for full color micro-display panel, they both meet lots of challenges when the pixel size drops below 10µm, such as the deposition method[3], cross-talk between pixels, and cavity design further limit the development[4]. On the other hand, the light-emitting uniformity and efficiency of µLED drop rapidly for the high PPI panels[5-7] which needs more promising work by the researchers.

In this paper, we proposed to use passively addressed matrix to verify the little crosstalk, fast response and high contrast ratio micro-display using deformed helix ferroelectric liquid crystal (DHFLC). The electro-optical response of the DHFLC has also been shown, which is ~ 400µs (including ON and OFF time) and show continuous gray scale depending on the driving voltage below 5V. The contrast ratio is over 600:1 with minimum temperature dependence.

2. Experiments

2.1 ITO pattern fabrication
We designed a certain ITO pattern on glass with fixed electrode gap. In total, there are 64 electrodes connected to the outside which makes resolution of the passively addressed matrix to be 64*64. The ITO pattern was fabricated by photo lithography and wet-etching process. The minimum pixel size can be 2µm with negligible gap between electrode which are only limited by the fabrication process and short circuit problem. The 3µm pixel size corresponds to ~2800 ppi and 8500ppi for RGB subpixel design and field sequential color (FSC), respectively.

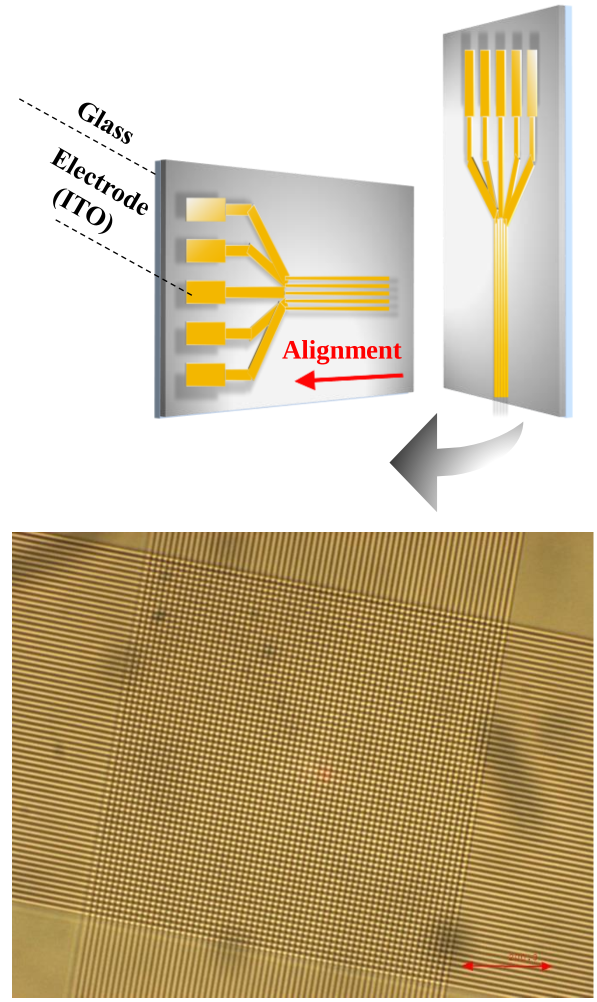

Figure 1. a) The schematic graph of the electrode structure of the empty cell; b) The empty cell with micro-ITO-pattern under microscope. The ITO width is 3µm and the ITO gap is 3µm. The scale in the picture is 100µm.

2.2 Cell preparation
The cell for ferroelectric liquid crystal (FLC), we use spin-coating to deposit Nylon 6 on the substrate with the patterned ITO with 3000 rpm for 2mins. After that, soft baking of the substrate at 100 degree for 10mins and hard baking at 180 degree for 1 hour are applied to make the Nylon 6 polymerized. Afterward, the substrate is rubbed unidirectionally. The cell is made using the two substrates, where the first substrate is with patterned ITO and another one is with patterned ITO coated with planarization layer.

The cell gap is maintained at 1.5µm by depositing photo spacer uniformly. Finally, we would inject the FLC material with the help of the capillary action from one side of cell to another side.

The FLC with the helix pitch p=120nm, and the birefringence is around 0.18. When the cell gap is 1.5µm, the cell meets the half-wave condition for 550nm[8-10]. The phase transition sequence of this FLC during heating cycle is Cr(12) SmC*(110) SmA*(127) Iso. The spontaneous polarization, Ps, and the tilt angle, at room temperature are 150 nC/cm^2 and 37 degrees, respectively.

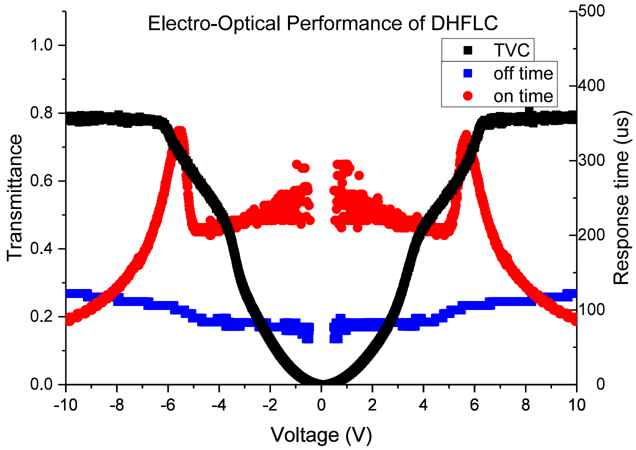

Figure 2. EO performance of the deformed helix ferroelectric liquid crystal. The transmittance is normalized by the intensity of the parallel polarizer and cross polarizer

The EO response is shown in figure 3. The maximum transmittance can reach 80% of the intensity between the two polarizers. And the reflectance of the surface gives near 8% loss in the transmittance. As a result, the DHFLC can achieve efficiency larger than 80% with response time faster than 400µs including the ON and OFF time within 5V. The EO-performance of the DHFLC perfectly fit the command of the high-resolution micro-display.

On the other hand, normal passively addressed driving scheme needs the DHFLC shows enough threshold voltage to avoid the driving crosstalk in the multiplexing of the display. Unfortunately, the DHFLC almost shows no threshold voltage, and therefore, the traditional passively addressed driving signal does not work wel for the DHFLCs. In this work, we introduced the high impedance state which means, the selective dark pixel experiences high impedance state on both sides and the selective bright pixel experiences voltage drop by 5V between the two electrodes. Thus, the pixels which experience the high impedance and voltage on the two sides feels part of the voltage drop and shows the transmittance smaller than the saturation state. The driving test of the driving scheme containing high impedance using 2*2 DHFLC between cross polarizer is shown below.

Figure 2. a) The driving scheme for the passively addressed DHFLC display; b) 2*2 DHFLC test cell using the driving scheme with high impedance state

3. Results and Discussion

After the DHFLC micro-display cells making, we checked the display performance using the microscope between cross polarizers. We firstly checked the fringe field effect of the DHFLC using based on our previous work the ITO pattern has fixed width by 7µm and the variable gap between each other ranging from 1µm to 50µm. The figure below shows the comparison between a kind of negative nematic LC and the DHFLC used in this work. We found that the size of the crosstalk region of NLC is larger than 7µm, which means the maximum pixel density can only be ~1200. But for the DHFLC, the minimum cross talk region is only 1~2µm corresponds to pixel density above 12700ppi for field sequential color and 4200ppi for RGB subpixel design.

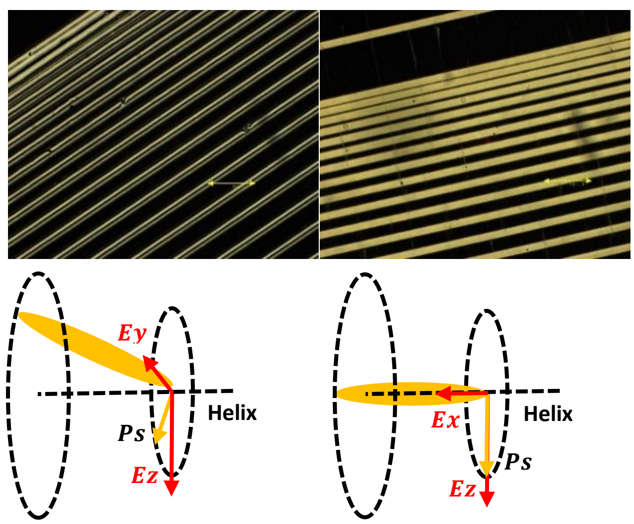

Figure 5. a) The fringe field effect comparison between nematic LC and DHFLC; b) the coupling behavior of the electric field Ex (in plane) and Ez (vertical direction) with the spontaneous polarization Ps

The reason for the little fringe field effect is the coupling between the electric field and the spontaneous polarization of the FLCs. The in-plane electric field Ex is along the helix direction, and therefore, the coupling between the electric field vector and the spontaneous polarization vector of the FLC molecules is minimum. As a result, FLC molecules do not show any response for the E_x. Only the electric field or the electric field component perpendicular to the helix direction can influence the FLC molecule. On the other hand, when the helix direction is parallel to the ITO electrodes, the in-plane electric field E_x and the vertical electric field E_z couples with the spontaneous polarization vector and try to rotate the FLC molecules. Although the E_x dominates the EO response of FLC near the edge, the rotation of the FLC molecule only deforms the helix to show the EO response, which in the case of FFE is absent. Finally, we multiplexed the 64*64 PM DHFLC micro-display and showed the results below. Figure 6(a) and figure 6(b) show the polarization optical microscopic images of the micro-display with different pitches. The size of the bright area almost follows the electrode size. The width of the pixel in both graphs is 3μm with different electrode gaps.

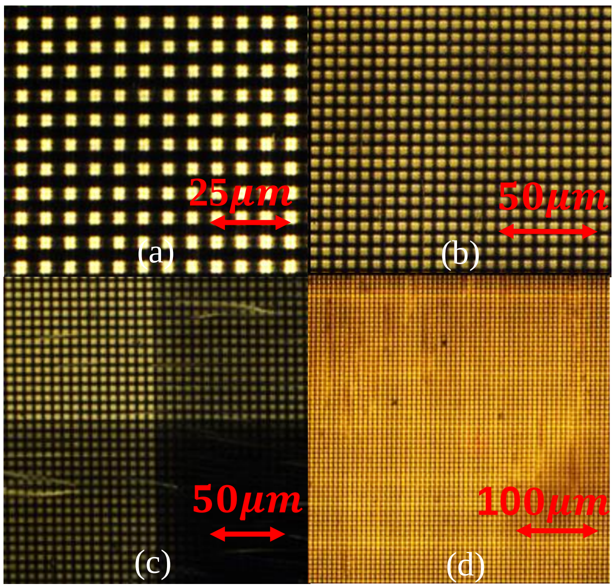

Figure 6. POM image between cross polarizer: a) the pixel size is 3μm and the gap is 5μm; b) the pixel size is 3μm and the gap is 3μm too; c) The multiplexed image which contains three kinds of bright ness, the driving voltage is 5V, 3V and 0V at different region; d) The whole picture of the display area when all the pixel is bright. The scale is shown in each figure.

The edge of the pixel in the DHFLC micro-display is clear and almost without any expansion compared with the electrode width. However, we realize the pixel size and pitch by 3μm and 6μm, respectively. However, with further optimization of the photolithography and etching process on glass, at least 2μm pixel size and 2.2 pitch can be achieved, which corresponds to 3800 PPI with RGB subpixel and 11500 PPI for field sequential color display. These fit the demand of the VR/AR display or even display in the future.

4. Conclusion

A glass-based micro-display with pixel size (<3μm) has been fabricated and verified in this work using deformed helix ferroelectric liquid crystal. High contrast (over 600:1), a fast response time (< 400μs), and a continuous grayscale within 5V driving voltage are achieved. For DHFLC, the minimum crosstalk size is 1-2um, which makes the fringe field effect in the FLC negligible for the display application. What's more, the disclination line exists in all the NLC case, and it breaks the pixel area and destroys the uniformity of the active region and so the contrast ratio. However, no disclination lines show up in the FLC system that makes the FLC one of the best choices for a high pixel density display system. In summary, DHFLCs are suitable for 2μm pixel size that corresponds to 3800 PPI with RGB subpixel and 11500 PPI for field sequential color display. These fit the demand of the VR/AR display or even display in the future.

The electro-optical response time of the DHFLC is ~400 μs and shows a continuous analog grayscale with maximum driving voltage ~ 5V. The temperature range of the FLC is 100 °C, which is large enough for the display and photonics applications. The fast response time and small fringe field effect make the DHFLC display (DHFLCD) a promising candidate for the next generation of higher PPI display technologies

5. Acknowledgements

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6. References

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