6.1: *Invited Paper:* Recent Progress in Color Flexible Reflective Cholesteric Displays

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Abstract

We report on highly flexible layered full color cholesteric displays built using ultra thin substrates with encapsulation through the phase separation approach. Recent progress of the state of the art of the cholesteric display technology will be presented as well.

1. Introduction

Bistable cholesteric liquid crystal displays (ChLCDs) are purely reflective and do not use polarizers, compensation films, or backlights.[1,2] They are driven with simple row and column addressing (passive drive). It is this simple architecture and driving that lends itself to numerous modes such as flexible displays and stacked full color. For the creation of highly ruggedized flexible displays, encapsulation has been achieved through the use of emulsification and phase separation.[3,4,5] With emulsification, the liquid crystal is encapsulated in droplets and then coated in an aqueous system. For phase separation, the homogeneous mixture of monomers and liquid crystal is first coated and then the droplets are created using polymerization induced phase separation (PIPS). The advances in flexible displays have lead to numerous innovations and the creation of ultra thin displays that are very flexible and even drapable. These flexible displays have all the features of conventional ChLCDs, but are also thin, rugged, and light weight. As such, these are highly desirable in applications that benefit from bistability (zero power to view image content) and reflectivity.

The innovations in flexible devices and full color modes are now in active product development cycles. In this paper, we report on the layered full color displays using the phase separation approach on ultra thin substrates.[6] The state of the art in cholesteric displays and their applications will also be discussed.

2. State of the Art of Cholesteric Displays

The current state of the art in ChLCDs includes numerous new modes and enabling applications such as displays in USB flash drives, portable hard drives, etc. The penetration of ChLCDs into the marketplace continues with these enabling applications that require the bistable and reflective modes of operation. The USB drive display with electronic labeling feature is becoming highly popular as a significant feature to a basic consumer product. The bistability of the display is clearly an essential ingredient in this application. Fig. 1 shows a photograph of these displays in their respective applications.

Figure 1: ChLCDs in USB flash drive and portable hard drive applications.

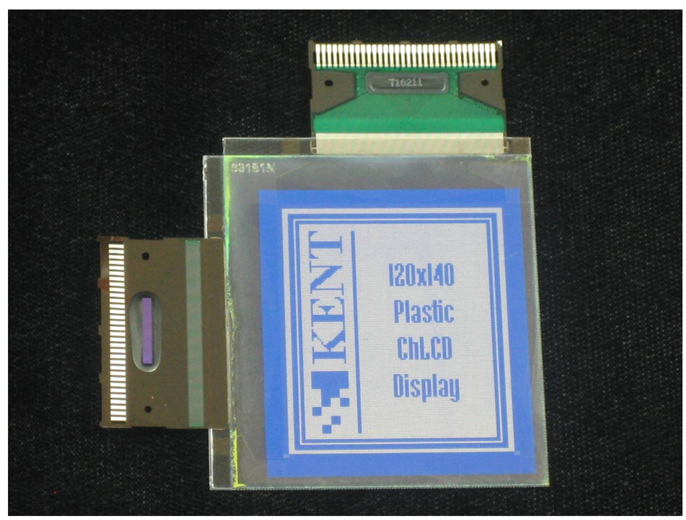

Figure 2: Flexible display made with 125µm PET substrates and ITO as conductor. The drivers are off-the-shelf LCD drivers.

Kent is aggressively pursuing both rigid displays as well as flexible displays. In flexible displays, the phase separation approach is in active product development. The basics of the approach are briefly described below and in detail elsewhere.[3] Manufacturing techniques, reliability, and new product designs are being developed. Fig. 2 shows a

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flexible display made using thin PET substrates (125µm thickness) and 1.85inches diagonal with 100dpi resolution. The display is capable of 16 gray levels and an operating temperature range of -5°C to 50°C. This display is being used in security card applications as well as other uses. The display is made in array form with approximate sheet size of 320mm × 370mm. The displays are then laser singulated and heat seal interconnects are put on. The drivers are standard off-the-shelf LCD drivers.

3. Flexible Displays Using the Phase Separation Approach

Encapsulation of cholesteric materials prevents flow of the liquid crystal during bending, curving, and flexing. As such, it is the key ingredient in enabling simple low cost flexible displays. We have explored two basic approaches, phase separation and emulsification.[3,4] The phase separation approach is in active product development and commercialization. There are several ways to do phase separation. Due to the control of droplet shape and size as well as manufacturability, we have chosen polymerization induced phase separation (PIPS). Other methods such as solvent induced or temperature induced phase separation are more difficult to manufacture due to evaporation and temperature stability. Fig. 3 shows a cross section of a flexible PIPS display. The spacers are used to maintain the cell gap between the substrates. This basic structure is the basis of the flexible displays made at Kent using the PIPS approach.

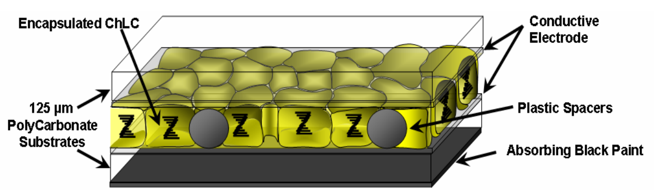

Figure 3. Schematic diagram of the two substrate phase separation (PIPS) based flexible encapsulated ChLCD.

4. Full Color Phase Separation Based ChLCDs

In flexible displays, the full color stacked mode using phase separation is one of the most recent developments. In this mode, 3 display layers are stacked on top of each other using 4 substrates and 6 electrode layers. Fig. 4 shows a cross section of this display architecture. The use of shared substrates is key in creation of such a flexible device. Shared substrates are defined as such when two electrodes layers are on opposite sides of the same substrate. In this case, the middle two substrates are shared. The shared substrates reduce the requirement of additional substrates as well as adhesive layers between multiple layers. The substrates used are PET sheets with only 12µm thickness and using inkjetted PEDOT:PSS (Poly(3,4-ethylenedioxythiophene) poly (styrenesulfonate)) based conducting polymer (CP) as the passive driving electrodes.[7] The typical ITO electrodes are not used since the substrate is so thin that the metal oxide based ITO electrodes would fail. The use of conducting polymers as electrode materials enables flexibility and ruggedization. The ultra thin substrates make a very rugged structure since it is highly flexible.

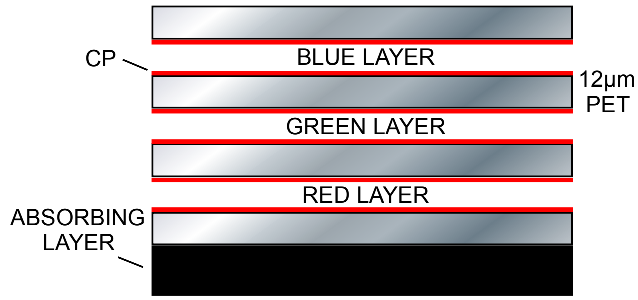

Figure 4: Schematic cross section of the stacked display architecture showing shared ultra thin PET substrates.

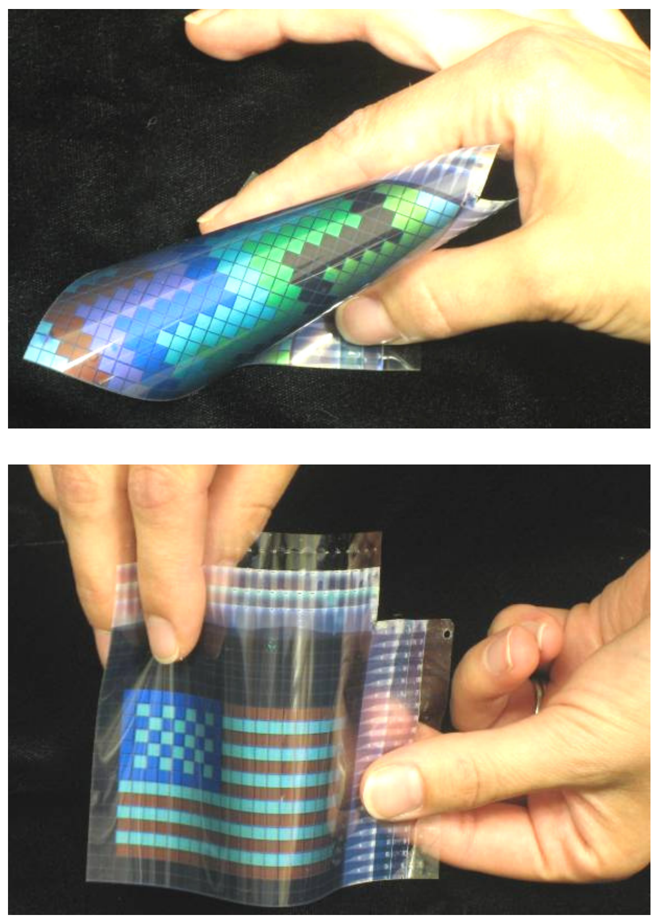

Figure 5: Photographs of the full color stacked ChLCDs using ultra thin substrates and the phase separation approach. The display format is 20×24 pixels.

The prototype display is 20×24 format with 8dpi resolution. The CP material is first inkjetted on the substrates. For the two internal substrates, the CP is inkjetted on one side, dried, and then the opposite side has CP inkjetted that is registered to the first side. The displays are made in array form with the sheet size of (305mm × 305mm). There are four displays on each array. The red layer is made using a simple lamination method. Following the lamination, the array is then polymerized. Subsequent layers are then sequentially laminated and polymerized.

The display photographs are shown in Fig. 5. The display is only about 70μm in total thickness (including the back absorbing layer) and the high degree of flexibility is clearly seen. There is no observable parallax since the display layers are so close to each other. In addition, the contrast, color saturation, and reflectivity are high as well. The conducting polymer coatings have approximately 1kΩ/square sheet resistance and greater than 97% transmission. The absorption in the conducting polymer layers adds quickly to reduce reflections from the lower layers of the display. However, as evidenced from the photographs, all displays layers and colors appear bright and saturated.

The displays are driven with off-the-shelf LCD drivers with a maximum drive voltage of about 35Vrms. The operating temperature range for the displays is -10°C to 45°C. Prototype displays of this construction with various resolutions are currently being explored by customers for different applications.

5. Conclusions

Penetration of ChLCDs into the consumer market with devices such as USB flash drives and portable hard drives demonstrates that the display technology continues to mature. Consumer demand for the enabling applications that ChLCDs offer in concert with global licensing will surely broaden their adoption in the future. The creation of the next generation simple full color flexible displays is key to continued growth with this display technology. The impact of lightweight, low power, flexible and rugged ChLCDs is significant in the marketplace.

6. Acknowledgements

Many thanks to the entire team at Kent Displays for creating this incredible display including inkjetting, fabrication, electronics, and interconnects. Special thanks to Kent State University for use of the Wright Project equipment at the Flexible Device Facility.

7. References

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