# Flexible Bistable Reflective Cholesteric Displays

*Joel Domino, Irina Shiyanovskaya, Duane Marhefka, Tod Schneider, Forrest Nicholson, Seth Green, Greg Magyar, Oleg Pishnyak, Asad Khan, and J. William Doane, Kent Displays, Inc., Kent, Ohio, USA*

## Abstract
*Reflective cholesteric displays are bistable and passively driven. As such, they can be integrated into thin polymeric substrates to create highly flexible displays. Alternative substrate materials such as paper and textiles have also been demonstrated. These displays are low power due to their reflective nature and bistability. They are also light weight and rugged. The applications for cholesteric displays can range from low-resolution signs to high resolution electronic books and everything in between. The advent of flexible technology greatly increases the realm of applications. The state of the art and the progression towards flexible displays will be discussed in this paper.*

## Introduction
Bistable reflective cholesteric displays[1,2] have been the subject of tremendous development and optimization programs. They are making a strong entrance in consumer devices and other electronics. As their uses and applications grow, the need for technological advancements continues to grow as well. On the forefront of this advancement is the advent of flexible, conformable, and even drapable cholesteric displays made on virtually any substrate material. This is a sharp departure from conventional glass based display products. Cholesteric displays can be used in a variety of applications including low resolution signs, medium resolution instrumentation, and high resolution electronic books and readers. Figure 1 shows typical cholesteric display modules on glass substrates.

In this paper we will discuss recent advances in flexible display technologies. How these technological advances advance the market penetration of the cholesteric display technology will also be discussed.

## Flexible Displays and Encapsulation
The creation of flexible cholesteric displays on thin polymeric substrates entails the use of encapsulated liquid crystalline materials. Although ChLCDs can be made with plastic substrates without encapsulation,[3] the encapsulated materials have much greater tolerance for flexing without creating flow of the liquid crystalline material. The lack of flow maintains the bistability during such flexing. As such, a rugged structure is established. We have explored two basic approaches to encapsulation: a phase separation approach and an emulsification approach. In different forms of phase separation, we have largely concentrated on polymerization induced phase separation (PIPS). This approach is similar to that developed for polymer dispersed liquid crystal (PDLC) systems and involves the creation of droplets after lamination of two substrates.[4,5] The emulsification approach involves the creation of droplets prior to coating and enables coatable displays on a single substrate.[6]

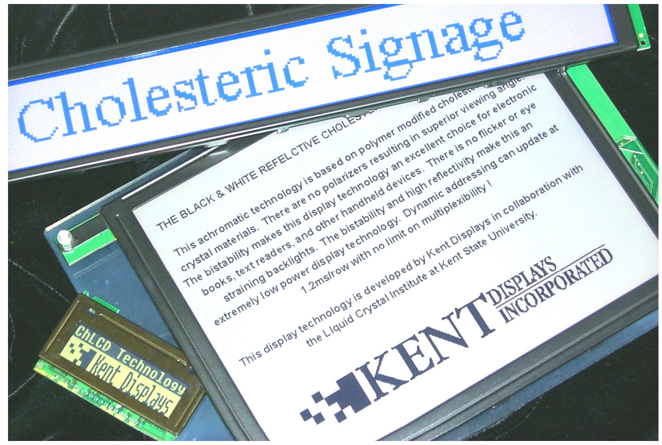


*Figure 1. Various ChLCDs in typical office lighting. Shown in the photograph are the wide 12.1" sign type display (blue/white), large 9.4" electronic book type display (black/white), and small 2.3" instrumentation type display (green/black).*

## Phase Separation
The phase separation approach allows the rapid deployment of flexible displays into the market. This is because this approach utilizes existing infrastructure, materials, and know-how. Using the PIPS approach, we have been able to make highly reflective, flexible, ChLCDs on thin polymeric substrates with high contrast and good electro-optics.

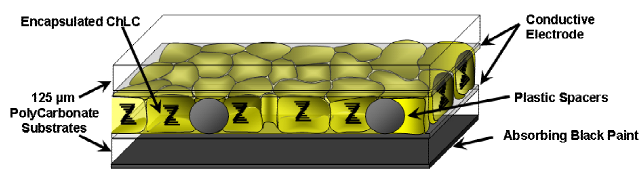


*Figure 2. Schematic diagram of the flexible encapsulated cholesteric LCD.*

Solutions of a pre-polymer are mixed and then added to the cholesteric liquid crystalline mixture. The pre-polymer mixture is composed of acrylate based materials and a photoinitiator. The pre-polymer:liquid crystal ratio is 20:80 by weight. Spacers are added to the mixture to preserve substrate spacing before polymerization. ITO coated 125µm thick polycarbonate substrates are used for the display. A bead of the pre-polymer/LC mixture is rolled down between the polycarbonate sheets using a hand roller and any excess is cleaned off. The substrates do not typically have alignment layers and/or insulating layers. The polymer itself serves to align the LC and provide the bistability. The material is polymerized under a UV light source at 3.75 $mW/cm^2$ intensity for approximately 15 minutes. During the PIPS process, droplets of liquid crystal are excluded from the bulk via phase separation as the polymeric chains grow in molecular weight. Figure 2 shows a schematic of the cell. The encapsulated liquid crystal is shown between the polycarbonate substrates. The back of the lower substrate is coated with a dark absorbing layer in the usual way to create contrast.

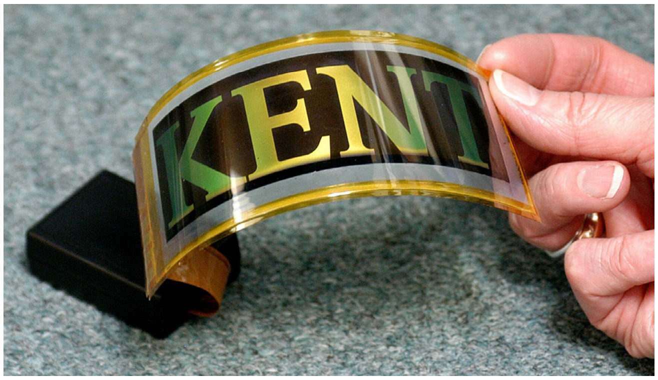


*Figure 3. Photograph of a test display being bent. Note that the dark and bright states maintain their appearance through the flexing process.*

The encapsulated material from the PIPS process maintains all the optimal properties of cholesteric LCDs. These materials are bistable, have high reflectivity and contrast. The flexible ChLCDs can be passively driven in the same way as conventional ChLCDs with typical voltages. Off-the-shelf STN drivers are used to drive a multiplexed display. Figure 3 shows a photograph taken in outdoor lighting of an actual PIPS based flexible ChLCD being bent after being switched to the bright state. In fact, the display can be driven while being flexed as well. There is no flow of the LC during bending and flexing thereby allowing the image to be maintained without any power applied. The flexibility depends largely on the thickness of the substrates.

## Emulsions

Our approach to a highly rugged coatable encapsulated display involves the use of emulsification to create liquid crystalline droplet structures. This approach is highly efficient as the entire process can use coating techniques thereby reducing cost of the displays dramatically. The result is display materials that can be put on virtually any substrate materials such as paper, plastic, and even fibrous textiles.

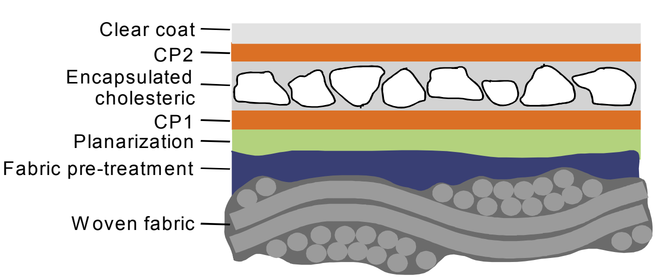


*Figure 4. Schematic of the cross section of the coated ChLCD on a fabric substrate. CP stands for conducting polymer.*

To form an encapsulated ChLC coating, liquid crystal is emulsified in an aqueous solution containing surfactants and polyurethane latex binder using high energy shearing to form the oil-in-water emulsion. The emulsion is then blade coated on the substrate with a conducting electrode and the water from the emulsion is allowed to evaporate. Typically, the ratio between the liquid crystal and the polymer binder is about 5:1. The thickness of encapsulated LC layer is in the range of 10-12 μm. Fig. 4 shows a schematic cross section of such a coated display on a fabric substrate. An average size of the droplets formed during emulsification process varies for cholesteric LCs with different pitches due to the different viscosities. The droplets appear to be flattened during emulsion drying, reducing light scattering and enhancing the display brightness. Conducting polymer based materials (PEDOT:PSS) are used as the top and bottom electrodes.

Figure 5 shows a photograph of a coated cholesteric display on a fabric substrate having 16 x 13 pixels and passive driving. The interconnects shown are highly flexible as well. The photograph demonstrates the great amount of flexibility and drapability of the coated display.

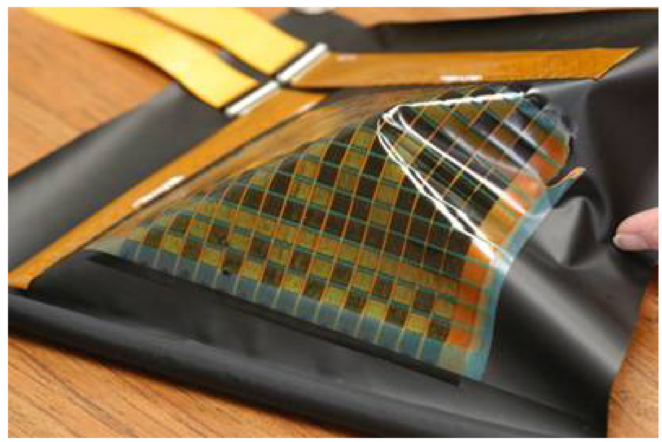

*Figure 5. Photograph of a coated ChLCDs on a textile substrate under substantial deformation. Deformed displays are fully addressable without any image degradation.*

A variety of different polymer and colloidal binder materials can be employed to serve as a flexible polymer matrix for encapsulated liquid crystals, including polyvinyl alcohols and gelatins.[7] The binder material plays an important role in mechanical properties, electro-optical behavior and processability of the entire display. Our choice of the polyurethane latex was based on its water insolubility after drying and ability to be coated with conductive electrode materials. Moreover the polyurethane binder forms excellent rugged coatings and exhibits a good index matching at the boundary between LC and polymer.

## Markets

The markets for ChLCD products varies widely from small battery operated handheld devices to large area signs. The most significant factor affecting large area displays is the cost to produce large area screens. A technology that has as simple a structure as ChLCDs, penetration of markets for signs is assured due to potential for high volume manufacturing. Roll to roll processing of the cells can increase the typical throughput of a facility by 50-100 times that are normally used for STN LCD production. Additionally the cost of substrate material is significantly reduced compared to glass displays. Other enhancements for plastic cell production that become even more significant with large area signs is reducing weight of the product by as much as 90% as well as enhanced ruggedness.

Sign markets that will be served by plastic based ChLCDs will vary from small information boards that can be used for directional signs, conference room scheduling, or building directories. Larger poster sized signs can be used for providing public information at airports, train stations and bus depots as well as stadiums and convention centers and any place where people need to have information that will change from time to time. The bistable nature of ChLCDs will allow for these displays to be operated with ordinary batteries, to be updated wirelessly through local networks, and easy to install and maintain.

Even larger area displays will be utilized for road signs, billboards and various military applications. These large area displays will be possible because of the change from a batch process for handling individual pieces of glass to the continuous process that roll to roll coating will provide. The proportion of electronics cost to the total cost of a device is very high for small devices (as much as 6:1 for small devices) while this ratio decreases significantly as display size grows. For billboard applications, the total cost will be significantly lower than is achievable with any other display technology.

One of the primary targeted markets for ChLCD technology is electronic books. This paper like ChLCD display technology gives the consumers everything they want in an electronic book display. Low power consumption, long battery life, non-flicker reading, lightweight, and low cost. ChLCD technology costs approximately one third of competing displays that require an active matrix for this application.

## Conclusions

In this paper, we have reviewed recent advances in flexible bistable cholesteric displays on various substrates including plastic and fabrics. The bistable cholesteric reflective display technology offers numerous advantages such as low power, high reflectivity and contrast, simple structure, and passive driving. These advantages combined with flexible and highly rugged display structures make this a strong contender for new applications such as large area signs, electronic books, etc.

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## Author Biography

*Joel Domino is the President of Kent Displays Inc. of Kent Ohio. Prior to becoming President in 2003, Joel was Chief Financial Officer of Kent joining the company shortly after it’s start-up in 1993. From 1982 – 1993 Joel worked for Ball Corporation. He held various financial positions at Ball including Chief Financial Officer of a $100 million Joint Venture Subsidiary, and his last position there was Director of Strategic Planning. Joel has a Bachelor of Arts degree from Mount Union College, and an MBA from California State University Fresno.*