

8.3: Thin Flexible Photosensitive Cholesteric Displays

**Nithya Venkataraman^{†*}, Greg Magyar[†], Erica Montbach[†], Asad Khan[†],
Tod Schneider[†], and J. William Doane[†]**

[†]Kent Displays, Inc.
343 Portage Blvd., Kent, OH, USA 44240

Lisa Green^{*} and Quan Li^{*}

^{*}Liquid Crystal Institute
Kent State University
Kent, OH, USA 44240

Abstract: *We present a novel optically addressable, flexible bistable cholesteric display. These displays utilize azo-binaphthalene photosensitive chiral dopants to create inherently high resolution, light weight displays that are optically written and require no attached electronics. As such, they are a natural fit for badges, shelf labels, and point of sale cards.*

Keywords: Cholesteric Liquid Crystal; Photochiral Materials; Bistable Display; Flexible Display

Introduction

Reflex™ displays, based on the bistable, cholesteric liquid crystal display technology, are a natural fit for optically addressable displays since they require low power, can be flexible, and have a paper-like reflectance.^[1,2] In a conventional cholesteric liquid crystal display (ChLCD) device, the electronics are the most expensive component, sometimes costing nearly six times more than the display alone. By combining the characteristics of a photosensitive chiral (photochiral) dopant with those of a cholesteric liquid crystal (ChLC), a display device is produced that doesn't require attached electronics or patterned conductive coatings and can be produced on a roll-to-roll web line, which departs from other photoaddressable displays mentioned in literature.^[3,4] The optically addressable display has two inherent advantages; high resolution, limited only by the domain size of the cholesteric phase (~1-2 μm) and a substantially reduced cost approaching an order of magnitude less than an electronically driven display.^[5]

The Reflex™ optically addressable display incorporates a high helical twisting power (HTP) azo-binaphthalene chiral compound that is photosensitive.^[6] Upon irradiation, the azo linkage in the compound absorbs light and photoisomerization is induced which results in a conformation change.^[6] The conformation change is not permanent and is thermally reversible.^[6] When combined with a nematic liquid crystal, a ChLC phase is produced. When irradiated, the resulting conformation change affects the HTP and changes the pitch of the cholesteric, therefore, changing the peak reflected wavelength of the display.

We previously reported our findings in a system consisting of glass substrate filled with just ChLC containing the

photochiral dopant. In this current work, we discuss the development of these materials in a flexible system where the liquid crystal is encapsulated through polymerization induced phase separation (PIPS), and the display utilizes plastic substrates as opposed to glass^[2]. This new system results in a bright, thin, flexible device (Fig. 1).



Figure 1. An optically addressed flexible photochiral display

Results

The photochiral dopant used in this paper is an azo-binaphthalene chiral compound with an ether linkage and a hydrocarbon chain.^[6] When combined with a nematic liquid crystal, the photochiral dopant has an approximate HTP of $58\mu\text{m}^{-1}$ for the unexcited state. When irradiated, cis-trans isomerization begins and the HTP is reduced resulting in the unwinding of the ChLC helix. This causes the reflection of the ChLC to shift into the infrared such that the image is not visible to the naked eye. To prevent the reflection from shifting out of the visible spectrum, the photochiral dopant is added to a pretwisted ChLC host instead of a nematic LC host.

The pretwisted ChLC host consists of a light stable chiral dopant of the opposite handedness than the photochiral dopant. For a pretwisted display with photochiral dopant, the unexcited state initially has a reflection peak in the red spectral range. This is due to the two opposite handed chiral dopants competing with one another, thereby

decreasing the overall HTP. Upon irradiation, only the HTP of the photochiral dopant decreases resulting in a net increase of the overall HTP and a blue shift in the reflection.

A flexible photochiral display is created using the traditional PIPS process except that a photochiral dopant is included in the liquid crystal mixture.

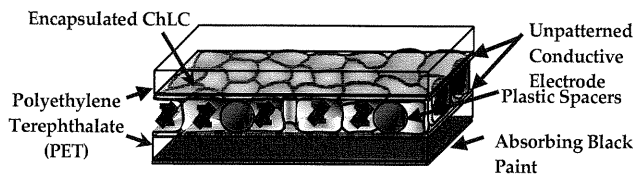


Figure 2. A cross-section of a flexible Reflex™ on plastic substrates

The polymerization that occurs during the PIPS process is initiated when a UV sensitive photoinitiator breaks down into radicals. The typical PIPS photoinitiator and the photochiral both absorb in the UVA region. Initiation of the polymerization process to encapsulate liquid crystal can be difficult to achieve when both the photoinitiator and photochiral absorption spectra overlap. As a result, a photoinitiator with an absorption spectrum in a different wavelength range than the photochiral dopant was used to enable phase separation and resulting encapsulation.

Writing an image on an encapsulated photochiral display utilizes the same method as writing on an unencapsulated photochiral display (photochiral ChLCD without polymer dispersion). Both rely on the change in pitch with irradiance.^[5] For ChLCDs, the pitch is indirectly proportional to the voltage so a change in the reflected color results in a corresponding change in the threshold (driving) voltage. For a pretwisted display, this relationship provides a voltage range at which a planar texture is

obtainable in the unexposed region and a focal conic texture is obtainable in the exposed region with the application of a single pulse voltage (Fig. 3a).^[5] The optically addressed display has inherent bistability regardless of light conditions since the unexposed regions are switched to the planar texture after exposure and the exposed areas are switched to the focal conic texture after exposure.^[5]

For the unencapsulated optically written display, the shift in wavelength between the unexcited state and the excited has to be large enough to obtain a voltage such that one can simultaneously switch both the planar and focal conic textures in the unexposed and exposed regions, respectively (Fig. 3a). For encapsulated displays, a high optical contrast between the exposed and unexposed electro-optic curves occurs at higher voltages and lower frequencies than unencapsulated displays (Fig. 3b). However, the encapsulated display has much higher resolution than the unencapsulated display for several reasons, including: parallax during image exposure due to glass thickness and diffusion of the photochiral dopant, which is reduced in the encapsulated display with the polymer walls.

Results of the photosensitivity and thermodynamic relaxation of a photochiral flexible encapsulated display are presented and compared to an unencapsulated photochiral display (Fig. 4a and 4b). Figure 4a shows the photosensitivity of the photochiral dopant in both a pretwisted green ChLC unencapsulated and an encapsulated display exposed to UV light. For the encapsulated display, the approximate effective HTP is $26\mu\text{m}^{-1}$ and $8.1\mu\text{m}^{-1}$ for the unexcited and excited states, respectively, whereas for the unencapsulated display it is $47.9\mu\text{m}^{-1}$ and $2.4\mu\text{m}^{-1}$, respectively. The photosensitivities of the unencapsulated and encapsulated displays are comparable to one another.

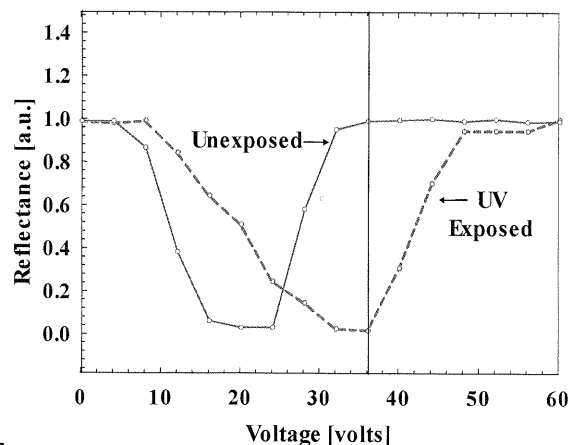
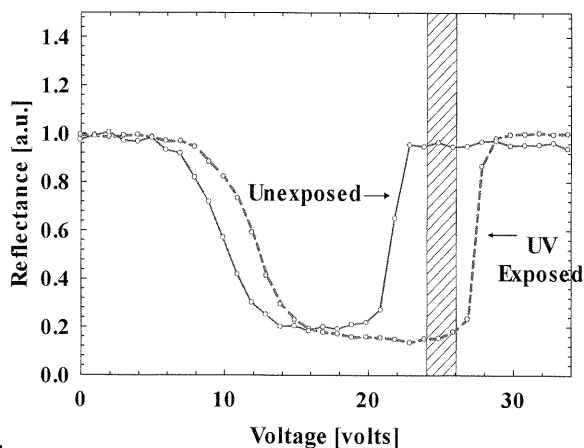


Figure 3a and 3b. Electro-optical curves for the exposed (green curve) and the unexposed (red curve) parts of an unencapsulated display (a) and PIPS encapsulated display (b). Applying a voltage in the shaded region results in switching the exposed regions of the display to the focal conic state while the unexposed regions switches to the planar state

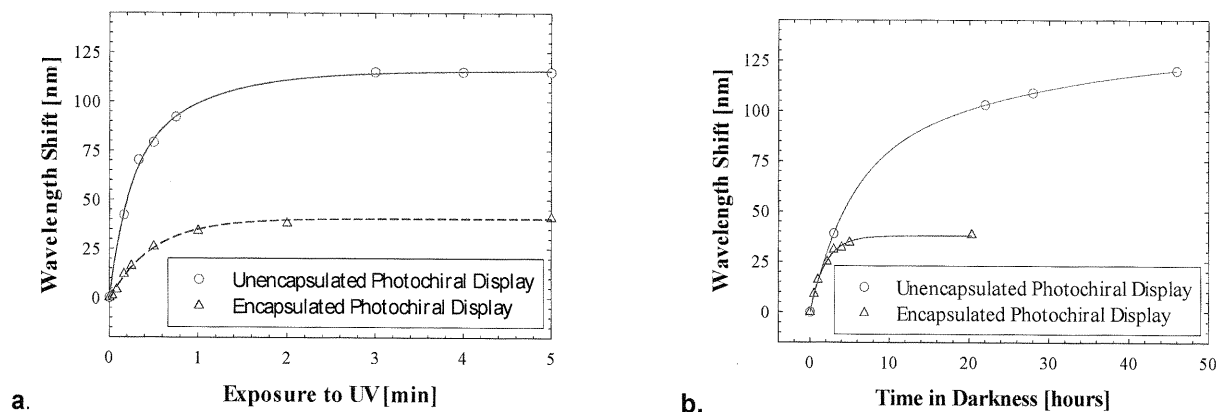


Figure 4a and 4b. UV sensitivity (a) and thermal relaxation (b) of both photochiral displays.

Upon UV exposure, the photochiral dopant in both displays is nearly fully excited to the cis-trans conformation after 1 minute of UV exposure. In regards to the relaxation, the unencapsulated photochiral display requires a significant amount of time compared to the encapsulated display to relax back to the unexcited state. This may be due to the fact that the wavelength shift in the unencapsulated display is more than four times the wavelength shift in the encapsulated display. Regardless, the initial relaxation curves of the two displays have approximately the same slope.

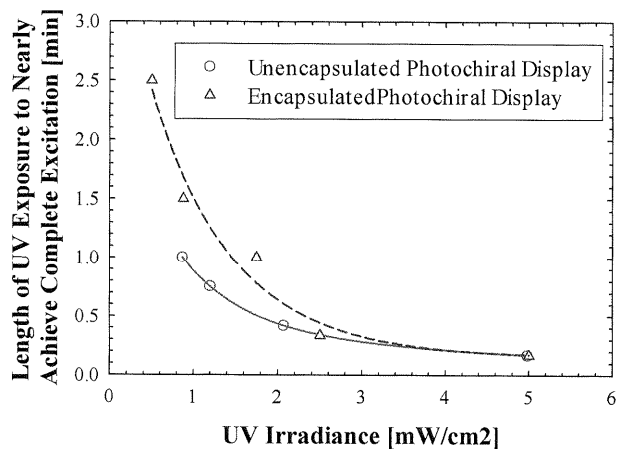


Figure 5. The length of UV exposure required to achieve nearly full wavelength shift for various UV irradiances.

To reduce the time it takes to fully excite the photochiral display, different irradiances were investigated (Fig 5). The irradiance required to write an image in less than a minute in an encapsulated display, is approximately 2mW/cm² or greater, whereas for an unencapsulated display an irradiance approximately 1mW/cm² or greater is sufficient.

Conclusion

A flexible optically addressable ChLCD has been demonstrated. Traditional liquid crystal displays tend to be bulky and heavy due to not only the glass but also the electronics. In addition, the electronics are a significant

portion of the cost. Here we show an optically addressable display that does not require attached electronics or patterned electrodes. It is thin and flexible resulting in a light weight, high resolution, low cost display that can be produced on a continuous roll-to-roll web line. As such, this product can be used in applications, such as store shelves, badges, point of sale cards, and many others. This product is particularly useful when the display is infrequently updated and does not need attached electronics but requires high resolution and low cost. For these devices, a single optical writer can be used to update many displays. Currently, a digital optical writer that can write an image to the display is in development.

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