

62.4: Flexible Bistable Smectic-A LCD Based on PDLC

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Abstract

The combination of two advanced technologies developed by Kent State University and TechnoDisplay ASA has resulted in the creation of high performance flexible bistable displays. While the bistable SmA (EASL DMD™) technology offers a more simplified display mode, long term stability, and an excellent contrast, the PDLC technology provides simplicity of manufacturing while maintaining the standard characteristics and strength of the display. Along with their lighter weight, the flexible display prototypes demonstrate high contrast ratio, excellent viewing angle characteristics, low power consumption, and a long lifetime.

1. Introduction

Development of bistable displays is highly significant, because they maintain their optical states without an electrical field being applied, and are ideal for portable electronic devices. Bistability allows high resolution images to be produced using simple multiplex drive schemes. Examples of bistable displays, such as bistable reflective cholesteric displays [1], zenithal bistable displays (ZBD™) [2], bistable SmC* ferroelectric displays [3], 360° BTN displays [4], and 180° bistable nematic (BiNem®) displays [5] have been researched and well-documented.

Another advanced approach that achieves a bistable switching is based on ion-doped SmA materials [6,7]. The materials can be switched between stable homeotropic and focal conic textures by changing the frequency of an applied electric field. Application and removal of low frequency (<1 kHz) electric fields results in the formation of focal-conic scattering texture through electrohydrodynamic instability. However, at higher frequencies (>1 kHz), homeotropic texture forms due to the dielectric re-orientation of the smectic molecules. Bistability, wide viewing angles, and sunlight readability make smectic A material devices based on this effect promising for a wide variety of applications.

Future generation displays will use polymer substrates instead of glass substrates because the flexibility of polymer substrates opens up new display application opportunities, such as smart cards, electronic paper, and various electronic signage applications. The most reliable way to fabricate mechanically stable, self-adhering, self-sustaining flexible displays is using liquid crystal/polymer composite systems. This can be done by means of polymer dispersed liquid crystal (PDLC) systems or polymer walls [8, 9]. Bridging the two plastic substrates, polymer chains or walls create a robust lamination that can withstand essential multiple bend deformations of flexible displays.

In this article, we demonstrate that PDLC technology can be perfectly adjusted for working with the bistable ionically-doped SmA materials. Development of SmA based PDLC films was described earlier in 1988 by Montgomery et al. [10]. Later,

Aristov and co-authors demonstrated that ionically doped SmA materials fully preserve their intrinsic properties while being dispersed within a polymer structure [11]. Here we demonstrate that combining PolyDisplay's patented Electrically Addressed Smectic Liquid Crystal Daylight Memory Displays (EASL DMD™) technology with a polymer network has made it possible to develop a lightweight flexible display with excellent viewing angle characteristics, high contrast ratio, and low power consumption.

This article first provides photographic evidence of SmA PDLC based flexible bistable displays. We then present details of the manufacturing of the displays along with a description of the challenges and details of the electro-optical performance.

2. Flexible Bistable SmA PDLC Display

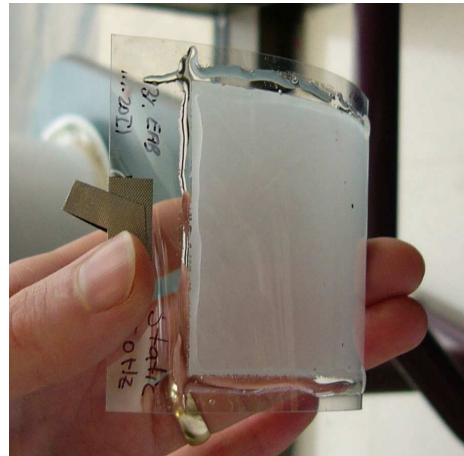


Figure 1. Pictures of SmA PDLCs in an opaque state (top) and in a transparent state (bottom) on 2.5" x 2.5" PET substrates. No voltage is applied to maintain optical states.

Plastic SmA PDLC light shutters in transparent and opaque states are shown in Figure 1. As seen from the pictures, the static homeotropic texture formed in SmA PDLC has very good transparency, whereas the focal conic scattering texture provided by plastic SmA PDLC offers good opacity even when plastic cell is bent. We also prepared a dyed SmA PDLC on PET (Figure 2). It has been found that adding dichroic dye to the LC material has no significant influence on the phase separation process or the electro-optical characteristics.

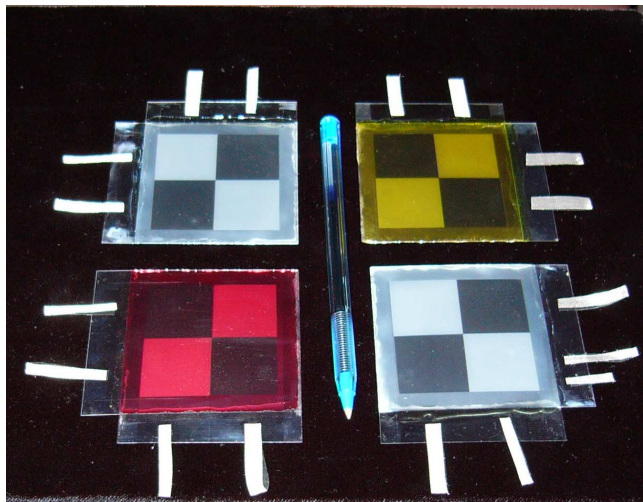


Figure 2. Pictures of red and yellow dyed SmA PDLCs in an opaque state and in a transparent state on PET substrates.

3. Experimental

The ionically doped SmA material used in this study was supplied by PolyDisplay ASA. The temperature range for this SmA mesophase was from -5°C to 50°C . The indices of refraction for this material have been measured by an Abbe refractometer as $n_o = 1.51$ and $n_e = 1.70$. In order to prevent haze while the SmA PDLC is in homeotropic state, we used NOA65, from Norland Products Inc., as a polymer precursor with a refractive index of 1.52.

Here flexible SmA PDLCs were prepared by the lamination technique, which makes easy fabrication of large area flexible devices possible. First, a sheet of the plastic substrate was placed on a smooth surface, and then the mixture with $16\ \mu\text{m}$ spacers was spread across the surface of the PET substrate. Finally, the second PET substrate was laminated onto the bottom one by means of a rubber roller. NOA65 has a maximum absorption within the range of 350-380 nanometers. Therefore, the film was irradiated with UV light from an Electro-Lite Corporation ELC 4000 light curing unit to cause a phase separation. Such a simple algorithm of flexible films preparation makes it suitable and easily adjustable for real manufacturing conditions.

The performance of the SmA PDLC films was compared with that of the pure ionically-doped SmA material also placed between plastic substrates.

4. Results and Discussion

4.1. Morphology of SmA PDLC Films

It is well known that the electro-optical properties of PDLC composites strongly depend on the morphology of the films [12, 13]. The PDLC morphology is largely determined by liquid crystal/monomer composition, temperature, and the method of polymerization. By changing the polymerization rate, we can obtain various sizes and shapes of droplet structures. Therefore, we carried out experiments to modify the structure of PDLC composites to obtain a similar electro-optical performance to that of the pure SmA mixture.

The polymerization rate of the phase separation process can be controlled by the intensity of the UV light and the polymerization temperature. We observed that the best morphology for SmA PDLC composite from the electro-optical and mechanical view point were provided using a combination of low and high intensities of UV light. At lower intensities and elevated temperature the polymer networks form larger domain sizes. A second exposure to higher UV intensity at room temperature stabilizes and strengthens the polymer network of the PDLC. In our case, we obtained a chain-like polymer network structure, which is robust enough to hold both of the substrates together, as shown in Figure 3.

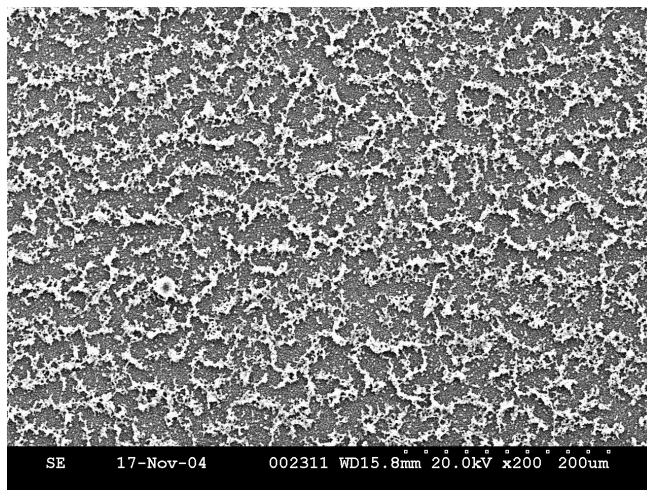


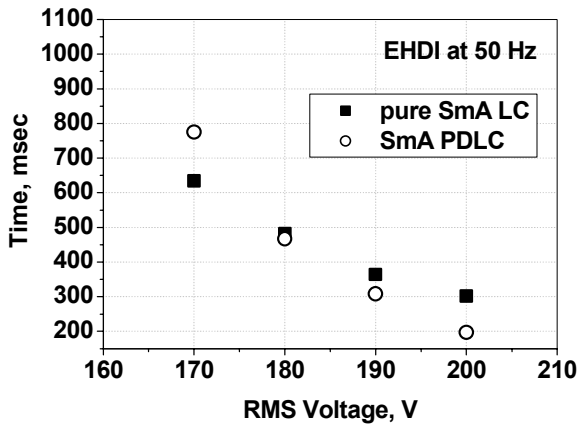
Figure 3. SEM picture of SmA PDLC composite film

4.2 Electro-Optical Characteristics of SmA PDLC films and pure SmA LC

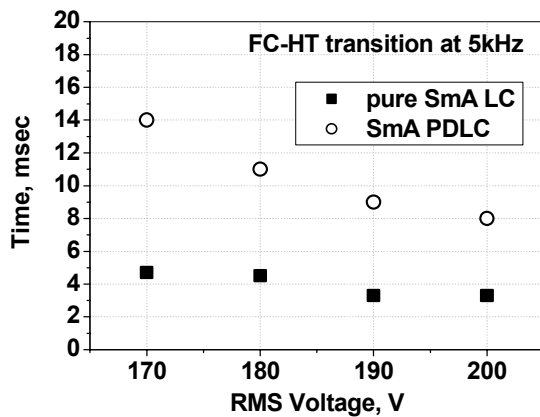
We compared SmA PDLCs and pure SmA LC in terms of their electro-optical characteristics, such as time-response and static-response, threshold voltages, and contrast ratios.

The response times as a function of applied voltage for the pure SmA LC material and SmA PDLC composite are shown in Figure 4. Response times of the electrohydrodynamic instability (EHDI) and focal conic-homeotropic (FC-HT) transition were obtained at 50 Hz and 5 kHz, respectively. The EHD and FC-HT response times were calculated at the 90% change in transmission when the cell was driven by voltage pulses. Table 1 also summarizes the static-responses of PDLC and SmA material. These results show

that SmA PDLC with the optimal formulation and preparation conditions gave us electro-optical results similar to those of the pure material.



(a)



(b)

Figure 4. Response times - voltage dependencies for pure SmA LC and SmA PDLC composite films for EHD and FC-HT transitions at a) 50 Hz and b) 5kHz, respectively

Table 1: The summary of static-response measurements of SmA LC and SmA PDLC

Frequency	SmA LC V_{th}	SmA LC V_{sat}	SmA PDLC V_{th}	SmA PDLC V_{sat}
50 Hz	104	107	105	109
5 kHz	52	54	67	70

4.3 Contrast Ratio Measurements

Due to a strong interaction of the polymer chains and the liquid crystal molecules, the main challenge of development of bistable SmA based PDLC materials was to preserve the initial electro-optic properties intrinsic to the pure SmA material, such as saturated scattering in an opaque state and crystal clear transparency in a homeotropic state. From this point of view, the contrast ratio of the films is a significant parameter of their electro-optical performance. SmA LC and PDLC film performances as a function of collection angle were measured by the optical system shown in Figure 5. The collection angle (2θ) was calculated as $2\theta = 2 \cdot \arctan((D/2)/L)$ where θ is the half collection angle, D is the diameter of the photodiode, and L is the distance between the sample and photodiode.

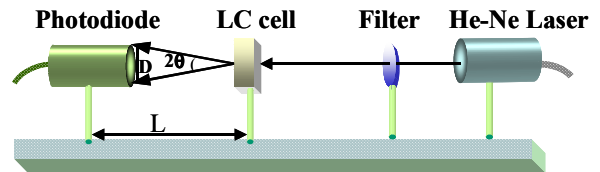
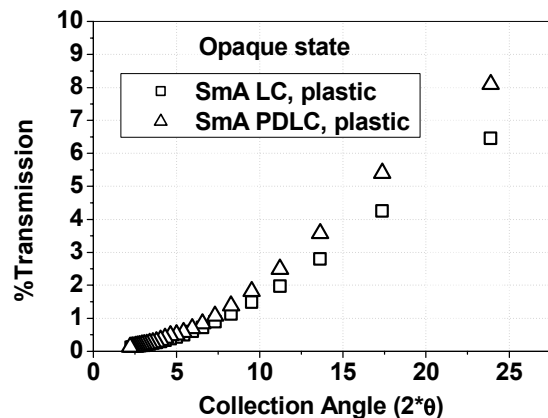


Figure 5: Experimental configuration for contrast ratio measurements.

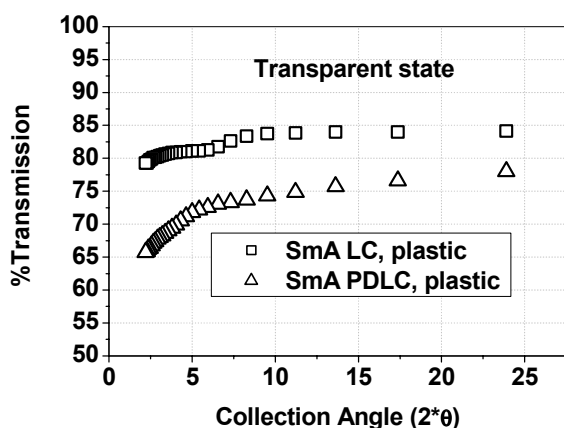
Light transmissions at opaque and transparent states at different collection angles for pure material and SmA PDLC on PET are shown in Figure 6.

Transmission contrast ratios for SmA PDLC films and pure material were calculated using the normalized signal from a photomultiplier as the ratio T_{HT}/T_{FC} where T_{HT} and T_{FC} are the percent transmissions of homeotropic and focal conic textures, respectively. The measurements were taken in static state after removing the field. At a 5° collection angle for the optimum SmA PDLC, we found that the contrast ratio is 83% of that of the pure material on PET substrates. The corresponding contrast ratio-collection angle characteristic is shown in Figure 7.

At higher collection angles or at shorter distances, the difference between pure SmA material and SmA PDLC films is about 5%. However, at lower collection angles or at larger distances, the difference is about 10-15%. This is because of the light scattering between polymer-polymer and polymer-LC interfaces in the PDLC system. As seen in Figure 1, the SmA PDLC with 83% CR provides a very good appearance on plastic substrates. We have attained almost the same percent of light transmission for SmA PDLC as that of the pure material in their opaque states.



(a)



(b)

Figure 6: Transmission of cells versus collection angle for pure SmA LC and SmA PDLC in (a) an opaque state, (b) a transparent state on plastic (PET) substrates. Measurements were collected while the cell was in its static states.

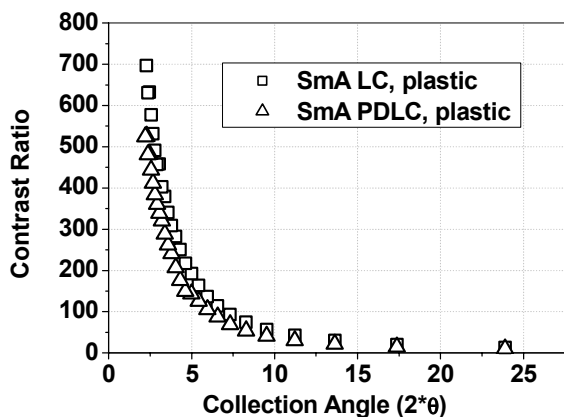


Figure 7: Contrast ratio versus collection angle for pure SmA LC and SmA PDLC on plastic (PET) substrates.

5. Conclusions

We have developed a flexible bistable SmA liquid crystal/polymer composite display that has electro-optic characteristics comparable to pure PolyDisplay ASA SmA material. This lightweight display features flexibility, bistability, sunlight readability, and a wide viewing angle that opens up new possibilities for large area, high-resolution display applications. From a manufacturing viewpoint, photopolymerized polymer dispersed liquid crystal systems offer simplicity, flexibility, and ease of manufacture on plastic substrates.

6. Acknowledgements

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7. References

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