

Shutter-free full colour Solid State Reflective Display (SRD®)

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Abstract

We demonstrate for the first time a simplified thin-film optical architecture that results in a fully bistable, full-colour, video-capable SRD frontplane without the need for top shutters or optical filters. The expected performance of the new architecture is quantified using simulations and initial experimental results shown on non-pixelated, continuous films.

Author Keywords

Phase-change material; bistable; video-rate; reflective; LTPS; PCM; SRD.

1. Background and Objective

Solid-State Reflective Displays (SRD®) are a highly capable new class of video-capable, colour reflective displays [1]. SRD pixels modulate light reflected off a mirror using a switchable, ultra-thin layer of chalcogenide-based Phase Change Material (PCM) [2-4]. PCM are functional materials that exhibit at least two stable phases at room temperature with different optical properties, typically between their amorphous and crystalline phases. An energy pulse is used to switch between the phases repeatedly; this is the mechanism for traditional optical disc data storage technologies (CD, DVD-RW) as well as the latest generation of storage class electronic memories [5].

A full-colour implementation of the SRD technology was previously presented in [6]. Since most PCM stacks can only switch between two stable states, an additional low contrast, high-transmissivity top shutter is typically required to achieve black states required to display high contrast, full-colour content. Although compelling in terms of optical performance, integrating this functionality within the optical stack itself would simplify the manufacturability of the display as well as the electrical signals needed to drive it. Furthermore, top shutter technologies such as polarizer-free liquid crystals or electrowetting type shutters are traditionally non-bistable; an architecture that does not need additional components to display full-colour content, would greatly benefit from the inherently true bistable nature of phase change materials.

In this paper we present a new and improved optical architecture enabling full-colour SRD display implementation without the need for additional optical components beyond the SRD® pixels.

2. Simplified SRD® full-colour architecture

A schematic of the simplified optical architecture is shown in Figure 1a. Here the pixel is divided into three separate subpixels, each one capable of switching between 3 states: a primary colour (Red, Green or Blue), a pale or white colour and a dark or black colour. The ability to add a third state to a PCM stack is the key functionality enabling the simplification of the architecture without sacrificing the predicted optical performance of the SRD® display. In particular, the third state is added into each subpixel by modifying the PCM stack to exhibit two distinct crystalline transitions with well separate thresholds, together with the standard amorphous phase.

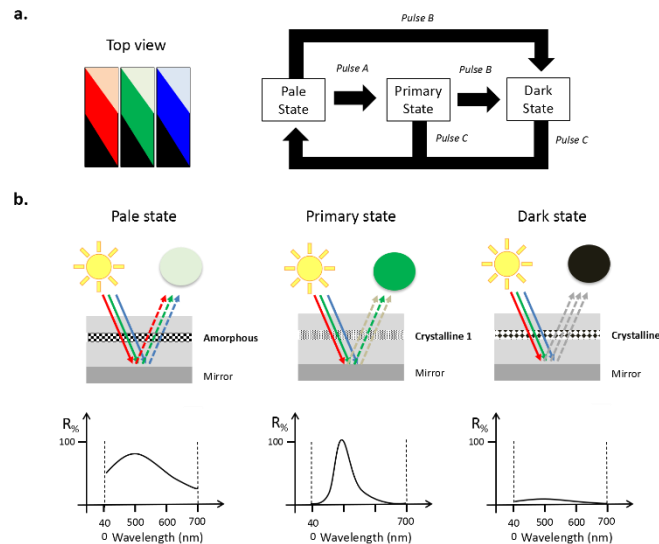


Figure 1. Diagram explaining a simplified optical architecture for full-colour SRD displays.

Switching between these three states requires different (yet simple) pulses which can be readily generated by the electronics driving the pixel. As an illustration, starting from a pixel in the “Pale colour state” (fully amorphous phase), a pulse (Pulse A) of a certain amplitude and length will switch the pixel to its “Primary colour state” (first crystalline phase). Applying a pulse of similar length but higher amplitude (Pulse B) will switch the pixel into its “Dark colour state” (second crystalline phase). Then, a shorter but higher in amplitude pulse (Pulse C) will switch the pixel back into the initial “Pale colour state”. One such case for the

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green subpixel is shown in Figure 1b. In this example the SRD[®] nano-cavity was designed to initially reflect a broad spectrum of the visible light (Pale State) and as close as possible to the white point. When the nano-cavity is switched to its Primary State (green in this case), the light reflected off the surface becomes narrower, reflecting a saturated green spectrum with the remaining wavelengths absorbed by the cavity. Finally, when the SRD subpixel is switched to its dark state, the nano-cavity absorbs most of the light reaching it and only a small portion of spectrum is reflected off the surface. This creates the dark state.

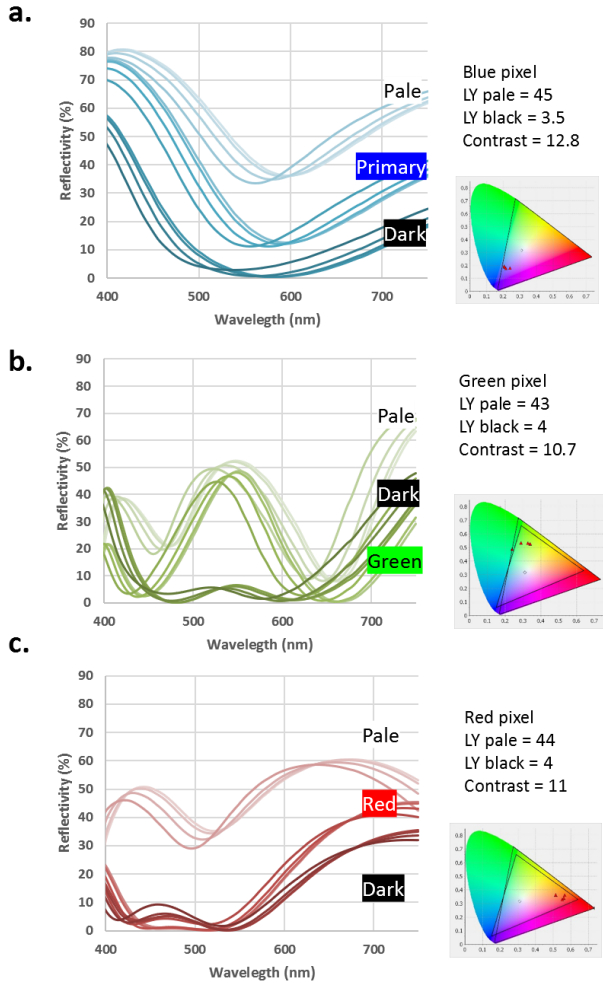


Figure 2. Optical thin-film simulations for the new three states SRD design showing the expected reflectivity spectra for R,G and B from 0, 15, 30 and 45 degrees viewing angle.

At a pixel level, the architecture will use the combination of the three sub-pixelated pale states to create a white pixel and the three dark states to create a true black. Interestingly, in this new architecture both black and white contrast and white reflectivity are derived directly by the degree of change in refractive index between the different phases of the PCM

material. High contrast between the optical properties of the amorphous and crystalline phases leads directly to a pixel with high white to black contrast and high reflectivity of the white state. It is very important to highlight that the entire optical architecture operates via a strong-interference effect modulated only by the change in refractive index of the ultra-thin PCM layer. Structurally, the SRD[®] pixel does not physically move nor change in shape, size or volume. Other well-known colour changing effects such as electrochromism are not responsible for the reflectivity change as demonstrated previously [2].

3. RGB subpixels design and deposition

The RGB subpixel stacks are designed using a thin-film transfer matrix methodology with optimized targets chosen as luminosity of the Pale state, colour saturation of the Primary state and luminosity contrast between the Pale and Dark states. Optical thin-film simulations for the multi-state RGB stacks are reported in Figure 2a, b and c respectively and for 0 to 45 degrees viewing angles. Corresponding CIE plot for the saturated states are shown for multiple angles, for each primary colour. Luminosity and contrast are calculated and reported in each case. Minimum angle dependence is shown in every case thanks to the ultra-thin nature of the nano-cavity film.

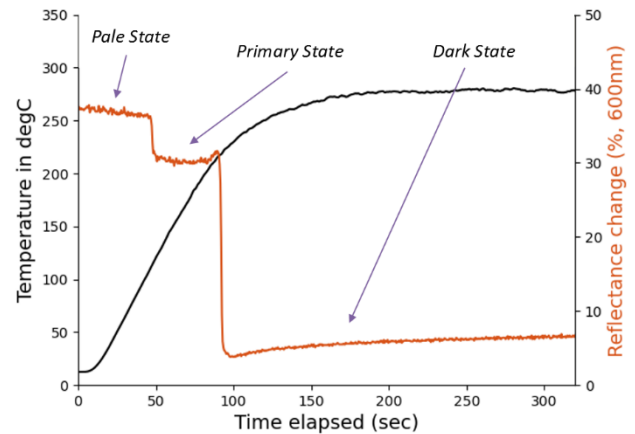


Figure 3. Hot plate ramping-up experiment for the multi-state Blue stack deposited on glass. The stack shows two clear switching events at roughly 100 °C (from Pale state to Primary state) and 200 °C (from Primary state to the Dark state). Monitoring wavelength chosen as 600 nm.

The multi-layered stack begins with a mirror followed by an alternating structure of transparent layers and PCM layers. The entire film is deposited via PVD sputtering, without breaking vacuum and measures roughly 300 to 400 nm in thickness depending on the colour.

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A series of prototype films are deposited on glass following the cavity designs identified using the methodology described in the previous paragraph. Samples are fabricated by sputter deposition at room temperature and in their Pale state (fully amorphous state). After the deposition is completed, each sample is placed on a hot plate and then gradually heated up to 275 °C while the reflectivity is being continuously recorded. Two switching events are consistently recorded at roughly 100 °C and 200 °C, confirming the multi-state nature of these stacks. The first event corresponds to the film switching from the Pale state to the Primary state (first crystallization) while the second transition switches the stack to its final Dark state (second crystallization). An example for the Blue stack is shown in Figure 3. At each switching event the reflectivity (at 600 nm) drops consistently with the film undergoing a transition between Pale to Primary and finally to the Dark state.

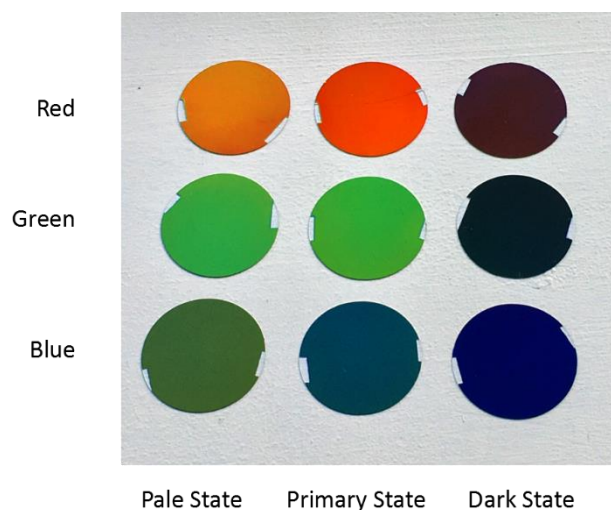


Figure 4. Prototype RGB sub-pixel stacks showing 3 states (Pale, Primary and Dark) for Red, Green and Blue colours.

The experiment is repeated for three colours and the total matrix of 3 samples for 3 states (9 total cases) is shown in Figure 4. Prototype stacks show high contrast, good saturation and sufficient reflectivity of the Pale state.

4. Summary and future work

This work seeks to validate a simplified and improved optical architecture specifically designed for full-colour, video-capable, bistable SRD® displays. This new architecture has several advantages compared to the other implementations of full-colour SRD® displays:

- No additional components besides the SRD® pixels are necessary to implement a full-colour, reflective display based on PCM materials.

- Bistability of the display is preserved.
- The high switching speed capability of the technology is fully retained.
- Electrical driving is robust and straightforward. The backplane and driving architecture developed for 2-colour SRD® [7] remains the same.
- Optical performance is now driven by the inherent properties of the PCM material which can be tailored for specific applications.

Future work will focus on implementing the proposed architecture on an LTPS backplane together with improving the reflectivity of the Pale states. Modifying the surface of the pixels to reflect light close to a Lambertian approximation will increase the appeal of SRD® as a new standard for high-performance, full-colour, video-capable e-readers.

Acknowledgements

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