# Solid-State Reflective Displays (SRD®) for Video-Rate, Full Colour, Outdoor Readable Displays

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**ABSTRACT**

*Solid State Reflective displays (SRD®) have been proposed as a new route for next generation reflective displays. We present the first optical measurements of a combined RGBW states, together with a simulated black state. These results demonstrate the feasibility of a future high performance, video capable, full colour, SRD display.*

## 1. BACKGROUND AND OBJECTIVES

We recently demonstrated the feasibility of a low-power, high colour reflective display based on a new optical modulation mechanism – reversible phase-change material crystallisation in an ultra-thin film stack – which is entirely new to the field of displays(1-3). Our simulated performance indicates that a display utilising this effect can be designed to provide white-state luminance reflectivity of over 50% and a colour gamut between 40% to 80% of sRGB depending on fabrication complexity. This compares very favourably with current monochrome e-reader displays which offer similar luminance reflectivity but no colour capability, and reflective LCD displays which have much reduced reflectivity and typically ~20-30% sRGB gamut capability. A solid-state reflective display (SRD) is intended to be suitable for a range of potential applications where zero power image maintenance, vivid colour freedom of design and video capability are desirable simultaneously. Examples ranging from simple 2-colour displays for wearable devices, internet-of-things objects, and secondary notification displays for mobile phones, to full-colour reflective displays for colour e-readers, automotive and outdoor signage applications have been discussed. The basic characteristics of the technology, and the first demonstration of reversible electrical switching of display pixel sized phase-change material based devices, have been described elsewhere(4) and summarized in Figure 1 for convenience to the reader. In brief, an ultra-thin optical cavity is designed to reflect a targeted colour using a strong interference effect. The interference properties of the cavity are actively modulated by electrically switching the physical state of an ultra-thin solid-state phase change material embedded within the cavity. The modulation produces a large optical change that can be designed to create a unique type of reflective display system. Recently, we have shown how a full colour SRD displays requires at least three separate subpixels designed to switch between a primary, highly saturated colour and a pale, more luminous, version of the same colour. The combination of the three subpixels, together with a top optical shutter, enable the implementation of a high performance, video capable, full colour, reflective display.

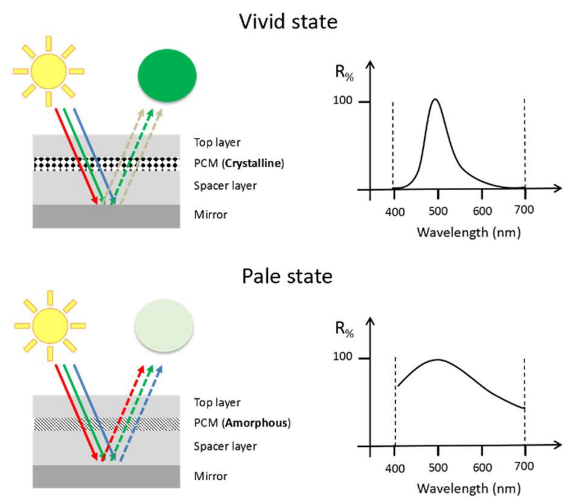


**Figure 1 –** Basic description of a RGB type SRD display.

In this work, we present the spectral measurements of three primary RGB to pale, prototype films together with their combined high brightness white state and simulated black state.

## 2. RESULTS

Large area, uniform colour, RGB static films were deposited on a rigid glass substrate using a standard vacuum sputtering technique. The films were deposited at room temperature and designed to appear in their pale state as deposited, with the phase change material in the fully amorphous phase. Each sample was subsequently diced in half using an automated dicing saw machine and one half heated up to 200 C for 1 minute in order to fully crystallize the ultra-thin, active PCM layer. Figure 2 shows a picture of a total of 6 samples; R,G and B combinations in both the pale (right) and the vivid (left) states, viewed from both normal (top) and oblique (bottom) viewing angles. The film show good colour saturation, measured at 47% of that of s-RGB and good luminosity.


**Figure 2 –** RGB static samples in the vivid (left) and pale (right) states at two different angles on a cloudy afternoon. No contrast enhancement of any kind has been applied to these pictures.

The RGB reflectivity spectra for both pale and saturated states and the resulting bright white state are shown in Figure 3 **a**,**b**,**c** and **d** respectively. It is important to note that the resulting white state has not been optimized for pixel size nor white point fidelity; each colour (sub pixel) was divided into 1/3 of a total pixel. The measured luminosity of the white state is 30% which is small compared to the 50% expected from the optical thin film simulations but still remarkable considering the large (47% s-RGB) measured area of colour gamut. Continuous optimization of the deposition process, together with a deeper understanding of the thin film optical properties are expected to push the performance of the films close to the simulated ones.

Pictures of a lithography defined SRD white state from both normal and tilted angles can be found in Figure 4**c**. The exact design and composition of the white SRD sample will be explained later in this paper.

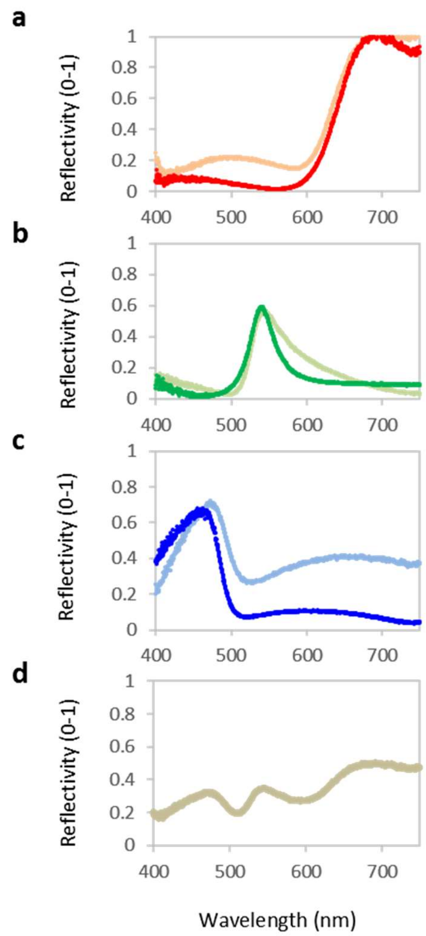


**Figure 3 – a,b,c.** Spectrum measurements of RGB static film prototypes in both their pale and saturated phase. **d**. Resulting white state with an identical 1/3 subpixels architecture.

As previously discussed, an SRD display requires an optical shutter in order to achieve full RGBWK colour performance using an adjacent sub-pixel primaries type architecture, as shown in Figure 4**a**. It is known that such an architecture could limit the amount of brightness of a reflective display as well as delivering an optically unappealing white state. We fabricated a series of 9 static RGB subpixel like structures in order to quantify the performance of a future SRD display with an adjacent subpixels architecture, as shown in Figure 4**b**. Each R, G and B subpixel structure has 100 μm width and 1 cm length, fabricated using a standard three steps optical lithography process. A microscope picture of the final sample comprising the three lithographically defined R, G and B subpixels can be found in the center of Figure 4**b**. A total of 9 structures were fabricated on a single substrate named “colour tiles”. Each part of the colour tiles sample was then selectively covered with a black resist mask to show:

1. A white state when no resist was used. Such state would resemble a pixel with all subpixels in the white state and all 3 optical shutters left in their clear state. Pictures of a white state sample, from both normal and tilted angles can be found in Figure 4**c**.
2. A black state when resist was deposited on all subpixels. This state would resemble a pixel with all shutters set in their dark state. Figure 4**b** shows the black subpixels in the center line of the colour tiles sample.
3. A red, green and blue state when resist was deposited on 2 out of 3 subpixels leaving the remaining visible pixel the defining colour pixel. Figure 4**b** shows the G, B and R states in the top row of the colour tiles sample.
4. A cyan, yellow and magenta state when resist was deposited on only 1 out of 3 subpixels. Figure 4**b** shows the M, Y and C states in the bottom row of the colour tiles sample.

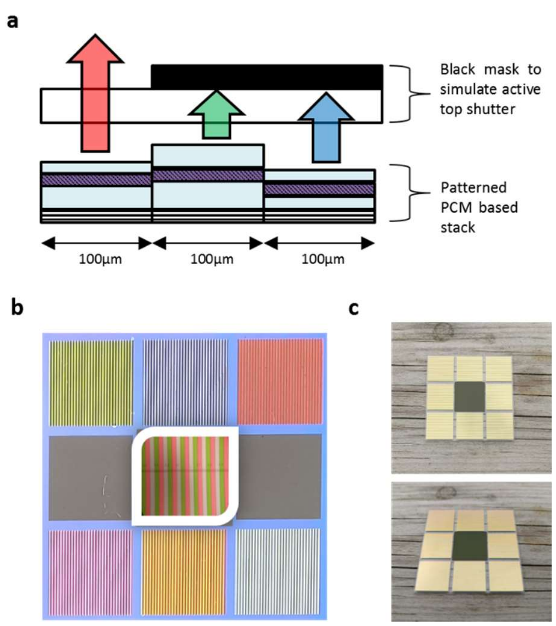


**Figure 4 – a.** Proposed architecture for a full RGBWK SRD reflective display. 3 RGB subpixels define the gamut and bright white state while an integrated top optical shutter is used for the black and grey scales.

## 5. IMPACT AND CONCLUSION

The current state of the art reflective display technologies, primarily electrophoretic and reflective liquid crystal mode displays, are inherently unable to deliver high colour gamut (>40%), high brightness white state and video on the same platform concurrently. The results shown in this paper are the first experimental evidence of the potential for SRD to achieve those combined characteristics at the same time without compromising in optical performance. Improved colour characteristics, especially in terms of brightness contrast, are expected to become available as the technology maturates and a deeper understanding of the manufacturing processes is achieved. Finally, integrating SRD pixels with standard TFT driven backplanes, over large areas, is another important innovation that remains to be demonstrated.

## REFERENCES


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