Luminescent Enhancement of Reflective Displays

Gary A. Gibson, Xia Sheng, Pramit Manna, Dick Henze

HP Laboratories
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Gary A. Gibson, Xia Sheng, Pramit Manna, Dick Henze
Hewlett Packard Laboratories
Palo Alto, CA USA
gary.gibson@hp.com

Abstract— **Achieving bright reflected colors is a major challenge for reflective display technologies. We demonstrate the potential for photoluminescence to enhance the color performance of simple reflective displays based on electrophoretic or dichroic guest-host technologies.**

I. INTRODUCTION

Worldwide interest in low-power, daylight-readable reflective displays is rapidly accelerating with the market acceptance of e-Book readers. Commercial reflective displays are currently monochrome, such as the E-Ink Vizplex film used in Amazon's Kindle, or capable of only dim color gamuts, such as the Fujitsu FLEPia. High-quality color technology would be rapidly adopted in existing reflective display markets and would enable new markets such as advertising, and product categories such as interactive electronic paper (ePaper). Technical breakthroughs are required to enable wide, bright color gamuts. Device architectures using side-by-side colored sub-pixels face a fundamental challenge because they use only a fraction of the display area to reflect incident light of a given color and are, therefore, unacceptably dark. Device architectures employing three or more stacked color primaries suffer from absorptive losses in their many electrode and substrate layers that degrade brightness, and are more expensive to manufacture.

Existing reflective color ePaper technologies create a desired color by reflecting a portion of the incident spectrum while absorbing undesired wavelengths. We are investigating methods for harvesting the absorbed light, which is otherwise wasted, by converting it to the desired wavelengths via photoluminescence. To this end, we are developing highly luminescent composites and the means to incorporate them in both single and multiple layer reflective pixel configurations that utilize existing electro-optic shutter technologies.

II. EXAMPLE PIXEL ARCHITECTURE

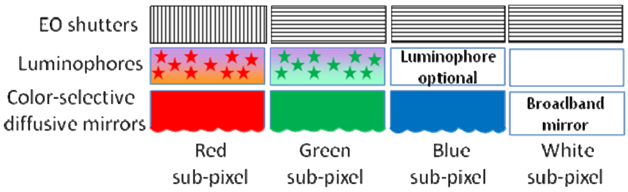

Figure 1. Cross-sectional schematic of simple reflective pixel utilizing luminescence.

An example pixel configuration that incorporates the benefits of luminescent light-harvesting is shown in Figure 1. Here luminescent films are positioned below electro-optic (EO) shutters that can be switched from opaque (black) to clear through shades of gray. Appropriate EO shutter technologies include those developed for reflective display configurations that require transparent states, such as dichroic guest-liquid crystal host shutters [1] and in-plane electrophoretic [2] and electro-wetting technologies [3]. To display red, the red sub-pixel's shutter is opened while those of the other sub-pixels are closed. The luminophores within the red sub-pixel absorb the incident light from the near-UV to orange, and re-emit it as longer wavelength red light. A mirror is used below the luminescent film to reflect both downward directed luminescence and the ambient red light. This approach can provide a several-fold increase in the perceived intensity of red light returned to the viewer relative to a purely reflective technology. Green is produced in a similar fashion by opening just the green sub-pixel's shutter. The luminophore in this cell absorbs near-UV through cyan and emits green, with a green reflector positioned below it. This again provides a large increase in the efficiency with which the available light is used, in particular because short wavelengths are converted to green wavelengths near the peak of the human photopic response at 555 nm. The benefit of using luminescent materials in the blue sub-pixel is minimal in most cases due to the limited light available for harvesting at shorter wavelengths. Thus, a simple blue reflector suffices and only red and green luminescent systems need be developed for the overall device. The relative areas of the sub-pixels can be adjusted to compensate for differences in the luminescent gain obtained for the different colors. The white sub-pixel is added to improve the brightness of the white state.

III. LUMINESCENT MATERIALS

Three factors are critical to the successful use of luminescence in boosting the brightness of any reflective color display. First, the luminophores must absorb a majority of the incident light over a wide range of wavelengths shorter than their emission wavelength. Second, the luminophores' internal emission efficiency, η_{int}, must be high so that they re-emit most of the light they absorb. Finally, a reasonable fraction, η_{out}, of the emitted light must be coupled out of the device without being trapped in waveguide modes by total internal reflection. We have made significant progress in demonstrating the needed performance in all three of these areas.

In general, luminescent materials that efficiently emit at a desired wavelength while absorbing most of the shorter wavelength incident light do not exist. To circumvent this problem, we are developing material combinations where one or more species act as absorbers that transfer the light they harvest to a highly efficient emitting species via energy transfer processes such as Förster exchange [4]. This allows us to tailor the composite's absorption spectrum while maintaining a high η_{int}. Using this mechanism, we have successfully demonstrated nearly 100% energy transfer from broadly absorbing series of coumarin and pyromethene dyes to highly efficient emitters such as sulforhodamine 640 or perylene red dispersed within a transparent host polymer film. Our measurements indicate that η_{int} of these dyes in the polymer films approaches the values of 80-100% reported for the same dyes in solution. The photofastness of these dye-polymer combinations also appears promising. We are currently developing luminescent material systems compatible with patterning methods capable of producing side-by-side sub-pixel elements.

To improve the out-coupling of the luminescent light we are tailoring the properties of the diffusive mirror structures used below our luminescent layers (Fig. 1). These mirrors randomize the propagation direction of light trapped in waveguide modes, thereby allowing much of it to eventually escape. By engineering the topography of the diffusive mirror to control its range of reflection angles one can optimize the luminescent out-coupling while minimizing the loss of non-absorbed incident wavelengths that should be directly reflected. We have achieved η_{out} ~80% using mirrors that diffuse light over a characteristic angle of 30°.

These successes have allowed us to demonstrate color swatches that are brighter than can be achieved using colored reflectors. Figure 2 shows that the peak apparent reflectance for swatches made from our dye-polymer combinations on diffusive mirrors can exceed 200%. The color coordinates of these swatches compare favorably with the Specification for Newspaper Advertising (SNAP) standards. In fact, the CIE lightness (L*) values of these swatches are superior to theoretically perfect colored reflectors with similar color coordinates. Note that these swatches show minimal illuminant metamerism because their brightness is dependent on a broad spectrum of absorbed wavelengths and their emission wavelength is independent of the illumination spectrum.

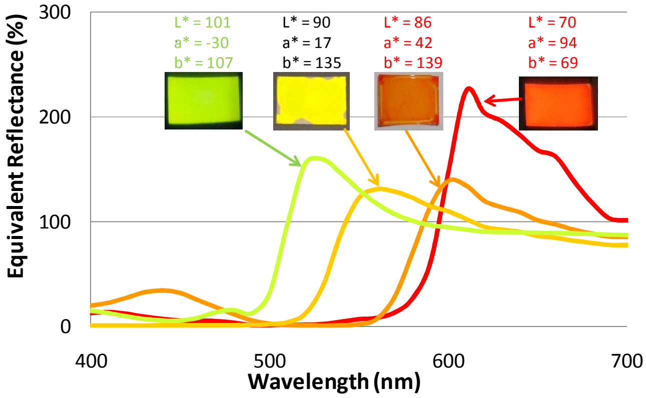

Figure 2. Equivalent reflectance of four luminescent dye-polymer composites. Lightness (L*) of swatches is greater than achievable for perfect colored reflectors with same (a*, b*). Green swatch spectrum includes red wavelengths that would not be reflected in a display. Spectra taken with diffuse illumination and normal detection.

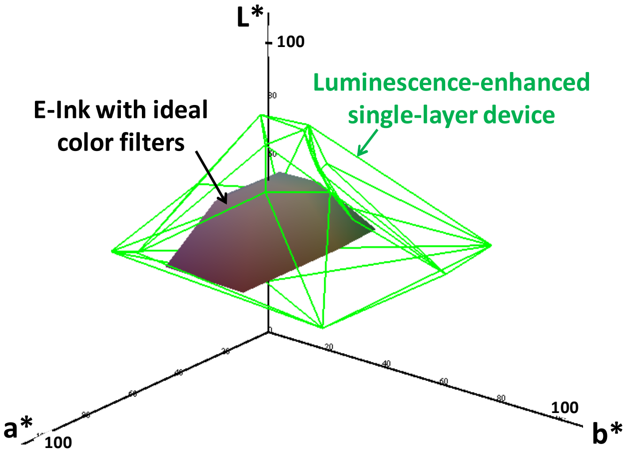

Figure 3. Estimated color gamut (green wireframe) for device of Fig. 1. This gamut compares favorably with that estimated for a color-filter implementation above E-Ink Vizplex film (solid).

IV. PREDICTED PERFORMANCE

To date, the most successful commercial reflective displays use the monochrome electrophoretic film of E-Ink Corporation. To achieve color, color filters can be added over their black-to-white pixels. Figure 3 compares an estimate for the color gamut attainable with this approach to that predicted for the device of Figure 1. The latter assumes achieved η_{int} and η_{out} values for red and green sub-pixels and conservative estimates for the shutter performance.

V. CONCLUSION

We are developing lightfast, ink-jettable red and green-emitting dye/polymer combinations capable of greatly boosting the brightness and color saturation of reflective displays.

REFERENCES

[1] [1] D.L. White and G.N. Taylor, "New absorptive mode reflective liquid. crystal display device," J. Appl. Phys., vol. 45, 4718 (1974)

[2] [2] J. Chung, "Microcup electrophoretic displays, grayscale, and color rendition", IDW '03, 243 (2003).

[3] [3] R.A. Hayes, and B. J. Feenstra, "Video speed electronic paper based on electrowetting", Nature 425, 383 (2003).

[4] [4] T. Förster, Ann. Phys. 437, 55 (1948).