

Color Electrophoretic Display for Outdoor Signage

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Abstract

E Ink has developed a full-color electrophoretic display platform with excellent color and contrast ratio performance targeting outdoor signage applications. Full color displays utilizing colored particles, no color filter array, and a single TFT array backplane have previously been demonstrated in a microcup structure using E Ink's ACeP technology and black-and-white displays are well-established using microcapsule structures. This new E Ink platform combines the ACeP pigment color making mechanisms with the microcapsule structure to enable large area displays (up to 75") and wide operating range (-20°C to 65°C).

Author Keywords

E Ink; microcapsules; electrophoretic display; full color; outdoor signage; digital out of home; DOOH; Advanced Color ePaper; ACeP®; pigment; reflective

1. Introduction

The growing demand for dynamic, energy-efficient, and environmentally friendly outdoor signage has led to the exploration of various display technologies, with electrophoretic displays (EPDs) emerging as an attractive candidate, even possibly an ideal solution [1].

One challenge in this application is ensuring readability in a wide variety of lighting conditions. Emissive display technologies such as liquid crystal displays (LCDs) and light-emitting diodes (LEDs) must be bright enough to compete with full sun illumination and must continuously emit light even when the image content is not changing, necessitating the consumption of large amounts of energy. In contrast, EPDs reflect ambient light and consume no energy when the image content is static and not being refreshed. This gives them an efficiency that is critical for long-term outdoor installations where access to power may be limited.

Partly in response to the growing need for reflective signage, E Ink reflective displays have evolved from black-and-white to spot-color and finally to full color. This paper describes a further development in this area that inherits features from three predecessor embodiments that are described in additional detail below.

The Spectra™ 6 platform, released in 2024, provides vibrant colors, a high black/white contrast, and image quality approaching that of magazine print. Spectra 6 features red, yellow, blue and white particles contained within a Microcup® array. When mixed in carefully controlled combinations these pigments produce 6 color states (red, green, blue, yellow, white and black) that are dithered together to make full-color images [2].

The Kaleido™ platform utilizes a color filter array (CFA) applied on top of a black and white microcapsule film to display full color images. This platform has the inherent advantages conferred by the capsule architecture, including a high display fill factor, mechanical flexibility, large area capability, and wide operating temperature range [3]. In this case color is achieved by area sharing. The presence of the color filter reduces the reflectivity of the white state, but this can be compensated for by well-designed front lighting. Because the outdoor signage application is dominated by

larger signs with correspondingly large pixel sizes, any parallax associated with gap between the CFA and the electrophoretic ink layer is effectively minimized.

Additionally, E Ink has developed the Gallery™ platform using an Advanced Color ePaper (ACeP) pigment system capable of producing any color at any pixel location. In this embodiment, the locations of three absorptive colored pigments (cyan, magenta, yellow) relative to a light-scattering white pigment are manipulated within a microcup array. The color states are formed through at least 8 pigment arrangements to form the minimal color set necessary for a full color dithered image, as detailed previously [4]. Intermediate positioning of the transparent pigments produces additional colors, reducing dithered pattern visibility and improving image quality [5].

The newly developed E Ink Marquee™ platform for outdoor signage combines inherent advantages of two of these previous platforms: the ACeP pigment color-forming mechanisms of Gallery and the microcapsule structure of black-and-white or Kaleido displays. Because microcapsules pack more densely than microcups in an array (see Figure 1), they enable white states with higher reflectivity [6]. Using the ACeP pigment system, the capsules produce vibrant colors at each pixel. The platform currently uses 8 - 32 colors per pixel but is capable of many more. The capsule architecture gives Marquee large area capability and a wide operating temperature range. Marquee produces reflectivity values approaching those of black-and-white displays with color quality approaching that of Spectra 6.

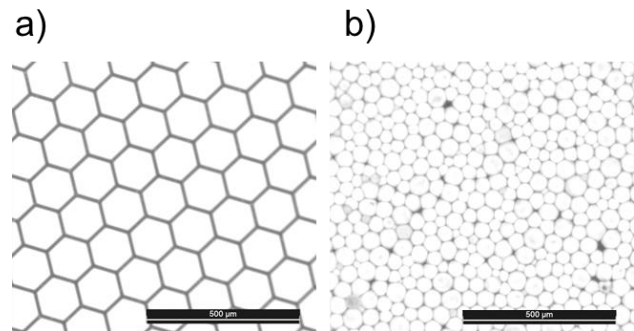


Figure 1. Microcup versus microcapsule coated fill factor a) microcups with 80% switching area b) microcapsules with 92% switching area

2. E Ink Marquee™: Concept and Mechanism

The Marquee imaging film has the structure shown in cross-section (not to scale) in Figure 2. From the top (viewing) side to the bottom, a display module typically comprises a protective film (including, for example, a barrier to the ingress of water and oxygen and a UV-absorber), an optically clear adhesive, the Marquee imaging film, and a backplane bearing the pixelated electrodes, typically a thin-film transistor (TFT) array. The Marquee imaging film itself consists of a transparent substrate coated with a transparent

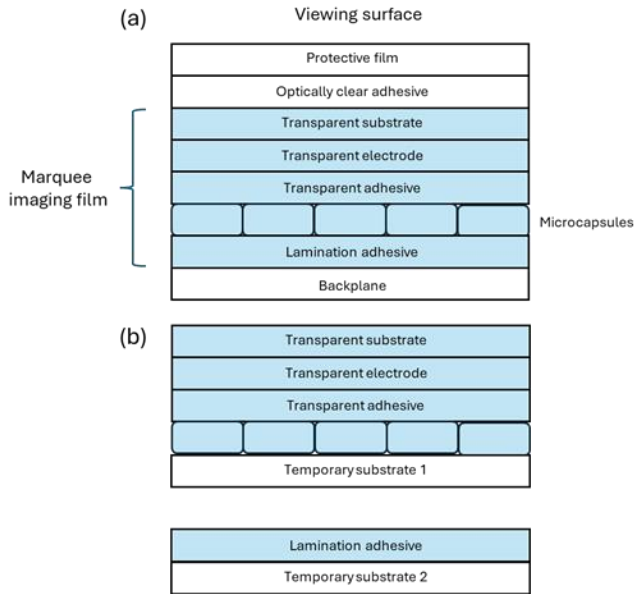


Figure 2. Structure of Marquee imaging film a) as incorporated into a display module; b) intermediate steps in device construction

electrode (typically PET/ITO), a specially formulated viewing-side adhesive, the encapsulated ink layer, and a backplane adhesive layer. The ink layer consists of microcapsules containing the colored and white particles in a nonpolar solvent, as well as binder material and additives for optimal color, reliability, and electro-optical performance over a wide temperature range.

The viewing-side adhesive layer plays an important role in enabling a wide operating temperature range for the platform, as it lies in the electrical path between the transparent electrode and the backplane. If the electrical conductivity in this layer varies too much with temperature it may become impossible to provide reasonable low-temperature performance without incurring problems at high temperatures. The viewing-side adhesive layer in the Marquee imaging film has been designed to avoid such potential problems (see Figure 3) and additionally provides excellent long-term reliability when subjected to a variety of stress conditions.

The Marquee imaging film is made through a series of coating and lamination steps achieved with roll-to-roll processing: (1) a slurry of capsules, binder, and additives is coated onto a temporary substrate bearing a release layer (temporary substrate 1 in the Figure) and dried; (2) the dried material is coated with the new viewing-side adhesive; (3) PET-ITO is laminated to the top surface; and finally, (4) the temporary substrate is removed and the backplane adhesive layer, also coated onto a temporary substrate bearing a release layer (temporary substrate 2 in the Figure) is laminated to the stack. Once this intermediate structure has been cut to size, temporary substrate 2 is removed and the Marquee imaging film is laminated to a backplane.

The capsules can be coated in a continuous pass without interruption, enabling arbitrarily long display modules in the downweb direction. The display dimensions are only limited by the width of the coating (see Figure 4).

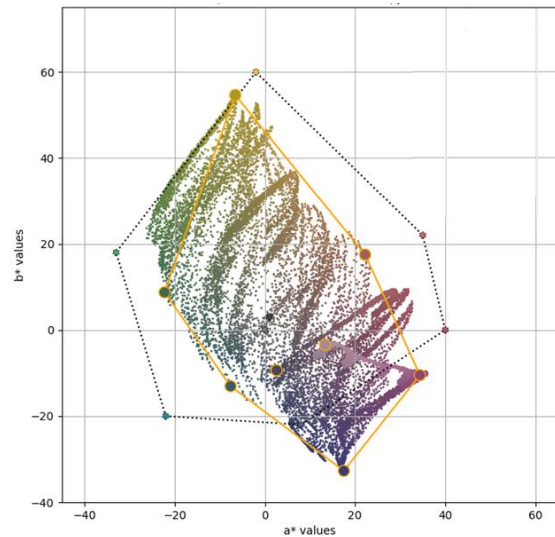


Figure 3. Color gamut (a^*/b^* projection) at -20°C with Marquee imaging film made with new viewing-side adhesive designed for improved conductivity at low temperature



Figure 4. Demonstration of Marquee at 75" diagonal dimensions

3. Electro-optical performance of Marquee module

The ink system design and electrophoretic display composition described here was built into modules for performance assessment. A 6" diagonal, 79ppi oxide TFT array backplane was used, simulating the design of the 75" backplanes targeted for outdoor signage in resolution and electrical characteristics. The display was addressed with three different positive and three different negative

voltages, not exceeding +/- 24V, and the waveform was tuned to produce, in the simplest case, the 8 primary color states described above. With more complex driving strategies, more arrangements of the colored pigments were possible, giving in one instance 32 but in principle almost arbitrarily large numbers of different colors within the gamut volume of the display.

Performance for this configuration was confirmed for an operating temperature window from -20°C to 65°C. As shown in figure 5, a module using a 40.5" diagonal oxide TFT array backplane at 94ppi was constructed, giving similar imaging performance to the smaller display.

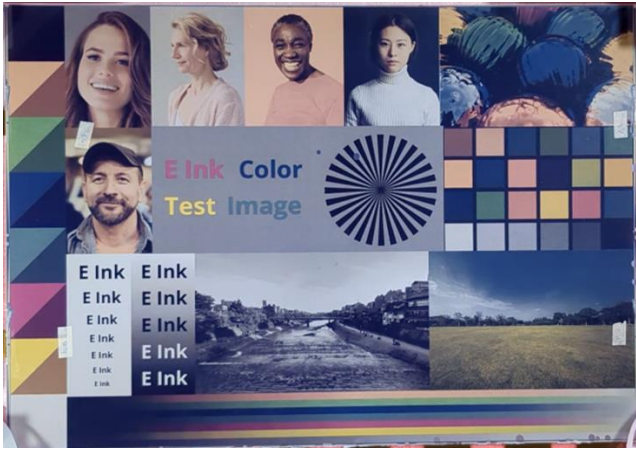


Figure 5. Photograph of a full color image on a 40.5" diagonal Marquee display module at 94ppi.

Figure 6 and Table 1 detail the color gamut and contrast ratio performance for this Marquee implementation as measured at 25°C. When limited to the 8 primary color states (yellow, green, cyan, blue, magenta, red, black, and white), this display is capable of achieving a color gamut volume of nearly 35,000 dE³ (in CIEL*a*b* color space), with a contrast ratio greater than 22:1. When additional palette colors are used, up to 32 in this implementation, the gamut volume is expanded to about 40,000 dE³ while maintaining the same contrast ratio. It is planned to optimize a front light and light guide plate for this platform, which would be expected to boost color performance still further.

Table 1. Gamut (dE³) and Contrast Ratio for 6" display module using 8- and 32-color palettes for image rendering.

	8-color palette	32-color palette
Gamut	34743	39904
CR	22	22

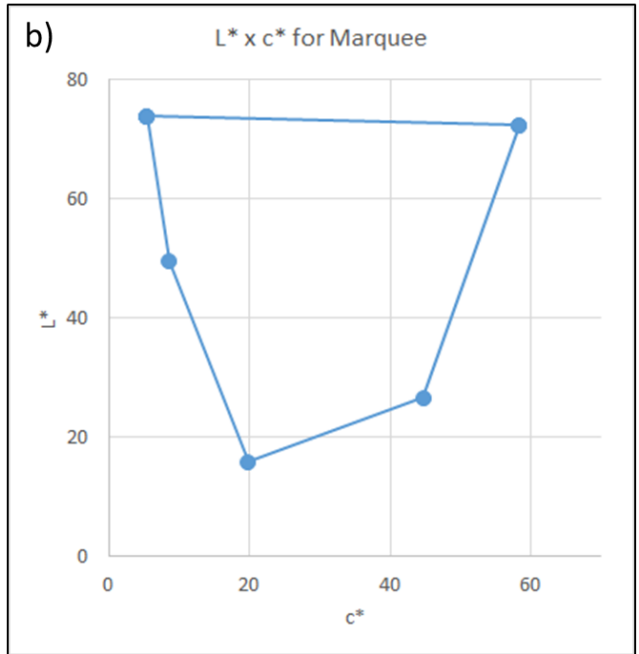
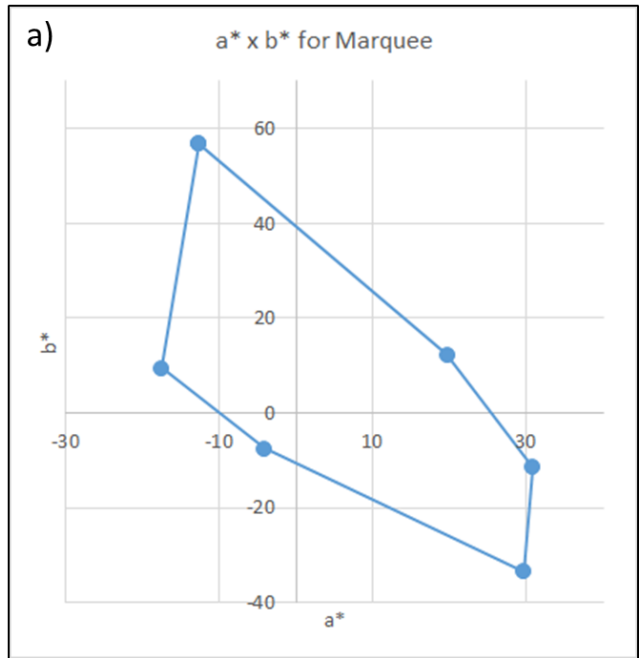


Figure 6. Color gamut available from a 6" display module, showing a) a* versus b* in CIEL*a*b* color space, and b) L* versus c* in the same color space.

Future work in the Marquee platform will continue to optimize the constituent materials of the ink and the adhesive layers, imparting further improvements in color and speed and an even wider operating temperature window.

Finally, the performance of the overall display would be improved if the colors made by each individual capsule were made more uniform. Figure 7 shows an evaluation of the capability of individual capsules in one experimental sample. As can be seen in the Figure, there was a significant variability in the color gamut achieved by each individual capsule when the whole array was

addressed using the same waveform. Through improvements in the methods to produce capsules, together with refinements in the ink layer coating processes, we expect that color performance of the display will reach that of a single optimized capsule and thereby be significantly enhanced.

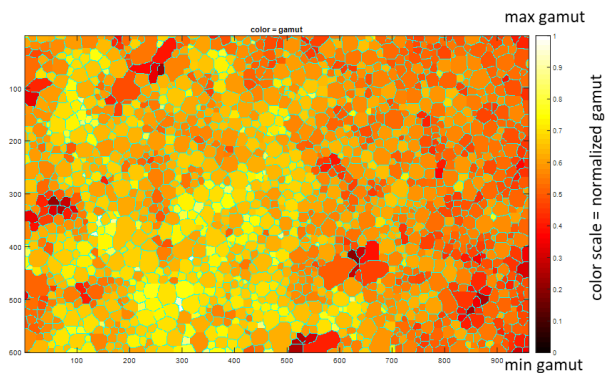


Figure 7. Normalized color gamut measured in individual capsule areas in an experimental Marquee display

4. Conclusions

E Ink Marquee, a full color, microcapsule-based electrophoretic display platform suitable for large-sized modules and wide operating temperature range has been developed by E Ink. The first commercial samples are scheduled to be released in 2025. Displays of up to 40.5" diagonal have already been demonstrated with the possibility of extending to 75". The operating temperature window and reliability support outdoor signage and DOOH markets.

5. Acknowledgements

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