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A Five-Color Electrophoretic Display

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ABSTRACT

The unveiling of the four-particle electrophoretic display, Spectra™ 3100 led to the development of an additional orange color using the same image film. A bright orange can be generated by mixing yellow and red particles through an advanced driving algorithm and demonstrated excellent color consistency from 0°C to 40°C.

1 Introduction

Electrophoretic Display (EPD) is the most commercially adopted ePaper technology that offers ultra-low power consumption and comparable optical properties to printed paper such as wide viewing angle, low eye strain viewing, as well as excellent readability in bright sunlight.[1] EPD is best noted for its ability to hold an image without power, which is one of the most important factors contributing to its ultra-low power consumption. [2] Due to the reflective display mechanism, EPD is able to operate without a light source, which is another key contributing factor to its ultra-low power consumption. With some applications, such as ereaders, front light can be incorporated into the device to enhance the optical performance of EPD with a small fraction of power consumption increase as front light is more efficient than backlight due to its high utilization rate.

An EPD electrical shelf label device can be powered by a coin cell battery for years under low update frequencies. Solar energy can be harvested to power small or large display EPD panels for outdoor signage applications. E Ink has further improved upon this unique characteristic to develop battery-less solutions that utilize wireless connectivity. Using wireless technologies such as NFC or UHF, power can be delivered directly to the EPD device to refresh the screen. The ability to use EPD without having to connect to a power line allows easy integration into new applications. Through these sustainability features, we continue to witness a broader adoption of EPD across market segments, including retail, transportation, health care, and manufacturing, for digital transition and business improvement through the use of big data.

There is a strong demand for color EPDs. Black and white text can convey information. Color offers additional benefits, such as attracting attention and triggering emotions. E Ink Kaleido™, E Ink Gallery™ and E Ink Spectra™ are three color EPD product lines offered by E Ink to meet different customer requirements. Kaleido™ features color filter arrays printed on top of traditional black and white EPDs while Spectra™ [3] and Gallery™ [4],[5] are based on multi-particle electrophoretic technologies to produce color that originates from the color particles in the electrophoretic ink. Spectra™ 3100,[6] launched in 2021, targets electronic shelf label applications and signage applications by providing highly saturated red and yellow colors and a high black and white contrast ratio of 30. Specially engineered black, white, red and yellow particles in the electrophoretic ink respond to different electric fields to show their intrinsic colors on the viewing side of the display. The imaging film was manufactured by a roll-to-roll process based on Microcup® technology. [7]

2 FUNDAMENTALS OF SPECTRA 3100 Plus ELECTROPHORETIC DISPLAY

Spectra™ 3100 Plus was released in 2022 along with an advanced driving algorithm to further enhance the product with a bright orange color.

2.1 Electrophoretic ink design and mechanism

The Spectra™ 3100 Plus uses the same ink as the previous generation, which consists of four opaque color particles in the electrophoretic ink dispersion. There are two positively charged particles and two negatively charged particles. The black and the red particles are positively charged, and the black has higher charge compared with the red. The yellow and the white particles are negatively charged, and the yellow is more negative compared with the white. The particle configurations in the five optical states are shown in Figure 1. All four color particles exhibit excellent hiding power, thus only the first few layers of particles near the viewing side contribute to the optical performance of the display. Orange color was generated by uniformly mixing of the red and yellow particles and bringing them to the viewing side.

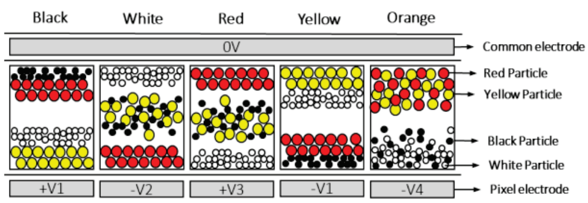

Fig.1 Optical States of Spectra™ 3100 Plus

2.2 Mixing of color particles of excellent hiding power

The four particles in this electrophoretic ink have been engineered to carry different amounts of surface charge and to have different protective colloids, surface protection functionalities, densities, and sizes. By controlling and utilizing these variables, different interactions among the particles and responses to different electrical fields can be maneuvered. Using advanced algorithms, any two particles in the ink can be mixed with a specific ratio and brought to the viewing side. This will produce gray tones or various tints and shades of red and yellow. Fig. 2 illustrates all the achievable particle mixing combinations on the imaging film. A number of examples of optical states from particle mixing were demonstrated on an active matrix module, as shown in Fig. 3.

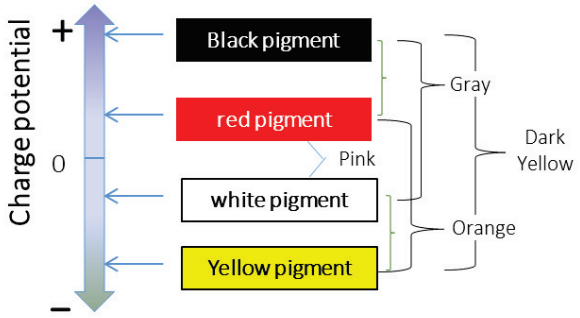

Fig. 2 Mixing of any two color particles in the four-particle Spectra^{TM} 3100 electrophoretic ink

In Figure 3, the left, center and right sections of the module showed varied yellow shades, different shades of red and neutral gray tones with varied reflectance. They are generated by advanced driving algorithms which ensure that only two colors are combined together in a controlled ratio with no contamination from other colors. As an example, the gray levels are neutral without tint values, suggesting a controlled mixing of the black and white particles without contamination of the red and yellow particles.

Fig. 3 Various ratios of color particle mixing

In Spectra^{TM} 3100 Plus, we have chosen to introduce the Orange color into the product offering, because in addition to red and yellow, orange is a popular color in the retail market to draw customers' attention.

2.3 Advanced Driving Algorithm to show bright orange color

Previously, we discussed how to achieve black, white, red, and yellow states.[6] Figure 4 illustrates how an intermediate yellow state can lead to the bright orange state via a saturated red state.

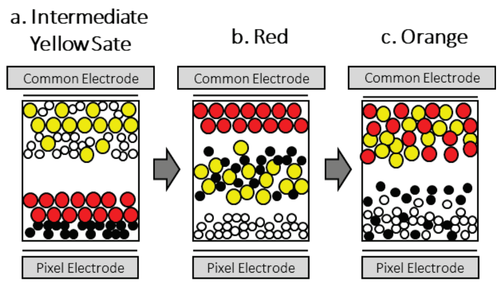

Fig. 4 Advanced driving algorithm to achieve excellent orange color

A strong negative potential is first applied to the pixel electrode relative to the common electrode on the viewing side. White and yellow particles then move toward the viewing side to reach an intermediate yellow state, which is not the best saturated yellow. A weaker positive potential is then applied to the pixel electrode, causing yellow and white particles to move toward the bottom electrode, while red and black particles move towards the viewing side. Due to the strong particle-particle interactions, the black particle moves at a slower speed than the red particle. As depicted in Figure 4b, this results in a saturated red color state. Following this, as shown in Figure 4c, a weak negative potential is applied to bring the yellow particle to the viewing side, where it will mix with the red particle and create the bright orange color.

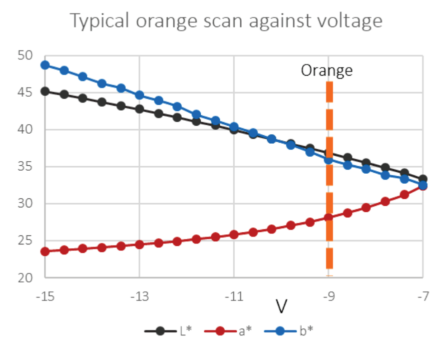

Fig. 5 Orange color performance in respective to the driving voltage

The typical orange voltage scan curve in Figure 5 illustrates that with a fixed driving pulse length, the hue of the color orange is dependent upon the driving voltage in the last phase of Fig. 4c. Higher field strength results in a yellowish orange, while lower field strength leads to reddish orange. This provides a lever to use voltage adjustment in production to reach a consistent orange color. A separate voltage level is set aside for the orange color in the power management IC. The specific orange color was selected based on its visual appeal, and color contrast to the other four optical states.

3 Results

This section describes the electro-optical property of Spectra^{TM} 3100 Plus modules.

3.1 Orange color performance

Figure 7 shows the chromaticity of Spectra^{TM} 3100 Plus's five optical states, measured at 20°C by Minolta CM-700D on a display module under a maximum driving voltage of +/-15V. Typical updating time at ambient is 12 seconds, with a black and white contrast ratio of 30.

Optical State	x	y	Y
White State	0.31	0.34	35.71
Black State	0.32	0.29	1.23
Red State	0.56	0.34	6.65
Yellow State	0.48	0.45	28.5
Orange State	0.51	0.37	9.01

Optical State	L*	a*	b*
White State	66.3	-2	2.1
Black State	10.77	6.1	-3.1
Red State	31	40.9	29.9
Yellow State	60.3	12.4	68.5
Orange State	36.0	29.0	31.5

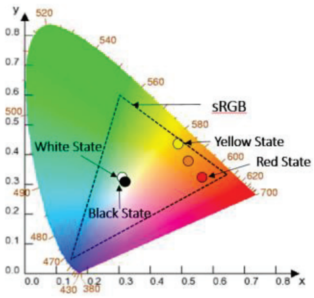

Fig. 6 Optical performance of the five optical states

3.2 Orange color performance across the operation temperature

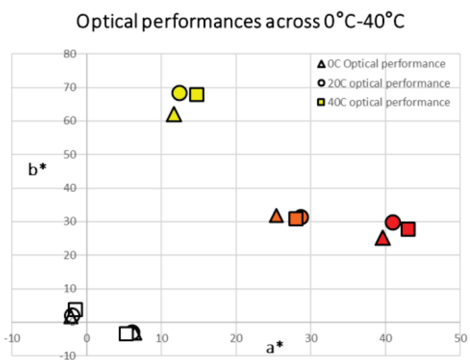

Fig. 7 Optical performance of the five optical states across the operation temperature of 0°C to 40°C

Spectra^{TM} 3100 shows consistent optical performance when operating across 0°C – 40°C, as shown in Figure 7. Orange performance is as stable as the other two color states. This requires the particle charge, mobility and the particle-particle interactions to be stable across the operation temperature.

4 Application

Spectra^{TM} 3100 Plus is ideal for applications such as electronic shelf labels and smart signage due to its high contrast ratio and highly saturated highlight colors.

4.1 Application in Electronic Shelf Label

A variety of display sizes, including 1.64-inch, 2.36-inch, 3-inch, 4.37-inch, 7.3-inch, and 8.14-inch were offered. Retailers can choose a suitable size of ePaper module for their application needs. A range of All-in-one (AIO) driver IC was co-developed with IC partners to support the additional color capability. These AIO driver IC include functions of TFT source/gate drivers, display timing controller, power management, security protections and memory to store the driving algorithms.

Fig. 8 Spectra^{TM} 3100 Plus modules for electronic shelf label application

4.2 Application for Signage application

First large size Spectra 3100 Plus module of 25.3 inch was introduced for smart signage application. At the same resolution, dithered images with three color states of yellow, orange and red exhibits higher image quality than those based on two color states of yellow and red.

Fig. 9 25.3 inch Spectra^{TM} 3100 Plus module

5 Conclusions

Spectra^{TM} 3100 Plus is a four-particle electrophoretic display to show five optical states of white, black, red, orange and yellow under a maximum driving voltage of 15V. An advanced driving algorithm was developed to show bright orange color by mixing the two color particles of red and yellow uniformly at the viewing side. The orange color showed excellent optical consistency across the operation temperature of 0°C to 40°C.

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