Towards a Colored Electronic Paper through a Fabrication of Color Microencapsulated Electrophoretic Display Panel

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Abstract
The color electronic paper display panel, which is fabricated with about 300 μm width of each color pixel strip and is possible to integrated into a fundamental full-color flexible display prototype, is presented. The monolayer of close-packed color electrophoretic microcapsules is formed on the ITO electrode. The color pixel strips are composed of each color electrophoretic microcapsules (i.e., cyan, magenta, yellow, and black).

1. Introduction
There are several different technologies to realize the electronic paper such as an in-plane electrophoretic display, a microencapsulated electrophoretic display (MC-EPD) [1,2], a twisting ball display [3], an electrochromic display [4], and an electrowetting display [5]. However among these investigations, the efforts to develop colored electronic paper display have been not tried extensively. The MC-EPD utilizing a color filter array [6], a photo-addressable electronic paper [7], and electrochromic display have been reported to be achieved multiple color states. By controlling the status of the light modulator in AMLCD panel, the backlight can be blocked or transmitted through the color filter on the RGB subpixels to form color image. The same concept is applicable for MC-EPD, where the MC-EPD used the color filter exhibits true paper-like performance i.e., largely insensitive to illumination angle. However, the light source for the reflective MC-EPD is not strong in intensity; this architecture may result in problem of low brightness and low contrast ratio. Only abut 1/3 of the reflected light from the MC-EPD panel can pass through the color filter [8].

To overcome these limits, the colored electronic paper displays are possible to be realized by superimposing the yellow-magenta-cyan (YMC) layers horizontally or vertically. Since there is no color filter to reduce the reflected light, the color microcapsule sup-pixel structure provides excellent opportunity to enhance imaging luminance of a full color reflective display. For the colored state, each color particles are moved up toward upper transparent electrode.

This study describes the fabrication of each color pixel strip that is possible to provide a full-color electronic paper without the color filter by superimposing the yellow-magenta-cyan layers horizontally as shown in Figure 1.

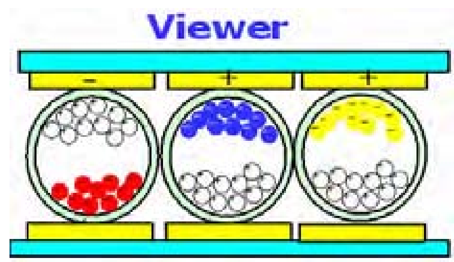

Figure 1. Schematic section of the color MC-EPD structure utilizing the YMC color electrophoretic ink sub-pixel strips.

2. Color microcapsule Synthesis
The high contrast-ratio colored electrophoretic particle suspension microcapsules show above 4 vs 1 of contrast ratio. Based on the color particle movement results in the electrophoretic cell tests, we prepared each color microcapsules which are improved the dispersion stability, the optical responses, and response time. We used the polymer coated TiO_2 pigment particle with the average particle size of 0.42 μm as the white pigment. The TiO_2/Polymer hybrid particles were prepared through a two-stage dispersion polymerization technique [9].

The color particles are obtained from Soken Chemicals Co. (Japan) and DPI Solutions Co. (Korea).

Cyan, magenta, and yellow microcapsules containing the polymer-coated TiO_2 (negative polarity) and each color particles (positive polarity) suspension as a core material, were manufactured. The obtained microcapsules have the diameter of 50 ~ 200 µm. The microcapsules show a good mechanical strength and thermal property. The apparent optical images of the color microcapsules are observed with an optical microscope.

3. Color Sub-pixel Manufacturing Process

3.1 Each Monochromic Prototype

Each color microcapsules are blended with aqueous urethane binder. The mixture is applied on the ITO electrode substrate used the doctor blade. After the layer of close-packed microcapsules is baked, the other electrode substrate is laminated on the capsule layer to be formed sandwich type. Figure 2 shows a series of microphotographs of two different colored-microcapsules layers containing cyan/white and magenta/white pigment pairs, which the different symbols (in Figure 2(a)) and word (in Figue 2(b)) have been electronically addressed. The synthesized microcapsules were sieved to have a mean capsule size of 70 ± 10 µm. The close-packed electrophoretic microcapsule monolayers are applied on the ITO common electrode substrate by a doctor blade with 100 µm gap.

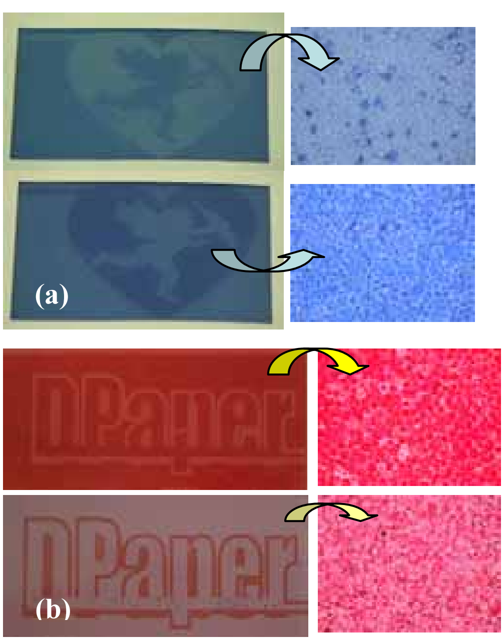

Figure 2. Optical microscopic photograph of the layer of two different colored electrophoretic ink.

The cyan/white microcapsule shows the contrast ratio of 6:1, where magenta/white microcapsule is 4:1.

We measured the optical response of the layer of close-packed microcapsule under the DC electric field wave application. Figure 3 shows the optical response of the cyan/white microcapsule layer with ± 30V application.

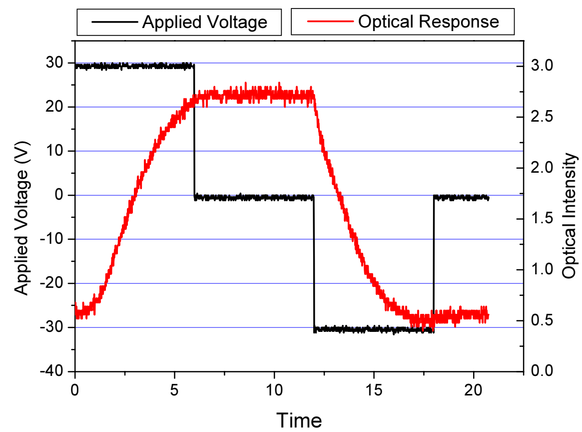

Figure 3. The Optical response of the cyan/white microcapsule layer.

The duration time of each state is one second, respectively. After the electric field is shutdown, the optical state of the microcapsulayer is maintained. This result shows the microcapsule have bistability.

3.2 The Sub-pixel Manufacturing Process

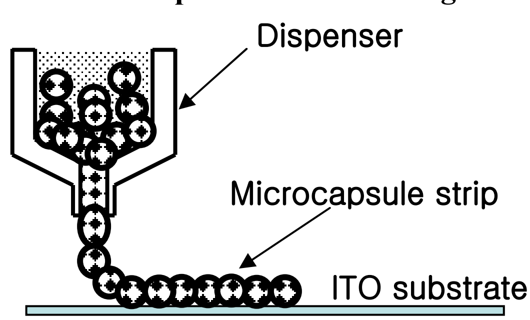

Figure 4. Schematic diagram of the microcapsule dispensing coating.

To fabricate each color pixel strip, we dispensed the microcapsule and binder mixture, of which the composition ratio is critical to control the thickness and width after baking the mixture slurry, on the electrode directly. The dispensing coating has more advantage such as the layer of close-packed microcapsules can be formed on the various electrode patterns. Figure 4 shows the scheme of the dispensing coating method we investigated. The formed magenta/white microcapsule strips is shown in Figure 5.

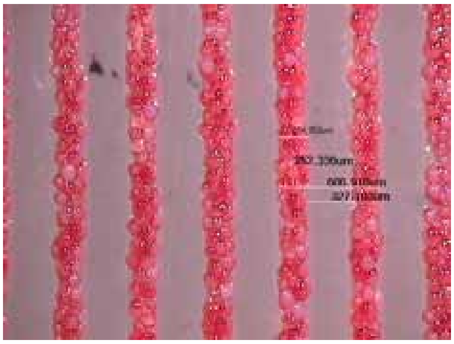

Figure 5. Optical micro-photograph of magenta/white microcapsule strips on ITO electrode.

Microcapsules composing the strip do not be damaged. To conform the dispensing coating method, we applied the electric field to the strips.

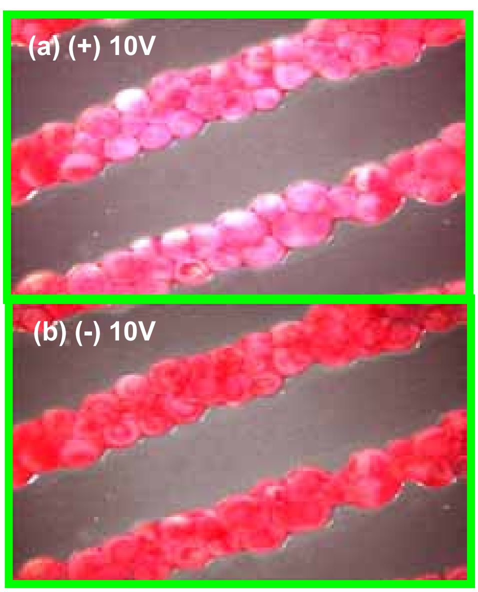

Figure 6. The magenta/white microcapsule strip in the electric field (E = 10 V) ((a) positive field is applied to the upper electrode, (b) negative field is applied to the upper electrode).

Figure 6 is the microphotograph of microcapsule strip suspending both magneta and white particles under electric field. Positive DC electric field (E = 10 V) is applied to the upper electrode, then the white particles moved fast in the upward (Figure 6a). When the field was revised, the magenta particles came to the upper electrode and white particles were pulled back (Figure 6b). The dispensing coating method is recognized as a unique method to form color sub-pixel in the reflective display.

To fabricate the full color display panel, we dispensed the four different microcapsule slurries. Figure 7 shows that the layer of close-packed microcapsules of the four kinds of microcapsules containing different color pigments are striped on the electrode. The width of each electrophoretic ink pixel strip is about 400±50 µm. The edge of electrode line is comparatively smooth.

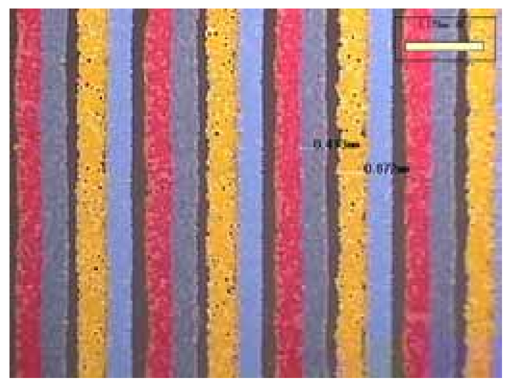

Figure 7. Optical microscopic photograph of the various capsule strips coated on the ITO electrode

4. Conclusion

We developed the technology to enable patterning of electrophoretic ink image pixels which can be fabricated the full-color electronic paper display without a color filter. Each microcapsules have the various color pigments suspension showing the different contrast ratio. 400 µm width mono-layers of close-packed electrophoretic microcapsules consisting the image pixel is formed directly on the electrode. Now we are trying to develop the narrow close-packed microcapsule strip about 200 µm width on the transparent electrode.

5. Acknowledgements
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6. References
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