Color Electrophoretic Image Display Based on Movement of Particles in Color Insulating Liquid

Yoshitaku Yoshimatsu*, Masahiro Masuzawa**, Sakiko Nakamura*, Nobukazu Miyagawa* and Takashi Kitamura*; *Graduate school of Advanced Integration Science, Chiba University, Chiba, Japan, **Research and Development Group, RICOH Company, Ltd., Yokohama, Japan

Abstract

Black and white Electrophoretic Image Display (EPID) is already commercially available as an electronic document viewer, sub-display in cell-phone, etc. Furthermore, Color EPID device coupled with color filters is demonstrated. In this system, there is a problem of the decreasing of the reflection light intensity of white view in order to pass a filter. We have proposed novel Color EPID based on the movement of white and black particles in a colored insulating liquid. We used two kinds of white particles, such as non-electrophoretic polymer particles and negatively charged titanic oxide particles. Non-electrophoretic white particles are used for light scattering and increasing the intensity of the color insulating liquid's luminosity. The display cell is consisted of one common transparent electrode coated on the top grass substrate and two driving electrodes coated on the bottom grass substrate. The movement of charged particles is controlled by the change of polarity of voltage applied to two driving electrodes. Both of white and black particles move to the driving electrodes when each driving electrode is applied to positive and negative voltage, respectively, we can see color image through the common electrode.

Introduction

An electronic paper is investigated as a next generation paper-like-display medium which has good features of both of hard-copy and soft-copy. Electrophoretic Image Display, EPID, is expected as one of the display technology with the feasibility in the electronic paper system. Although black and white EPID is developed in commercial available, Color EPID is yet in the study phase. Though, the Color EPID using a color filter array is demonstrated, there is a problem with a low reflection light intensity at white view due to loss the light pass the color filter. In this paper, we have proposed the new method of a color display using three kinds of particles of black, white, and color, and two driving electrodes in the display cell.

Color EPID

Fig.1 shows the principle of operation of the newly proposed Color EPID [1], [2], [3], [4], [5]. The display cell is made up with a pair of transparent glass substrates on which transparent electrode is coated. The full face of top glass is coated with transparent ITO electrode. The interdigitated electrodes which are patterned two electrodes alternately such as a comb are used for the driving electrodes. Thereby, one common electrode is on the top glass and two driving electrodes are on the bottom glass. The distance between pair electrodes is kept constant by spacer. Three kinds of particles, black and two kinds of white are dispersed in a color insulating liquid. We use two kinds of white particles which are not charged and negatively charged in a color solvent, and black particles are charged in positively.

Black, white and color image can be displayed by controlling the movement of the charged particles within the cell by changing the polarity of voltage applied to two driving electrodes. The color image is displayed by applying positive and negative voltages to the driving electrodes, respectively, as shown in figure 1(a). Thereby, positively charged black particles and negatively charged white particles move to the driving electrodes, respectively and white particles dispersed in a color solvent are observed through the common electrode. When negative voltage is applied to the both of two driving electrodes, positively charged black particles move to the driving electrodes and negatively charged white particles move to the common electrode, so the white image can be seen through the common electrode, as shown in figure 1(b). The black image is displayed by applying positive voltage to the both of two driving electrodes because negatively charged white particles move to the two driving electrodes at bottom glass and positively charged black particles move to the top electrode, figure 1(c).

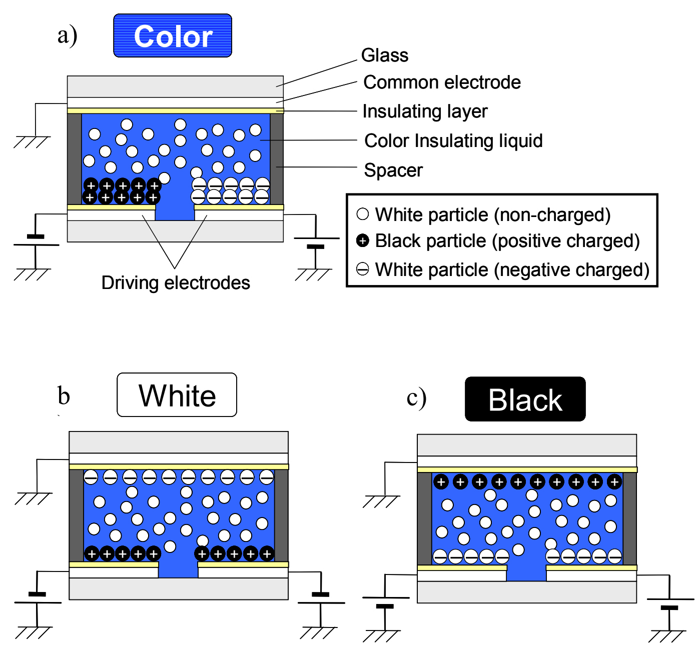

Figure 1. *Schematic illustration of Color EPID cell.*

Experimental

Materials

We used resin-coated carbon black, resin-coated TiO_2, and poly-vinyl-naphthalene (PVNp) [6] for positively charged black particles, negatively charged white particles and non-electrophoretic white particles, respectively. PVNp is the spherical particles of 450nm of diameter, and has high dispersion stability in insulating liquid. The insulating liquid Isopar G (Exxon Mobil Corp.) was used for solvent, and surfactants Solsperse17000 (Avecia) and Sorbitan Trioleate (Wako Pure Chemical Industries, Ltd.) were used as charge control agent and dispersant agent. Dye Oil Blue N (Aldrich, Ltd) was used to color the insulating liquid to cyan. Dye Sudan Red 7B (Aldrich, Ltd) was used to color the insulating liquid to magenta. Dye Quinoline Yellow (Aldrich, Ltd) and Oil Yellow 3G (Orient Chemical Industries CO., LTD) were used to color the insulating liquid to yellow.

Measurement

The structure of COLOR EPID cell is shown in Figure 2. Glass substrate coated with ITO electrode (display area is 1cm × 1cm) and glass substrate coated with interdigitated ITO electrodes were sealed at gap distance of 100 micrometers and dispersion liquid was injected into the cell. Reflectance measurement system is shown in Figure 3. Sample was exposed to the light at the cell set in the black box (A9665, Hamamatsu Photonics K. K.) through the optical fiber from spot light source (L8333, Hamamatsu Photonics K. K.), and reflectance measurement was performed by detecting reflection light with photonic multi channel Analyzer (PMA-11 C7473, Hamamatsu Photonics K. K.).White reflectance standard (Certified Reflectance Standard labsphere, Edmund Optics Japan Ltd.) was equated with 100 %, and evaluated samples by relative reflectance.

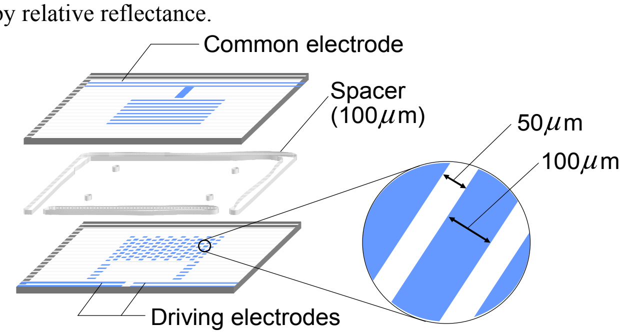

Figure 2. *Structure of COLOR EPID cell.*

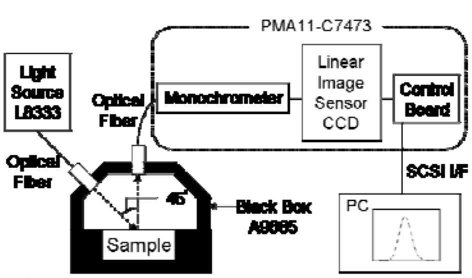

Figure 3. *Reflectance measurement system.*

Results and Discussion

Light scattering effect of non-electrophoretic white particles

We can see the black and blue stripe lines through the color insulating liquid in normal type of display cell due to transparency of color insulating liquid. Therefore, we used non-electrophoretic white polymer particles to scatter the light and improve the brightness of color. We prepared the normal type of display cell as shown in figure 4. The color insulating liquid was injected into the cell and put on the black and white stripe tape lines. The color insulating liquid was 0.5wt% Oil Blue N in Isopar G. Figure 5(a) shows the photograph of color insulating liquid through top glass of cell. The black and blue stripe lines were shown in the normal type of display cell. It is clear that the optical spectrum of display cell exhibits black and cyan color as shown in figure 5(b). Black spectrum is depended on the background.

Next, we prepared the display cell contained of non-electrophoretic white particles by 20wt% into the color insulating liquid. Figure 6(a) shows the photograph of display cell. The photograph indicated the cyan color is from independent of background color. The color spectrum is shown in figure 6(b). The spectrum shows a reflection of color dye due to scattering of light by addition of white polymer particles.

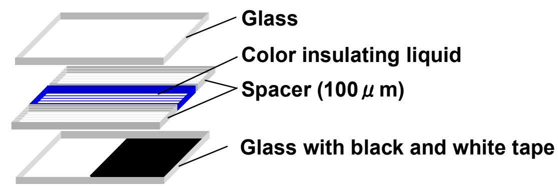

Figure 4. *Structure of simple cell*

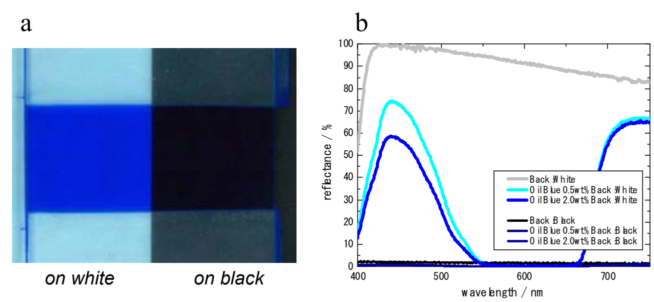

Figure 5. *(a) photograph and (b)reflection spectra of color insulating liquid in background of white and black.*

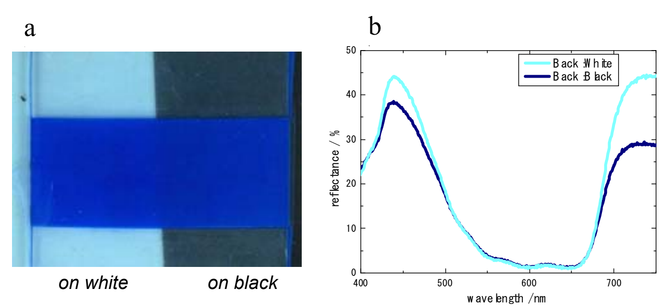

Figure 6. *(a) photograph and (b)reflection spectra of color insulating liquid with non-electrophoretic white particles.*

Display Properties of Color EPID

We have made three kinds of color display cells display cyan, magenta and yellow colors. The electrophoretic liquid of cyan system consisted of 0.5wt% Oil Blue N, 9wt% PVNp, 50wt% normal white and black electrophoretic liquid (40wt% white particles, 1.7wt% black particles, 0.5wt% Solsperse17000, 0.5wt% Span85, 57.3wt% Isopar G) and 40.5wt % Isopar G. About magenta system, 0.3wt% Sudan red 7B took the place of Oil Blue N, as for the rest is same. About yellow system, 0.1wt% Quinoline Yellow and 0.15wt% Oil Yellow 3G took the place of Oil Blue N, as for the rest is same. These electrophoretic liquid were injected into the color EPID cell like Figure 2, respectively. The cells were displayed in three states (black, white and color) by applying the positive and negative voltages to the two driving electrodes. Figure 7 shows the photographs of black, white and color states in the cells. We measured reflectance of black and white of cyan system sample at wavelength of 550nm by applying same voltage into two driving electrodes. In this color EPID, black and white states could be displayed easily as well as normal black and white EPID, as shown in figure 8. It was displayed the best by applying about ±15V. On the other hand, it wasn't easy so much to display color state. Color state could be displayed by applying voltage into one of two driving electrodes and applying voltage of the other at slightly different times. But there are needs to be improved in display method of color state. Next, we measured the optical reflection spectra of three states in the color EPID.

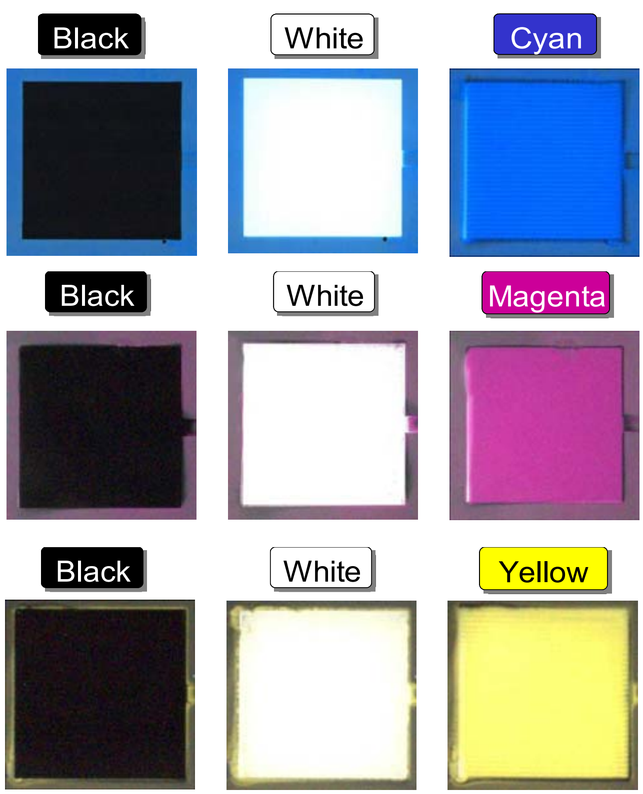

Figure 7. *Photographs of three states (black, white, color) of cyan, magenta and yellow, respectively.*

Figure 9, 10, 11 shows the reflection spectra of cyan system sample, magenta system sample, yellow system sample, respectively. The waveform of black of all samples showed the optical reflectance of below 1% in whole optical range. The waveform of cyan color showed the optical reflectance of 37%, 1.5%, 40% at 440nm, 600nm and 750nm, respectively. The waveform of magenta color showed the optical reflectance of 31%, 5%, 41% at 420nm, 550nm and 650nm, respectively. The waveform of yellow color showed the optical reflectance of 7%, 58%, 49% at 400nm, 550nm and 700nm, respectively. Whiteness degrees of three samples were over 35 % in whole optical range, and they can be regarded as a white image. The optical spectrum of white image decreased at absorption wavelength peculiar to dye because color liquid filled the interstices between white particles. However if these cells are pixelated, whiteness of the color EPID is over 60% by filling in gaps each other, as shown in figure 12. Figure 12 shows the average of each white spectrum of three samples. These optical spectra can be said that the image of white, black, and color was obtained by using normal black and white particles and non-electrophoretic white particles, color insulating liquid.

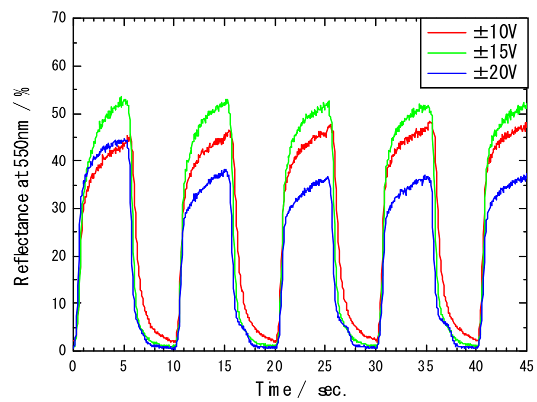

Figure 8. Reflectance of black and white states consisting of cyan system electrophoretic liquid. Same voltage were applied to two driving electrode.

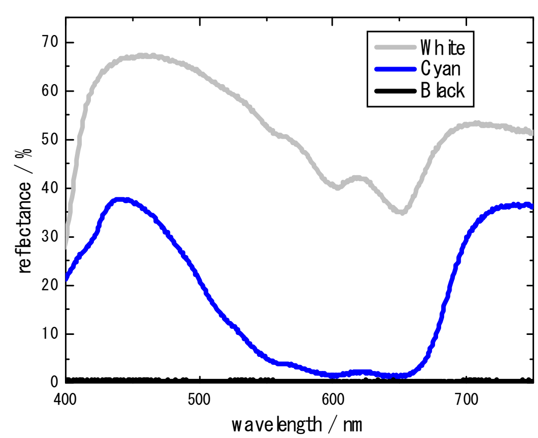

Figure 9. *Reflection spectra in white state, black state and cyan color state.*

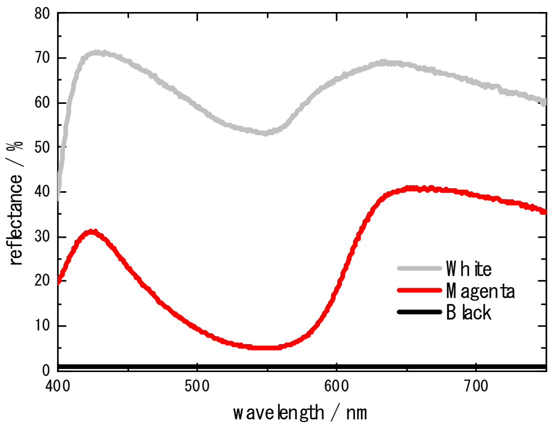

__Figure 10.__ Reflection spectra in white state, black state and magenta color state.

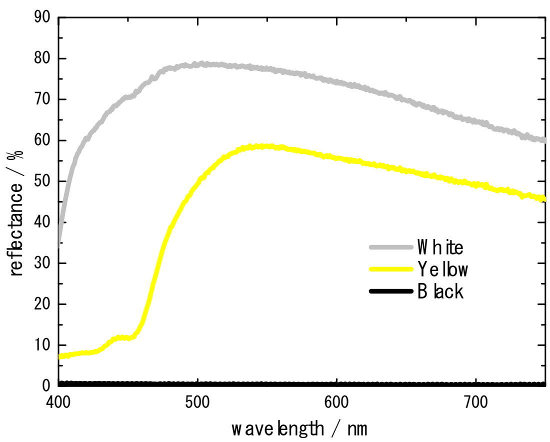

__Figure 11.__ Reflection spectra in white state, black state and yellow color state.

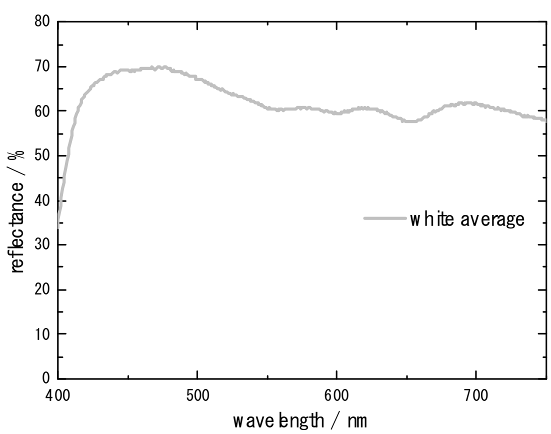

__Figure 12.__ The average reflection spectra of each white spectrum of three samples

Conclusion

Color Electrophoretic Image Display based on movement of particles using two driving electrodes was investigated. Using we have proposed novel Color EPID based on the movement of white and black particles in a colored insulating liquid. We used positively charged black particles and two kinds of white particles, non-electrophoretic polymer particles and negatively charged titanic oxide particles. Non-electrophoretic white particles are used for light scattering and increasing the intensity of the color insulating liquid's luminosity. White, black and color images were obtained by the change of polarity of voltage applied to driving electrodes of this Color EPID cell.

References

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Author Biography

Yoshimatsu Yoshitaku received the B.S. degree in information engineering from Chiba University in 2008. Since then he has been a student in Graduate School of Advanced Integration Science, Chiba University. He is a member of ISJ.