Novel Color Electrophoretic Imaging Display Based on Movement of Particles Using Two Driving Electrodes

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Abstract

We are studying a color electrophoretic imaging display. This display has an electrophoretic liquid, which contains non-electrophoretic particles, positively and negatively charged electrophoretic particles. We fabricated five kinds of white, black and magenta electrophoretic particles using chemical polymerization technique, and developed two types of electrophoretic dispersion liquid. One type contains positively charged electrophoretic magenta particles, negatively charged electrophoretic black particles, and non-electrophoretic white particles. The other type contains negatively charged electrophoretic magenta particles, positively charged electrophoretic black particles, and non-electrophoretic white particles. This display has three colored states, which are controlled by two driving electrodes. The two driving electrodes and a common transparent electrode were set on the back and front glass plate in this display cell, respectively. For the first state, the two driving electrodes were set at positive voltage so that negatively charged electrophoretic particles appeared at the visual surface. For the second state, the two driving electrodes were set at negative voltage so that positively charged electrophoretic particles appeared at the visual surface. For the third state, the two driving electrodes were set at opposite voltages to each other so that non-electrophoretic white particles appeared at the visual surface.

Introduction

It will be expected that electronic papers will be flexible and light display in the future. There are many types of method in electronic papers. Electrophoretic Image Display (EPID) is one type of them, and produced on a commercial basis as a black and white electronic paper. If YMC or RGB color filter is applied to this electronic paper, colored states can be indicated easily. However, there is a problem of low reflectivity and contrast, and it has not come to the practical use of the color EPID.

We reported the color EPID without the color filter in order to heighten the reflectivity and contrast. [1] This color EPID had two driving electrodes and an electrophoretic liquid that contained three kinds of particle. For example, the first particle is non-electrophoretic particle and white particle; the second particle is positively charged electrophoretic particles and black particle; the third particle is negatively charged electrophoretic particle and red particle. In this case, this color EPID indicates black, red and white state by setting two electrodes at positive voltages, negative voltages and opposite voltages respectively. (Fig.1)

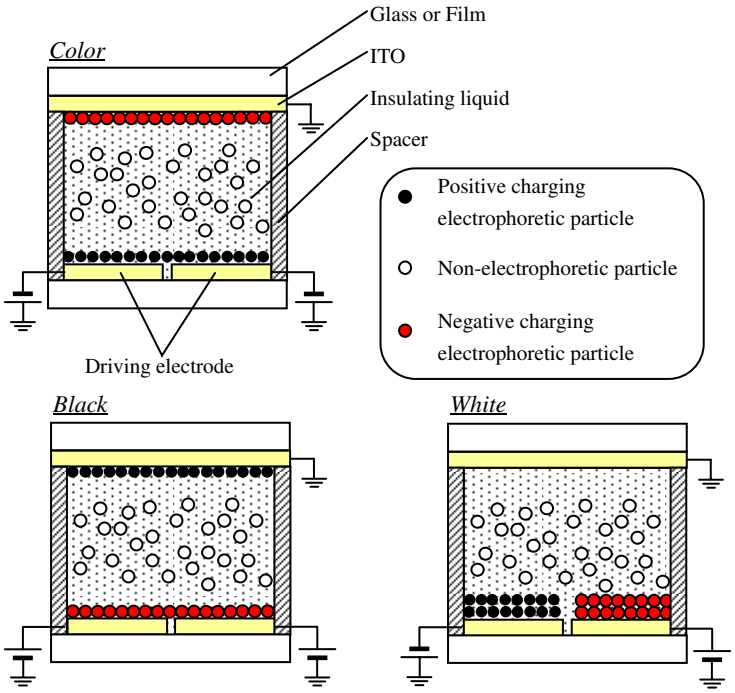


***Figure 1**. Schematic illustration of color EPID*

We reported that the first particle was composed of polyvinylnaphtalene (PVNp); the second and third particles were composed of dry toners of electrophoto-graphy[1]. Generally speaking, a diameter of a dry toner is between 5 and 10 micrometers, and a diameter of an electrophoretic particle in black and white EPID is between 0.1 and 0.5 micrometers. Therefore mass of dry toner is heavier than that of electrophoretic particles, and dry toner is not easy to move in insulating liquid. For electrophoresis, toner particles required a high applying voltage over ±50V to indicate three colored states. The purposes of this study is to design positively and negatively charged electrophoretic particles, which is suitable for our color EPID, and achieve a low applied voltage to indicate three colored states.

Experiment

In our color EPID, PVNp that is non-electrophoretic white particle is main component. We suppose that two types of electrophoretic liquid are suitable for PVNp. One type contains positively charged electrophoretic color particles, negatively charged electrophoretic black particles, and PVNp (Type1). The other type contains negatively charged electrophoretic color

particles, positively charged electrophoretic black particles, and PVNp (Type2).

Preparation of Type1 Electrophoretic Particles

According to Charles H. Honeyman et at.[2], positively and negatively charged electrophoretic particles were fabricated with graft-polymerization. More accurately, carbon and titanium dioxide particles were polymerized with 2-ethylhexyl groups and lauryl groups, respectively, for positively and negative charged electrophoretic particles. In the same way, we polymerized black and color particles.

We polymerized quinacridone pigments with 2-ethylhexyl groups for positively charged electrophoretic particles, and prepared these particles as magenta color particles. (Sample #1)

Previously, we had confirmed that carbon could not be polymerized with lauryl groups for negatively charged electrophoretic particles. Therefore, we focused on compounds of titanium dioxide and titanium nitride as another black particles. These compounds are produced by reducing titanium dioxide, so that the color change from white to black and blackness degree is in proportion to amount of titanium nitride. We predicted that these compounds could be polymerized with lauryl group as same as titanium dioxide could. We used compounds in which the ratio of titanium dioxide to titanium nitride was 50 to 50wt%, and polymerized these compounds with lauryl groups. (Sample #2)

Preparation of Type2 Electrophoretic Particles

In liquid process of electrophotography, Tsubuko had researched liquid toner particles, which consisted of negatively charged particles.[3] We studied whether these liquid toner particles were applied to negatively charged electrophoretic particles in our color EPID. We prepared four types of liquid toner particles, which color were magenta. (Sample #3-1,2,3,4)

Table 1 Liquid Toner Particles

Sample	Pigment	Side chain	Diameter (nm)
#3-1	PimentRed184	Laurylmethacrylate Methylhexyl-methacrylate	700
#3-2	PigmentRed57	Laurylmethacrylate Methylhexyl-methacrylate	700
#3-3	DisperseRed92	Abietic acid	300
#3-4	DisperseRed92	Abietic acid	150

We prepared carbon particles that were polymerized with 2-ethylhexyl groups for positively charged electrophoretic particles. (Sample #4) But we predicted that these carbon particles could not be suitable for those liquid toner particles. These carbon particles needed additional substances; surfactant and charge control agent (CCA), for dispersion and positive charge. On the other hand, those liquid toner particles did not need additional substance, because those particles dispersed and had charges by themselves. When carbon and liquid toner particles are mixed, surfactant and CCA may affect those toner particles harmfully.

In order to correspond this problem, we examined self-dispersing and self-charged particles, which is black and positive charge. We had polymerized monomers, which contained basic groups, on particles, so that particles had coated with polymers.[3] These monomers had supplied core-particles with dispersion and positive charge. We prepared methylmethacrylate (MMA) and dimethylaminoethylmethacrylate (DMAEMA) as a monomer, and some thicknesses of polymers that coated carbon particles. (Sample #5-1,2,3)

Table 2 Carbon Particles

Sample	Type	Side chain / Monomer	Diameter (nm)
#4	Graft Polymerization	2-ethylhexyl group	250
#5-1	Polymer Coating	MMA DMAEMA	360
#5-2	Polymer Coating	MMA DMAEMA	330
#5-3	Polymer Coating	MMA DMAEMA	290

Results and Discussion

ζ-Potential Measurements

Mobility of electrophoretic particle is in proportion to ζ-potential. We measured ζ-potential of all samples in order to select effective samples for electrophoretic particles. (Malvern Instrument Ltd.: Model Zetasizer 3000HS) ζ-potentials are shown in Table 3.

ζ-potentials of sample #1 and #2 were positive and negative sufficiently for TypeI electrophoretic liquid.

ζ-potential of sample #3-4 was the most negative of the sample #3 series. We adopted sample #3-4 for Typeζ electrophoretic liquid. On the other hand, it was difficult to select sample #4, #5-1, #5-2, and #5-3. Sample #4 may be incompatible with sample #3-4. ζ-potentials of sample #5-1, #5-2, and #5-3 were extremely low, and could not be distinguished. We tried to examine all of four samples whether these were compatible with sample #3-4.

Display Table 3 ζ-potential

Sample	ζ-potential Average (min. ~ max.)	Color	Type
#1	51.3 (45.9 ~ 54.9) mV	Magenta	Type Ⅰ
#2	-14.0 (-19.7 ~ -10.2) mV	Black	
#3-1	-18.2 (-28.2 ~ -7.9) mV	Magenta	Type Ⅱ
#3-1	-3.3 (-4.6 ~ -2.5) mV	Magenta	
#3-3	-0.8 (-1.2 ~ -0.6) mV	Magenta	
#3-4	-45.0 (-63.0 ~ -34.5) mV	Magenta	
#4	49 (30 ~ 60) mV	Black	
#5-1	1.4 (0.8 ~ 1.7) mV	Black	
#5-2	2.1 (1.7 ~ 2.2) mV	Black	
#5-3	1.4 (0 ~ 3.3) mV	Black	

Display Properties of Color EPID

We used color EPID cell; the surface area was 1 cm square; two driving electrodes were set alternately; spacer was 100 μm in thickness, as shown in Fig.2.

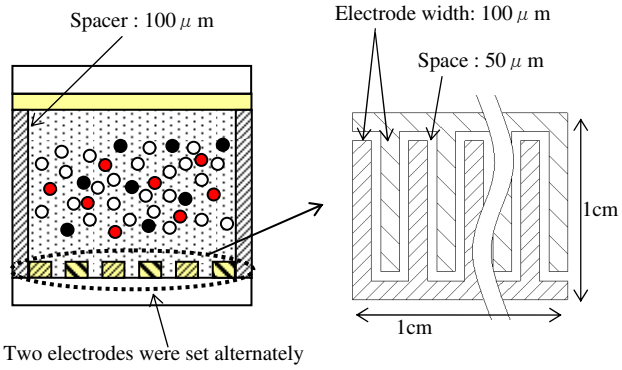


***Figure 2**. Schematic Experimental Cell*

Type1 electrophoretic liquid consisted of 2wt% sample #1, 2wt% sample #2, 25wt% PVNp, 0.5wt% surfactant, 0.5wt% CCA, and 70wt% nonpolar solvent. The surfactant was Span85 (Wako); the CCA was Solsperse17000 (Avecia); the nonpolar solvent was IsoparG (Exxon). This type1 electrophoretic liquid was injected into the color EPID cell like Fig.2. We measured reflectance of magenta and black at wavelength of 650nm by applying same voltage into two driving electrodes. In this color EPID, magenta and black states could be indicated easily with over ±20V, as shown in Fig.3. On the other hand, it was possible to indicate white state by applying varied voltages into two driving electrodes after repeated trial and error. Fig.4 shows photographs of magenta, black, and white states in this color EPID that consist of type1 electrophoretic liquid. Reflectance of white state was about 40% and 50% at wavelength of 550nm and 650nm respectively.

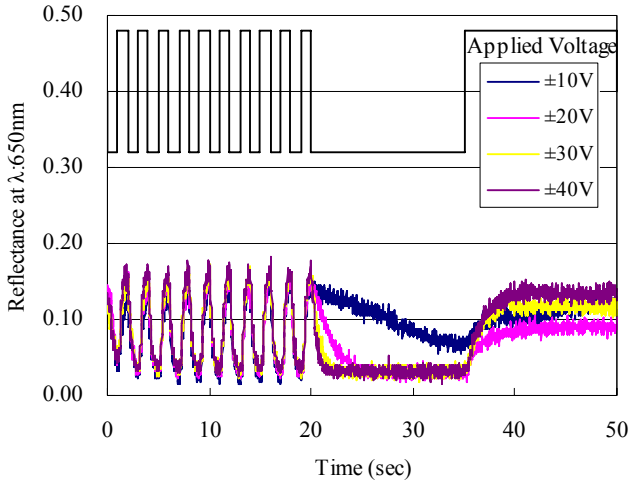


***Figure 3**. Reflectance of black and magenta states consisting of sample #1, #2, and PVNp. Same voltage were applied to two driving electrodes.*

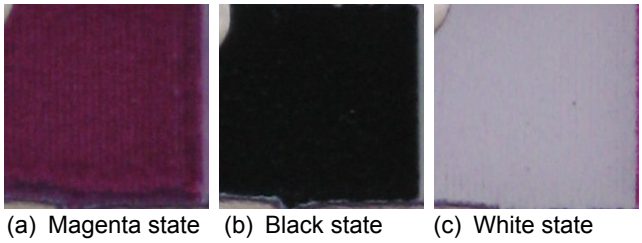


***Figure 4**. Photographs of color EPID consisting of sample #1, #2, and PVNp. (Size: 1cm×1cm)*

Type2 electrophoretic liquid consisted of 2wt% sample #3-4, 2wt% sample #4, 25wt% PVNp, 0.5wt% surfactant, 0.5wt% CCA, and 70wt% nonpolar solvent. The surfactant was Span85 (Wako); the CCA was Solsperse17000 (Avecia); the nonpolar solvent was IsoparG (Exxon). In case of sample #3-4 and #4, three- color states could not be indicated with any applied voltages. We guessed that particles of sample #3-4 and #4 cohered tightly and could not be separated with any applied voltages.

Another type2 electrophoretic liquid consisted of 2wt% sample #3-4, 2wt% #5-1 (#5-2, #5-3), 25wt% PVNp, and 71wt% nonpolar solvent. The nonpolar solvent was IsoparG (Exxon). Sample #5-1 was the best magenta and black states of three samples. Fig.5 shows reflectance of sample #5-1 at wavelength of 650nm. In this color EPID, magenta and black states could be indicated easily with over ±20V. However, it was not so easy to indicate white state as well type1. Fig.6 shows photographs of magenta, black, and white states in this color EPID that consist of type2 electrophoretic liquid. Whiteness degree of type2 was over 50 %, and higher than that of type2.

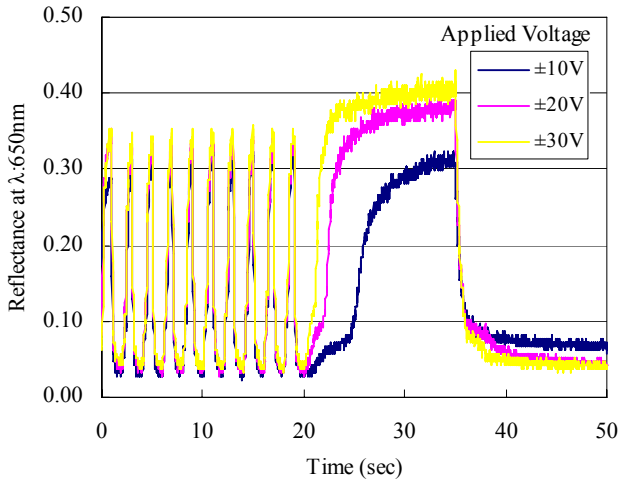
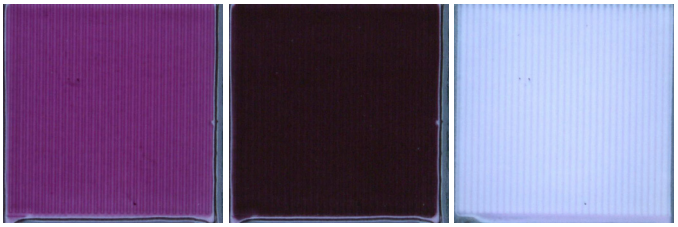


***Figure 5**. Reflectance of black and magenta states consisting of sample #3-4, #5-1, and PVNp. Same voltage were applied to two driving electrodes.*



(a) Magenta state (b) Black state (c) White state

***Figure 6**. Photographs of color EPID consisting of sample #3-4, #5-1, and PVNp. (Size: 1cm×1cm)*

It was not easy to indicate white state in either type1 or 2. We suppose that the difficulty of displaying white state was due to improper ratio among magenta, black and white particles. The amount of magenta particles was relatively much for white particles, so that magenta and white particles mixed at white state.

Another cause could be non-optimization of cell structure that was used in our experiment. By the way, when white state was indicated, magenta and black particles were set on two driving electrodes respectively and any particles were not set on the visual surface. To put it another way, magenta and black particles needed to be electrophoresed between two driving electrodes and not to be done between driving electrodes and visual surface at white state. In our experiment, driving electrodes were 100μm width and cell was 100μm depth. Distance between two driving electrodes was similar to that between driving electrodes and visual surface, so that electrophoresis between driving electrodes and visual surface could be occurred as well as that between two driving electrodes.

Conclusions

We could design positively and negatively charged electrophoretic particles that were suitable for our color EPID and achieve low applied voltages.

References

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[3] Kazuo Tsubuko: Ricoh Technical Report, 1982, **9**, p22-28

[4] Masahiro Yanagisawa: Ricoh Technical Report, 2002, **28**, p101-106

Author Biography

Masahiro Masuzawa received his B.S. and M.S. in applied physics from Tohoku University in Sendai, Japan, in 1988 and 1990, respectively. In 1990, he joined the Research and Development Group at Ricoh Corporation. Now he is developing paper like display.