

Electrophoretic Display by using Microcup Sheet and Charged Particles

Lee Soon Park*, Jin Woo Park, Hae Yun Choi, Yoon Soo Han¹

Younghwan Kwon² and Hyung Suk Choi³

Dept. of Polymer Science, ¹Advanced Display Manufacturing Research Center
Kyungpook National University, Daegu 702-701, Korea

²Dept. of Chemical Engineering, Research Institute of Nano Technologies
Daegu University, Gyeongsan, Gyeongbuk 712-714, Korea

BOE HYDIS Technology Co., Ltd., Ichon, Gyeonggi-do 467-701, Korea

Phone : +82-53-950-5627, E-mail : lspark@knu.ac.kr

Abstract

Electrophoretic display has recently stimulated tremendous interest due to potential commercialization in the field of information displays including e-books, e-newspapers, and other low-power portable displays. A new transparent soft mold press (TSMP) process developed in this study was found to give a good electrophoretic display panel with prepatterned micropools for the filling of charged particle slurry. It was also found that charged TiO₂ particles with 74.09 mV of zeta potential and 3.11×10^{-5} cm²/Vs of mobility were successfully prepared.

1. Introduction

Lightweight, flexible reflective paper-like displays are of great interest for applications in portable displays, such as PDAs, electronic newspapers, and e-books as well as out- and in-door advertisements.

Electrophoretic display also has merit of low-power portable displays. Electrophoretic displays typically consist of micron-sized capsules filled with nano-sized charged TiO₂ particles, suspension fluid, charge controlling agents, and particle stabilizers. When exposed to an electric field, these charged particles move either up or down within the microcapsules, creating text or graphic images. However, the process for microencapsulation of these charged particles has been one of intricate processes for the electrophoretic displays.[1-4] Recently, SiPix Co in U.S.A. developed new microcup process for electrophoretic display panels to eliminate encapsulation process. The company also demonstrated mass production capability of electrophoretic display panels by roll-to-roll process. [5-6]

Two key technologies for the fabrication of

electrophoretic display include 1) the fabrication of panels with micropatterned barrier ribs and 2) the preparation of charged particles with electrophoretic property. We have recently reported novel panel fabrication process utilizing transparent soft mold press (TSMP) method. The panel fabrication by TSMP method consisted of three steps; 1) preparation of base mold, 2) preparation of silicone soft mold from the base mold, and 3) fabrication of barrier ribs on the substrate using photosensitive resin.

In this work, studies on optimum formulation of photosensitive resin for TSMP method and fabrication condition of barrier ribs were performed. In addition, reaction conditions on the synthesis of cationically charged TiO₂ particles were studied. The fabrication and performance of electrophoretic display were also investigated.

2. Experimental

2.1. Fabrication of electrophoretic display panel

Figure 1 shows the TSMP process for the fabrication of electrophoretic display panel. In the first step, base mold was fabricated using photoresist (PR) solution. A glass was successively cleaned with acetone, ethanol, and distilled water for 3 min. three times. The SU-8 negative PR was dispensed onto the cleaned glass and then spin-coated. After leveling for 2 min, the coated glass was baked at 90 °C for 10 min in a convection oven. The PR coated glass was exposed to UV light at 365 nm through photomask, followed by development of unexposed area to give a base mold.

In the second step, the transparent soft mold was fabricated using base molds previously prepared. After spreading mold release agent on the base mold, Sylgard 184 was poured onto the base mold, followed by degassing. After curing it at 40 °C for 3 hr, the

transparent soft mold was taken from the base mold.

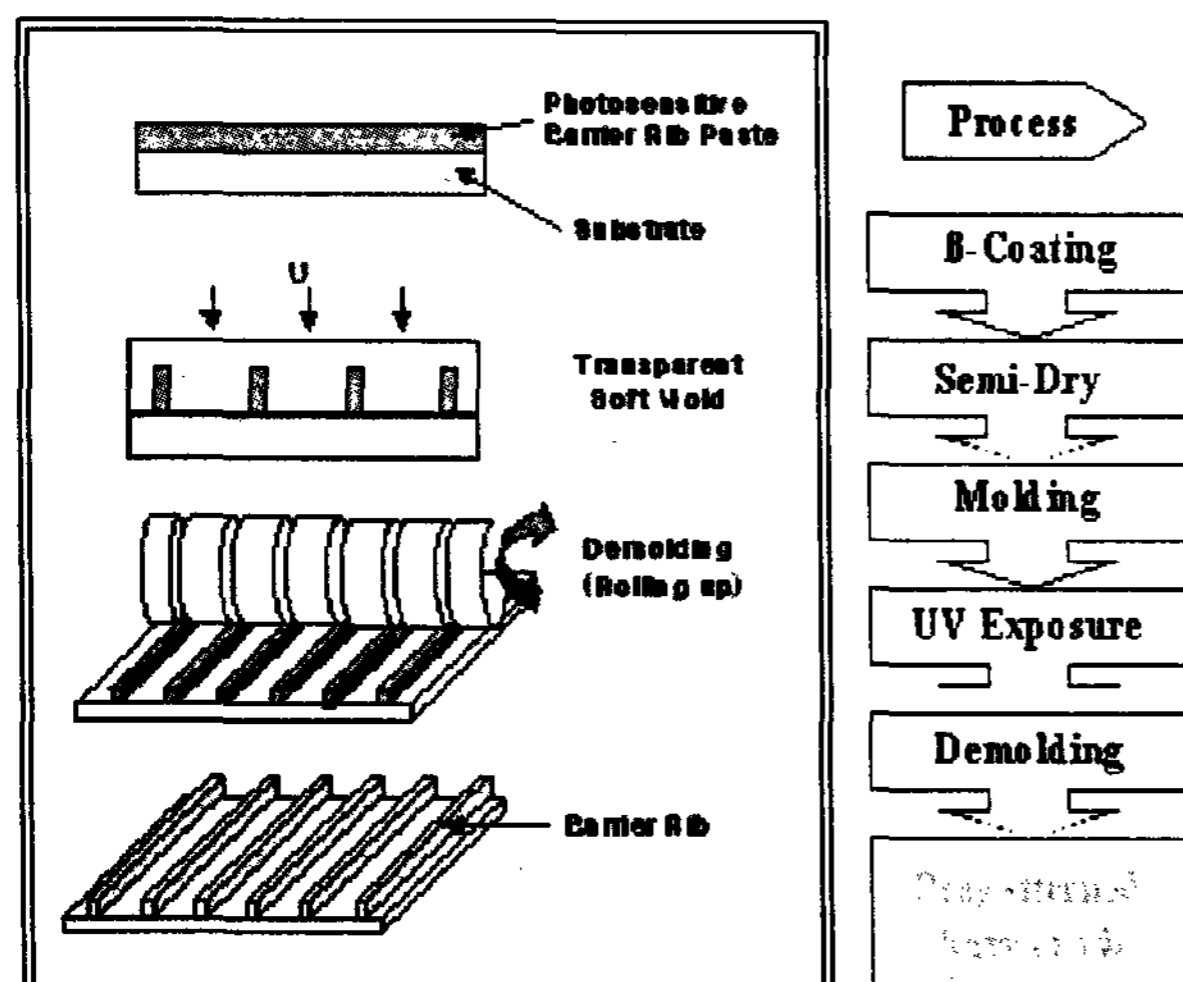


Figure 1. Patterning of barrier rib by TSMF process.

In the last step, photosensitive paste (200 ~ 300 μm of thickness) on a prepatterned ITO glass was coated using a bar-coater and then dried at 100 °C in an oven until the content of residual solvent remains less than 10 wt.% in the photosensitive film. While pressed with the transparent soft mold under 1.5 ~ 3.0 Kg/cm^2 of pressure at 60 ~ 90 °C, the photosensitive film was exposed to UV light at 365 nm in the range of 800 ~ 2,000 mJ/cm^2 . The transparent soft mold was demolded by rolling up to give box-typed barrier ribs of electrophoretic display panels with precise geometry.

2.2. Preparation of charged TiO_2 particles

As shown in Figure 2, TiO_2 particles with average diameter of 21 nm dispersed in suspension fluid were treated with ultrasonification for 10 min, followed by ball milling with aminosilane as a charge controlling agent and a dispersant for 8 hr. Then, acetic acid was added to impart cationic charges on the surface of TiO_2 particles.

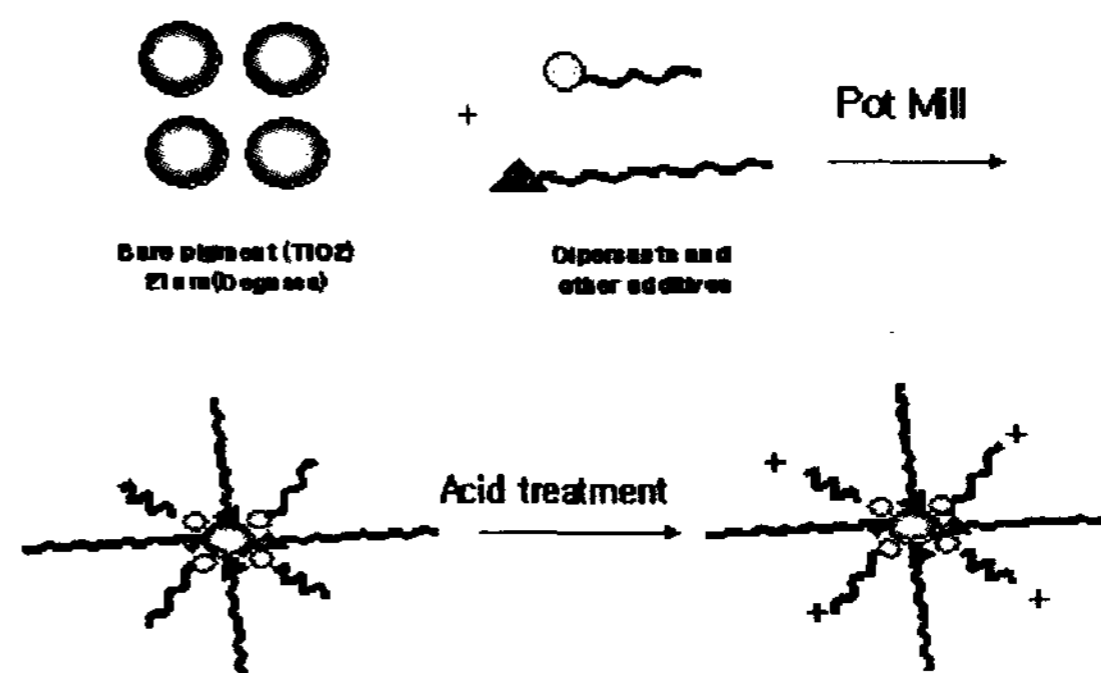


Figure 2. Fabrication of charged TiO_2 particles by surface treatment

2.3. Fabrication of electrophoretic displays

ITO-coated glass with a sheet resistance of 30 Ω/\square was cut into a 3.0 cm \times 7.0 cm, and the electrode area was prepared by a photoetching technique. It was sequentially cleaned in an ultrasonic bath of isopropyl alcohol, acetone and distilled water, followed by drying it at 120 °C. Two ITO-coated glasses were sealed with 100 μm thickness, and an e-ink slurry prepared by mixing charged TiO_2 particles with 1.0 wt% of solvent blue 35 in cyclohexanone was injected through the entry port to give rise to the electrophoretic display.

3. Results and discussion

3.1. Fabrication of electrophoretic display panel

Photosensitive paste consisting of binder polymer, solvent, photoinitiator and multifunctional monomer/oligomer [7-10] is important for the fabrication of barrier ribs in electrophoretic display panels. Binder polymer, poly(BMA-co-BA) for photosensitive paste was synthesized from butyl methacrylate and butyl acrylate with AIBN at 60 °C. Molecular weight of synthesized poly(BMA-co-BA) was 25,000 g/mol. Studies on the formulation of photosensitive paste were carried out for providing good adhesion with substrates, high flexibility and solvent resistance to the final film. The box-type barrier ribs for electrophoretic display panels were fabricated by using photosensitive paste. As shown in Figure 3, SEM images of patterned panel confirmed the formation of box-type barrier ribs with good geometry.[11-13]

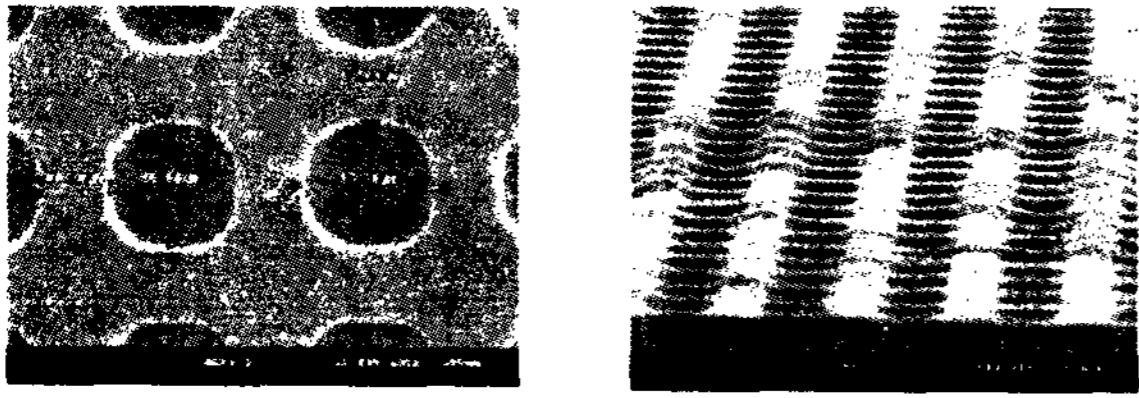


Figure 3. SEM images of box-type barrier ribs for electrophoretic display.

3.2. Preparation of charged TiO₂ particles

Cationically charged TiO₂ particles were prepared by milling of TiO₂ particles, a charge controlling agent (CCA) and a dispersant in suspension fluid, followed by treatment with acetic acid. The effect of suspension fluids were studied by determining switching time (t) of charged TiO₂ particles, which proportionally affects on the response time of electrophoretic display. For four different suspension fluids such as tetrachloroethane ($\eta^{25} = 0.844$ mPa, $\epsilon^{30} = 2.27$), methylene chloride ($\eta^{25} = 0.413$ mPa, $\epsilon^{25} = 8.93$), cyclohexanone ($\eta^{25} = 2.20$ mPa, $\epsilon^{20} = 16.1$) and Parasol-103 ($\eta^{25} = 1.38$ mPa, $\epsilon^{20} = 2.20$), switching time (t) was calculated with the following equation.[14-15]

$$t = \frac{6\pi d^2 \eta}{V \epsilon \xi}$$

Where η and ϵ represent viscosity and dielectric constant of suspension fluids at specific temperature expressed with superscript number, respectively. V and d are voltage difference and distance between electrodes and ξ is zeta potential of particles. In addition, the performance of charged TiO₂ particles were also evaluated in terms of zeta potential and mobility in different suspension fluids. It appeared that charged TiO₂ particles were precipitated out when methylene chloride and Parasol-108 were employed as suspension fluids. However, charged TiO₂ particles in cyclohexanone exhibited 0.125 of switching time, 53.72 mV of zeta potential and 2.30×10^{-5} cm²/V s of mobility. As seen in Figure 4, result on dispersion stability of charged particles showed that charged particles in cyclohexanone exhibited 55.41 μ m/min of average sedimentation velocity, representing higher stability among them. From the viewpoint of

switching time, zeta potential and mobility of charged TiO₂ particles, cyclohexanone was selected as the suspension fluid in this study.

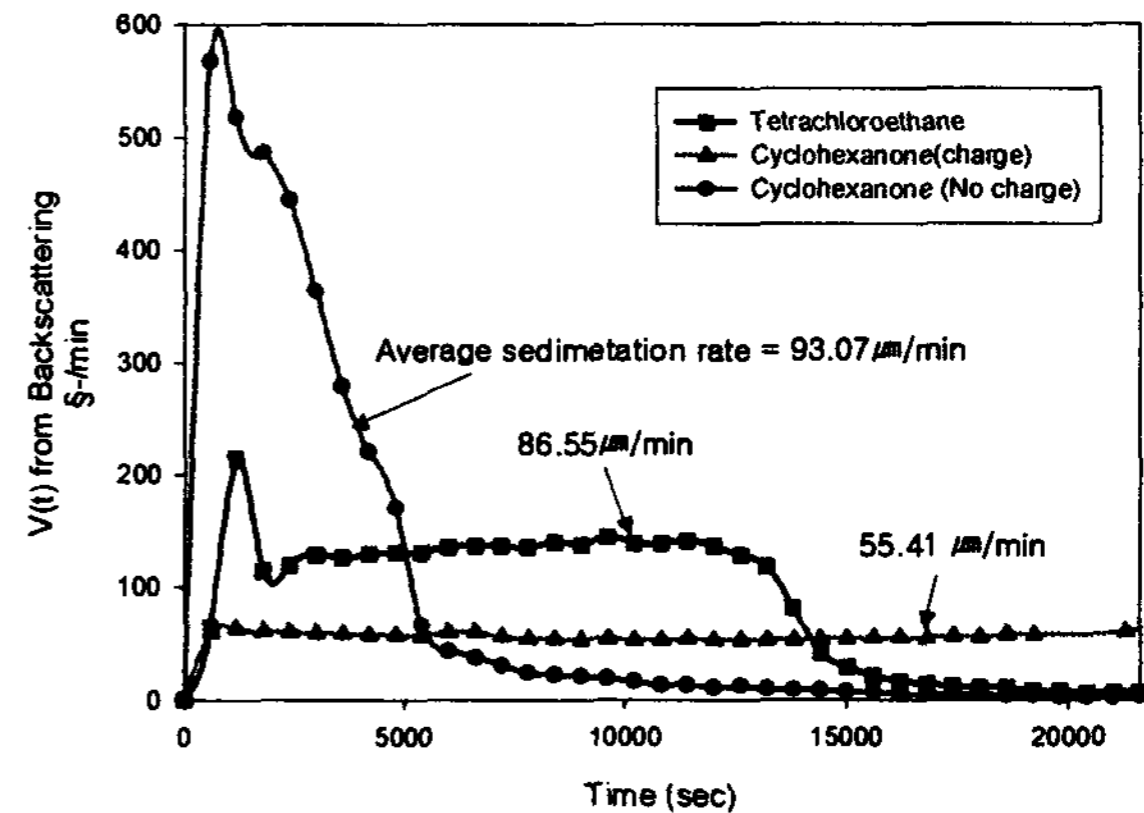


Figure 4. Dispersion stability of TiO₂ particles in different suspension fluids.

Amino silane compounds were used as charge controlling agents (CCA) for TiO₂ particles in order to impart electrophoretic property as well as dispersion stability by repulsive electrostatic forces between cationic charges. For comparison, two types of charge controlling agents were used; one was aminosilane with 2 amine groups(CCA-1) and the other was aminosilane with one amine group(CCA-2). Cationically charged TiO₂ particles were prepared by varying the concentrations of CCA-1 and CCA-2, respectively. It was found that charged TiO₂ particles prepared using CCA-1 exhibited high zeta potential and low average particle size, compared to those prepared using CCA-2, as presented in Figure 5 and 6. It could be explained by two cationic sites of CCA-1 compared to one of CCA-1

3.3. Fabrication of electrophoretic displays

Electrophoretic slurry was prepared by blending of charged TiO₂ particles with 1.0 wt% of solvent blue 35 in cyclohexanone. Using four different ratios of charged TiO₂ slurry/dye solution, contrast ratio (CR) of electrophoretic displays was calculated using the following equation.

$$\text{Contrast Ratio (CR)} = L_w / L_b$$

Where L_w (cd/m^2) and L_b represent luminescence in power-on and luminescence in power-off, respectively. In the case of electrophoretic display prepared with charged TiO_2 slurry/dye solution =80/20 (w/w), L_w and L_b were measured to be 30.7 cd/m^2 and 5.8 cd/m^2 , respectively, resulting in relatively high CR of 5.32/1.

Luminescence vs. voltage profile of electrophoretic displays prepared with 80/20 (w/w) charged TiO_2 slurry/dye solution is presented in Figure 7. It appeared that the electrophoretic display exhibited ca. 10 V of driving voltage and maximum luminescence at 30 V. Figure 8 presents photographs of an electrophoretic display with dimensions of $150 \mu\text{m}$ (t) \times 10 cm (w) \times 5 cm (l) before (a) and after (b) applying 30V.

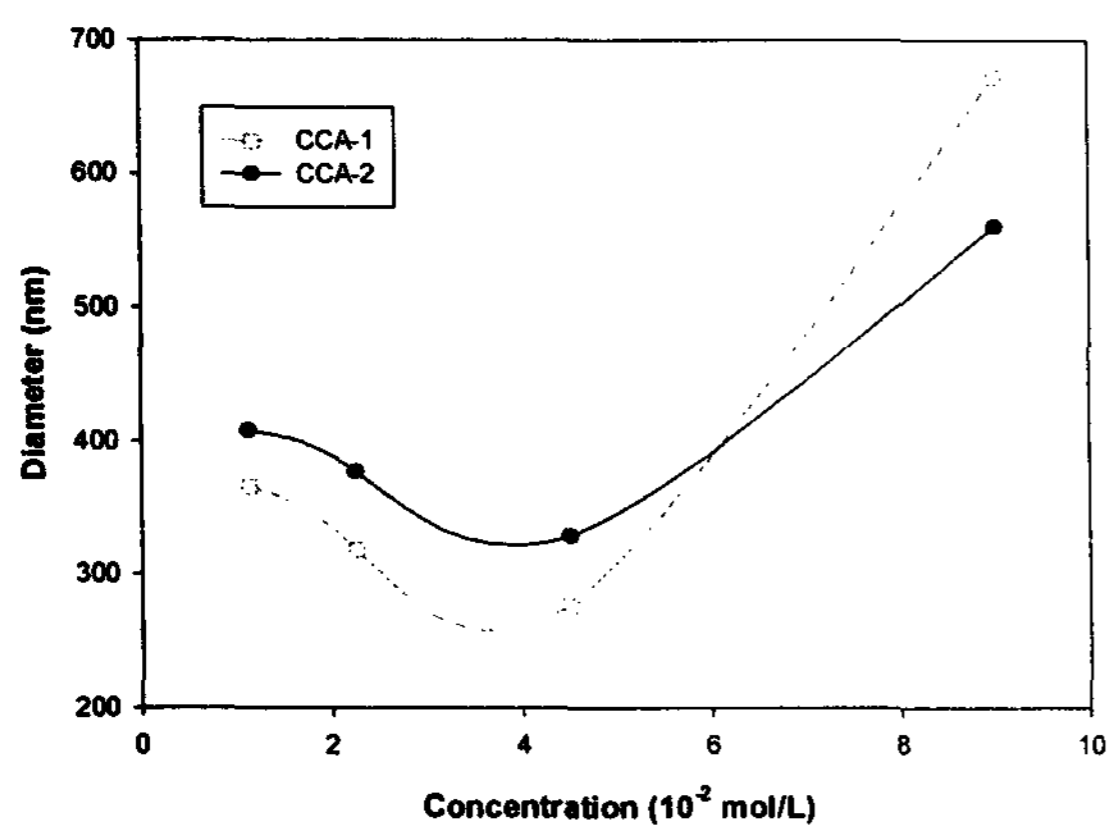


Figure 5. Average particle sizes of charged TiO_2 particles with CCA concentration.

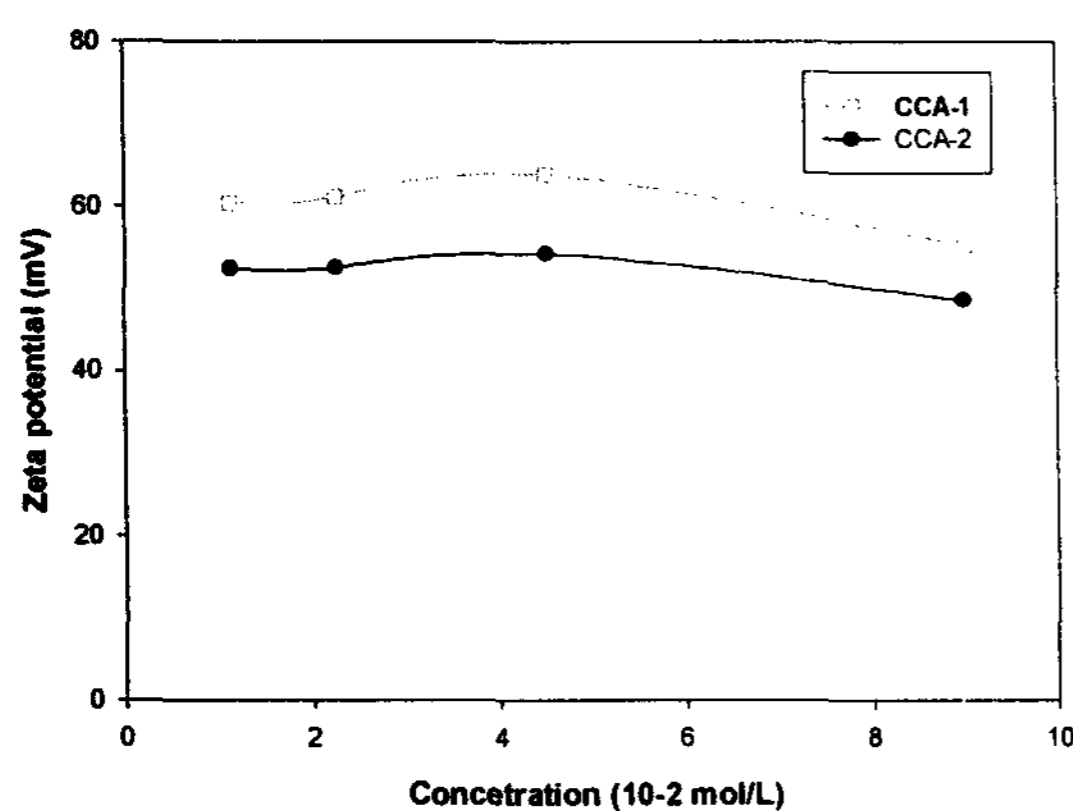


Figure 6. Zeta potential values of charged TiO_2 particles with CCA concentration.

4. Conclusion

Optimum formulation of photosensitive resin for TSMP method to produce electrophoretic display panels and reaction conditions on the synthesis of cationically charged TiO_2 particles were studied. In addition, the fabrication and performance of electrophoretic display were investigated.

It was observed that with the optimum formulation of the photosensitive paste, box-type barrier ribs with good flexibility and high solvent resistance on the substrate was fabricated after UV curing. It was also found that charged TiO_2 particles with 74.09 mV of zeta potential and $3.11 \times 10^{-5} \text{ cm}^2/\text{Vs}$ of mobility were successfully prepared.

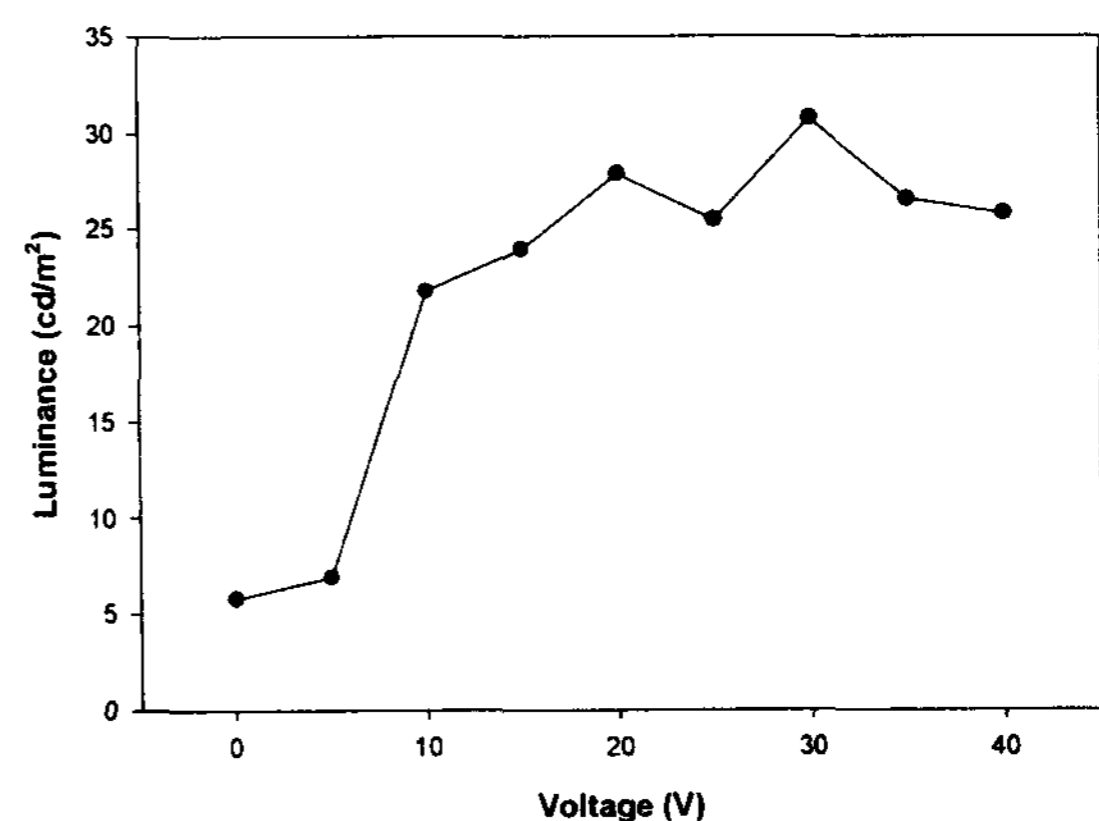


Figure 7. Luminescence vs. voltage curve of electrophoretic display.

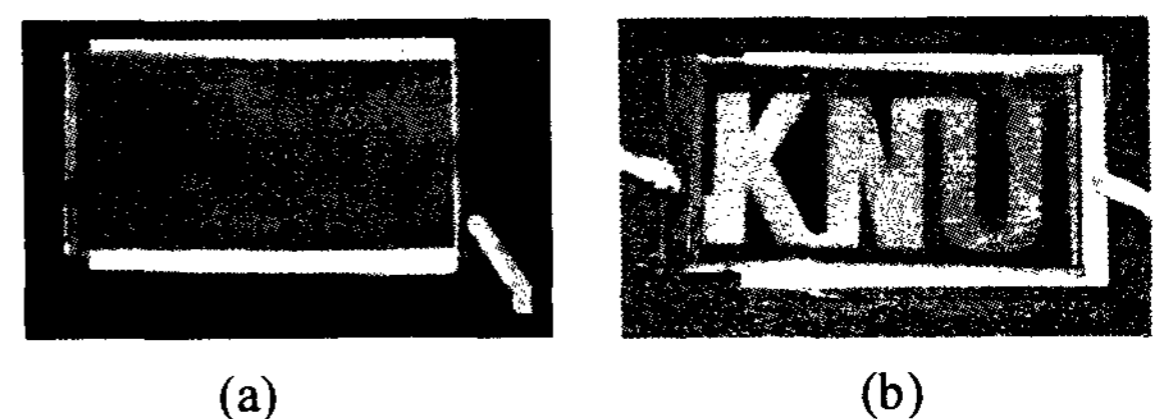


Figure 8. Photographs of electrophoretic displays in (a) power off and (b) power on (30V).

5. Acknowledgements

This work was supported by grant No. R12-2002-055-01001-0 from the Basic Research Program of the Korea Science & Engineering Foundation.

6. References

- [1] N. K. Sheridon et al., International Display Research Conference, 82 (1997).
- [2] J. M. Crowley et al., US patent 5,262,098 (1993).
- [3] G. Duthaler, K. Suzuki, T. Nakamura, SID02 Digest, pp. 1374-1377 (2002).
- [4] P. L. Luisi, B. E. Stranb(editors), Reverse Micelles, (Plenum Press), (1984).
- [5] R. C. Liang, J. Hou, J. Chung, and H. M. Zang , IDMC'03 Proceedings, Fr-17-05, p. 351, Feb., 2003, Taipei, Taiwan.
- [6] R. C. Liang, J. Hou, J. Chung, X. Wang, C. Pereira and Y. Chen, SID 03 Digest, p. 838 (2003).
- [7] J. H. Jean and T. K. Gupta, J. Mater. Sci., 27, 4967 (1992).
- [8] R. L. Coble, J. Appl. Phys., 3295, 787 (1961).
- [9] D. M. Mattox and J. H. Robinson, J. Am. Ceram. Soc. 80(5), 1175 (1997).
- [10] K. Dietliker, Chemistry & Technology of UV& EB Formulation for Coating, Inks & Paints.
- [11] S. A. Gallo, ISHM Europe, 1987.
- [12] J. H. Choi, L. P. Drozdyk, M. Tsuchiya, IDW '98 The Fifth International Display Workshops.
- [13] J. P. Cazenave, proceedings of the 1993 ICEMM, Denver, 301 (1993).
- [14] PCT/ US 1998/ 04705.
- [15] PCT/ US 1999/ 23313.