Novel Liquid Toner Electrophoretic Display

Pinyen Lin, Chieh-Min Cheng, and David H. Pan; Xerox Corporation, Webster, NY 14580, USA

Abstract

A novel method for producing charged particles suspended in a dielectric fluid for electrophoretic display is presented. Typical charged particles for electrophoretic display contain polymer resin, color pigment, and/or charge controlling compound. Many methods for producing charged particles have been reported including the polymerization in the presence of pigment particles. In this paper, we described a method to meltmix polymer resin, pigment, and charge controlling agent all together in the dielectric fluid such as Isopar. The resulting solution contains charged color particles with average particle size about 2 µm or less. The colored particle solution was mixed with white particle solution containing titanium dioxide to form a two-color switching electrophoretic display. The display built with such two-particle solution was demonstrated. The solutions of two-color particles can be sealed between two thin plastic films with small divided compartments. A roll-to-roll manufacturing method that provides large area of small compartment with two-color particle solutions was discussed.

Introduction

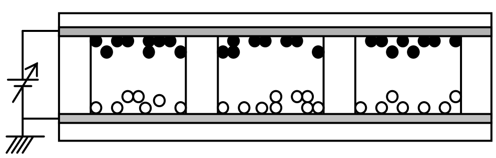

***Figure 1**. The schematic drawing of 2-color electrophoretic display*

Electrophoretic display has been demonstrated since 1990's. An electrophoretic display using microcapsule, liquid crystal image display, a twisting ball display, photo-address electronic paper and polymer dispersed liquid crystal electronic paper are reported as rewritable technology.[1-4] Figure 1 showed the concept of the 2-color electrophoretic display. The ink encapsulation with polymer shell as the ink compartment is the most popular approach.

Liquid toner xerography has been developed since 1980's. The toner was suspended in dielectric fluids such as oil. The average size of liquid toner can be about 2 µm or smaller, which provides superior image quality over the conventional dry toner. Conventional dry toner particles can not be so small since the particles will be air borne and cause human health problems.

Liquid toner particles are charged just like conventional dry toner. The charge of the liquid toner is due to the charge control agents on the toner surface and the counter charge director micelles in the fluid (Figure 2). Conventional toner has to be dried if it is produced from chemical methods or pulverized if it is produced by melt mixing. Since the final product format of the liquid toner is suspended particles in the fluid, it makes sense that the liquid toner is produced in the fluid for final use. In this paper, we will focus on a novel method for producing charged particles suspended in a dielectric fluid for electrophoretic display.

Figure 2 describe the charge mechanism. Liquid toner particles contain CCA and pigment in the toner resin. The charge director micelles act as counter charges in the dielectric fluids.

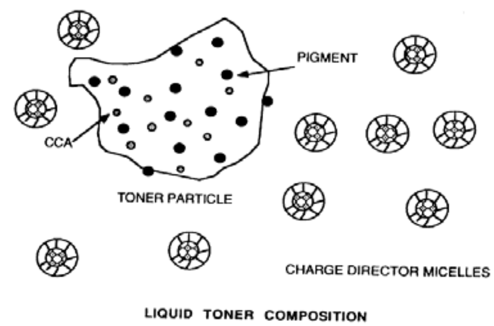

***Figure 2**. Liquid toner charge mechanism*

Experimental

The toner process include 2 major steps: melt mixing process and cool-kneading process. As shown in Figure 3, a stainless steel attritor with steam heating from the surface jacket was used for these processes. First, the resin, pigment, and charge control agent, dielectric fluid, and grinding balls were added in a preheated attritor at 100°C. After 2 hours of mixing, the steam was turned off. The mixing continued in this cooling and kneading process. Typical process time in this step is about 3 hours. After this step, the mixing was stopped and the grinding balls were filtered out from the final product. We have found that the surface charge on the particles were very sensitive to the material of the grinding balls. When stainless steel balls were used, the white particles turned a little gray color and the surface charge was not very high. zirconia balls were found to maintain very well the whiteness for white particles with our resin and charge control agent. All the toner presented in the paper was made with zirconia balls.

***Figure 3**. Attritor with grinding balls*

White particles

Titanium oxide particles (Tipure, from DuPont) were used as the pigment for the white particles. The resin is NUCREL 599 (a copolymer of ethylene and methacrylic acid, from E.I. DuPont de Nemours & Company, Wilmington, Del.). The charge control agent (CCA) is an organic aluminum complex such as aluminum-di-tertiary butyl salicylate (ALOHAS). The weight ratio for resin:pigment:CCA is 75:25:1. The dielectric fluid is ISOPAR M (Exxon Corporation) which was added to a Union Process 1S attritor (Union Process Company, Akron, Ohio) charged with 5-mm diameter zirconium balls. The solid content is 13% by weight. The mixture resulting was milled in the attritor, which was heated with running steam through the attritor jacket to 80°C. to 115°C for 2 hours. The mixture was then cooled to 23°C. by running water through the attritor jacket. The contents of the attritor were ground for an additional 3 hours. The mixture resulting was separated from the zirconia shots. The average particle size from this process is about 2.5 to 3.5 µm with GSD of about 1.2.

Black particles

The black pigment contains both magnetite particles and carbon black. Carbon black has good light blocking properties that can provide very good contrast, but it is not insulative to hold the charge when the percentage is too high. The weight ratio between the magnetite particles (such as MTH-009F from TODA, Japan) and the carbon black (such as REGAL 330 from Cabot Corporation) are 6 or higher. The resin is NUCREL 599 and the CCA is an organic aluminum complex such as aluminum-di-tertiary butyl salicylate. The weight ratio for resin:pigment:CCA is 60:40:0.25. The processing conditions are the same as described above. The final solid content for black dispersion is about 9.0%.

Blue particles

Blue particles also provide good color contrast when working with white particles. Blue pigments such as heliogen blue were used as the pigment for the blue particles. The resin (NUCREL 599) and the CCA are the same as previous particles. The weight ratio for resin:pigment:CCA is 75:25:0.25. The processing conditions are the same as described above. The final solid content for blue dispersion is about 3.9%.

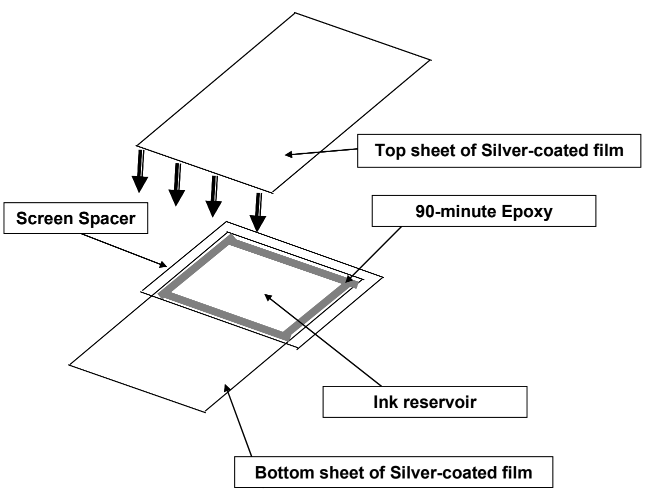

***Figure 4**. The process for making electrophoretic display*

Electrophoretic Display

The components of a typical electrophoretic display for testing liquid toners are shown in Figure 4. Both sides of the spacer were first coated with adhesive. The spacer was then mounted on the bottom sheet of silver-coated film, followed by mounting the top sheet of silver coated film. The liquid toner dispersion was then injected into the space between the top and bottom sheets. The final step is to connect the electrophoretic display to a power supply. The final electrophoretic display for testing liquid toners is shown in Figure 5. The connections between the power supply and the display are not shown in Figure 4 and 5. This spacer is polymeric films with pre-determined empty structures as ink compartments. This spacer-adhesive laminates can encapsulate ink and seal the ink for the display, which is feasible for roll-to-roll manufacturing method.

Two-color particle systems

The optimum composition of two-color particle system is determined by the optimum color contrast, switching filed (V/µ), switchability and 100K cycle switching test. The switching field ranges from 0.5 to 2.5 V/µ with an 80 µm gap between the two confining electrodes. The switchability was determined by how fast the white and the color refresh itself. Non-optimal color and white particle mixture tends to stick to plate, resulting in a slow color refreshing rate. Since the focus was on maximizing the color-white contrast initially, we used a scale: fast, medium and slow to qualitative screen the particle composition and two particle mixing ratio. It was found that the solid white particles should be more than the color particles and the weight ratio of white particles to color particles is above 2 and less than 4. More white particles are needed to achieve the best contrast in color.

***Figure 5**. Eletrophoretic display and device for testing*

Results and Discussion

Typical two-particle formulations are shown in Table I. For each individual particle formulation, the conductivity is also included in Table I. It was found that a conductive black particle formulation did not work too well. The last column of Table I lists the other mixing ratio tested for the two particle system. The best mixing ratio was determined by high color contrast and fast color refresh rate. Figure 6 displays the optical density (OD) contrast for the current best black/white and blue/white particle systems. The OD contrast can vary from 0.26 to 0.84. Even for the same black and white particle, the OD contrast increases significantly with the increase of the amount of white particles, e.g., in the EV particle system (see Table I).

Table I. Various tested black, blue and white electrophoretic particle systems.

INK NAME	COLOR COMP	WHITE COMP	BEST	OTHERS
A	;-12 Black	;-11 White	4/5	4/5, 5/5, 3/3
	Magnetite; 25%	TiO2; 25%		
	Nucrel 599; 75%	Nucrel 599; 75%		
	Alohas 6; 0.25%	Alohas 6: 1%		
	Solids; 8.07%	Solids; 12.96%		
	Conductiv, 0.30 p/cm	Conductiv, 0.29 p/cm		
Y	Heliogen blue	;-11 White	3/3	3/4, 2/6
	Pigment; 25%	TiO2; 25%		
	Nucrel 599; 75%	Nucrel 599; 75%		
	Alohas 6; 0.25%	Alohas 6: 1%		
	Solids; 3.88%	Solids; 12.96%		
	Conductiv, 0.31 p/cm	Conductiv, 0.29 p/cm		
R 1	;-21 Black	;-11 White	2/4	3/3, 1.5/6
	Mg/MTH-009F; 40%	TiO2; 25%		
	Nucrel 599; 60%	Nucrel 599; 75%		
	Alohas 6; 0.25%	Alohas 6: 1%		
	Solids; 8.54%	Solids; 12.96%		
	Conductiv, 0.31 p/cm	Conductiv, 0.29 p/cm		
R II	;-22 Black	;-11 White	2/4	3/3, 1/3, 1.5/6
	Mg/TMB-100; 40%	TiO2; 25%		
	Nucrel 599; 60%	Nucrel 599; 75%		
	Alohas 6; 0.25%	Alohas 6: 1%		
	Solids; 9.68%	Solids; 12.96%		
	Conductiv, 0.29 p/cm	Conductiv, 0.29 p/cm		
H	;-23 Black	;-13 White	2/5	3/3, 1/3, 1.5/6
	Magnetite; 36%	TiO2; 25%		
	Carbon Black; 1.35%	Nucrel 599; 75%		
	Nucrel 599; 60%	Alohas 6: 1%		
	Alohas 6; 0.25%	Solids; 12.09%		
	Solids; 9.25%	Conductiv, 0.29 p/cm		
	Conductiv, 0.31 p/cm	made as -74		
EV	;-29 Black	;28 White	2/5	2/4
	Magnetite; 32%	TiO2; 25%		
	Carbon Black; 2.7%	Nucrel 599; 75%		
	Nucrel 599; 60%	Alohas 6: 1%		
	Alohas 6; .25%	Solids; 14.32%		
	Solid; 8.79%	Conductiv, 0.27 p/cm		
	Conductiv, 0.27 p/cm			

Table I includes the formulations of the current best black/white (EV ink) and blue/white (Y ink) two-particle systems. The current best black/white system gave a very good OD contrast. The black OD is as high as 1.47. The system required about 110V to switch to white. The black and white particles showed very little agglomeration thus only some degradation of black OD and black-white OD contrast after 100K cycle switch test. By contrast the current best blue/white two-particle system appears to give a lower OD contrast than the current best black/white system although the blue OD of about 1.5 can be achieved. The lower OD contrast is due to the agglomeration of a small amount of blue particles with the white particles in switching to white background, while a small amount of white particles mixed with a majority of blue particles does not seem to affect the blue OD significantly. Other performance issues of the blue/white two-particle system include more degradation of both color OD and color contrast as a function of switching cycles during a 100K cycle test than the black/white system.

Although several two-particle electrophoretic inks with excellent color OD and switchability with a low expected switching field, the charging mechanism of two-particle system is still not clearly understood. It was shown that the color contrast degrades after 100K cycle test. This may be due to the undesirable particle adhesion of the color particles with the white particles. Lastly, the key parameters for ink process control are not fully defined yet. This may lead to a display to display various.

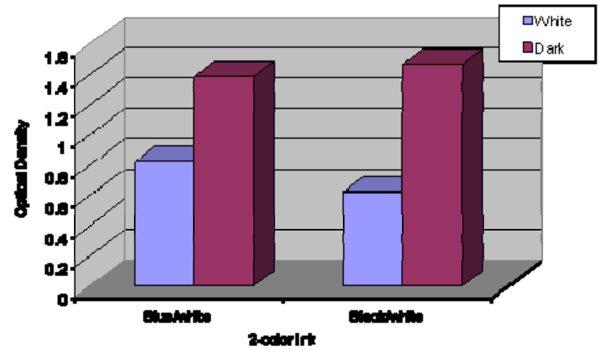

Figure 6. **Optical density of 2-color electrophoretic displays.**

References

[1] J. Doe, Recent Progress in Digital Halftoning II (IS&T, Springfield, VA, 1999) pg. 173.

[2] M. Smith, "Digital Imaging," Jour. Imaging. Sci. and Technol., 42, 112 (1998).

[3] B. Comiskey, J. D. Albert, H. Yoshizawa, J. Jacobson, Nature, 394, 16, pg. 253 (1998).

[4] H. Kawai, N. Kanae, Proceedings of Japan Hardcopy'99, pg. 237 (1999).

Author Biography

Dr. Pinyen Lin received his BS in Chemical Engineering from National Taiwan University (1982), MS in Polymer Science from Polytechnic University (1986), and PhD in Materials Science and Engineering from Massachusetts Institute of Technology (1990). After MIT and 2 years of visiting research at Hitachi Research Laboratory in Japan, he has worked in the Supplies Materials Division and Research Center at Xerox in Webster, NY. His research interests include the imaging materials and processes, inkjet, electrophoretic display, and MEMS.

Dr. Chieh-Min Cheng is a Principal Scientist and the Manager of the Chemical Toner Delivery in Xerox Corporation. He has worked at Xerox for over 13 years in both the toner design/manufacturing and thermal ink jet technology areas. He holds 58 U.S. patents on graphic art imaging, ink, toner, photoreceptor, and electronic paper technology. Chieh-Min received his M.S. in Chemical Engineering and Ph.D. in Polymer Science and Engineering from Lehigh University. He came to Xerox from a scientist position at Polaroid Corporation in 1995.

Dr. David H. Pan received his PhD in Chemical Engineering from the University of Wisconsin-Madison (1983). He worked as a research associate at the Materials Science and Technology Division, Argonne National Laboratory for two years during his PhD studies. After 6 months of teaching and postdoctoral research at the Department of Chemical Engineering, UW-Madison, he joined Webster Research Center at Xerox. His research interests include surfaces of polymer blends, elastomeric nanocomposites, fluoroelastomers, imaging materials, fusing materials, liquid and powder xerography, and phase change inkjet technology. He holds 79 US patents with another 14 at different stages of patent application, and published over 30 papers.