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Electro-Optic Response Characteristics of a Dual Particle Electrophoretic Display System

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Electrophoretic nanoparticles of polystyrene (PS)-encapsulated red pigments were prepared by an emulsifier-free in-situ *emulsion polymerization method and the zeta potential of the red nanoparticles was +190 mV. We demonstrated a dual particle electrophoretic display (DPEPD) system with red and white contrast using the positively charged PS-encapsulated red pigment particles and the negatively charged white particles of rutile titanium dioxide. The scattering light intensity ratio of the white and red images was ∼1.7 but we could clearly observe the reversible color change between red and white when the polarity of the applied electric field was switched. 4 The turn-on and turn-off response times of the device were measured to be ∼750 and ∼650 ms, respectively, when +1.4 and −1.4 V/μm DC field were alternately applied to the front electrode.*

Keywords: dual particle system; electrophoretic display; electric-optic response characteristics; polymer-inorganic hybrid nanoparticles

INTRODUCTION

The Electrophoretic display (EPD) is a reflection or scattering type display based on the electrophoretic movement of charged particles suspended in a dielectric medium. Epd offers unique performance advantages, including high reflectivity and contrast, portability, and extremely low power consumption due to the long-term image stability

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[1–3]. however, it possesses intrinsic problems for the achievement of perfect color, for instance, particles might become cluster or coagulation caused by a lower dispersion stability [4–5]. in addition, color particles were difficult to have high zeta potential [6–8].

In this work, we demonstrate a dual particle electrophoretic display (DPEPD) system with red and white contrast by using the nanoparticles of polystyrene (PS)-encapsulated red pigments and the white particles of rutile titanium dioxide (TiO_2), which may be implemented for a color EPD. Also, we analyzed the electric-optic response characteristics of the DPEPD in terms of scattering intensity, contrast ratio, and response time [9–10].

EXPERIMENTAL

Materials

The inhibitors in styrene (CiCa) and divinylbenzene (DVB, Fluka) monomers were removed by passing the monomers through an inhibitor removing column (Aldrich). Potassium persulfate (KPS, Aldrich) was recrystallized from deionized water and dried under vacuum for 24 hr. The red pigment (F5RK, Clariant), sodium lauryl sulfate (SLS, Aldrich) and BYK180 were used as received.

The Synthesis of Polystyrene (PS)-Encapsulated Red Pigments

The pigment-embedded polymer hybrid nanoparticles were synthesized using a miniemulsion technique. The aqueous phase, the solution of SLS dissolved in deionized water was prepared at 70°C with gentle mixing for 2 hr. The organic phase consisting of DVB and red pigment stabilized by BYK180 in styrene monomer was perfectly mixed under mild agitation for 5 min. The SLS solution was poured to the organic solution under vigorous mixing and ultrasonication for 10 min in a Branson sonic bath, followed by addition of KPS dissolved in deionized water. During polymerization, the reaction mixture was stirred with a mechanical stirrer at about 400 rpm. The red pigment-embedded styrene hybrid nanoparticles were cleaned via multiple cycles of centrifugation, removal of supernatant, and then freeze-drying for 48 hr.

Characterization

The zeta potential along with the mean size and size distribution of the red particles were measured with an electrophoretic light scattering

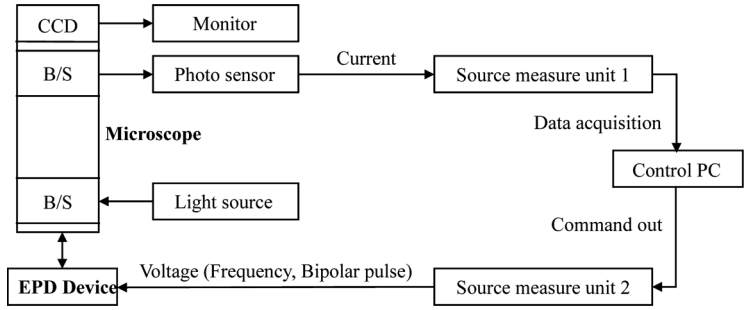

FIGURE 1 Schematic diagram of the experimental setup for measuring the electro-optic response characteristics of electrophoretic displays.

equipment (ELS-800, Otsuka). White TiO_2 (Rutile-104, 0.2 μm, Dupont) and the red particles were dispersed in the mixed solution of halocarbon as a dielectric fluid and OLOA1200 (Chevron) as a surfactant, and then injected to the blank cells with 70 μm thickness. The electrophoretic dispersion consisted of halocarbon, white TiO_2 particles, PS-encapsulated red pigment particles, and OLOA1200 with a weight ratio of 500:7.5:7.5:0.04, respectively. Electric-optic response characteristics of the DPEPD were analyzed by using a specially designed experimental setup shown in Figure 1.

RESULTS AND DISCUSSION

The PS-encapsulated red pigment particles have the mean diameter of ~120 nm, and Figure 2 shows the size distribution and the scanning electron micrograph of the red particles. The zeta potential that represents the surface charge, dispersion stability, and electrophoretic mobility of the red particles was measured to be +190 mV in a halocarbon fluid. Therefore the particles are expected to have high dispersion stability in the medium due to a strong repulsive Coulombic interaction among them. When a bipolar electric field was applied to the DPEPD device, the negatively charged white particles moved to the positive electrode while the positively charged red particles moved to the negative electrode, showing the red and white color contrast. Although the contrast ratio of the DPEPD, which was defined as the scattering light intensity ratio of the white and red images, was not very high (~1.7), we could clearly observe the red and white color change when we switched the polarity of the applied electric field. The above definition of contrast ratio, which is based on the conventional contrast ratio concept for backlit LCD, does not seem to be

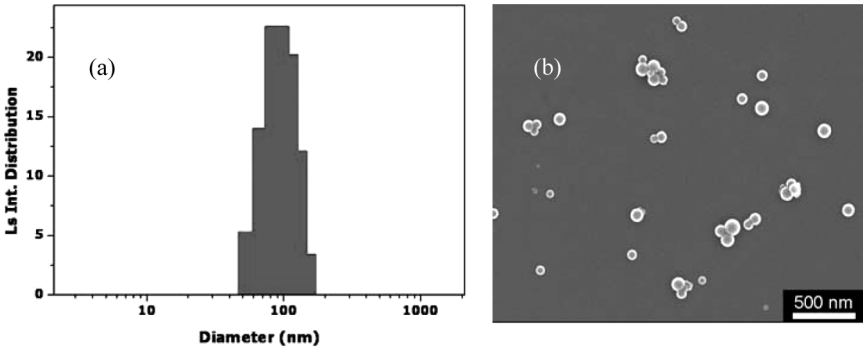

FIGURE 2 (a) The size distribution and (b) the scanning electron micrograph of the PS-encapsulated red pigment particles.

suitable to describe the color change by the scattering color particles, because it does not sufficiently represent the real color contrast perceivable by human eyes. Therefore it is quite necessary to develop a new concept of color contrast ratio for the dual particle color electrophoretic display system and the standard method to measure it.

The maximum minus minimum scattering intensity (i.e., non-normalized contrast) of the DPEPD device was plotted as a function of the applied bipolar field strength, as shown in Figure 3. The scattering

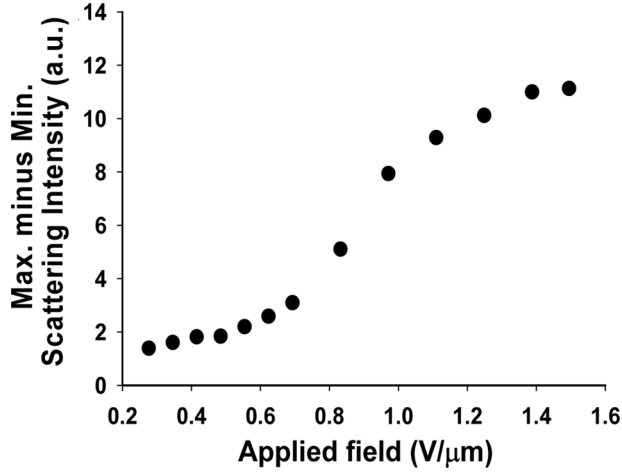

FIGURE 3 The maximum minus minimum scattering intensity of the red and white dual particle electrophoretic display system measured as a function of the applied bipolar field strength.

intensity difference between the white and red images increased with increasing field strength until it reached the maximum value when the field of 1.4 V/μm was applied. Because the scattering intensity difference originates from the electrophoretic separation of the oppositely charged red and white particles, it will largely depend on the zeta potential, average size, and size distribution of the both particles, and the applied field strength.

The strongest light scattering by particles occurs when there is the maximum refractive index difference between the particle and the surrounding medium. Also, the particle and the medium should match in specific gravity to prevent gravitational settling [11]; however, specific gravity of a particle tends to increase with its refractive index. For instance, the rutile form of TiO_2 has a high refractive index (∼2.9) but, its specific gravity is very high (∼4.2) compared with those of ordinary dielectric mediums. The DPEPD device tested in this work could not show a brilliant red image due to a relatively low refractive index of the polymer-inorganic hybrid red particles. In addition, the mismatch in the specific gravities of the white particles (∼4.2), the red particles (∼1.2), and the halocarbon medium (1.3∼1.4) degraded the dispersion stability and therefore the color contrast of the device.

Figure 4 shows the electro-optic response of the DPEPD system. We calculated the response time (t_{on} or t_{off}), which is defined as the time required for a 90% change in the scattering light intensity just after the polarity of the electric field applied to the device is reversed [12]. The turn-on response time (t_{on}) for white image and the turn-off response time (t_{off}) for red image were measured to be ∼750 and ∼650 ms, respectively, when +90 and −90 V DC pulses were alternately

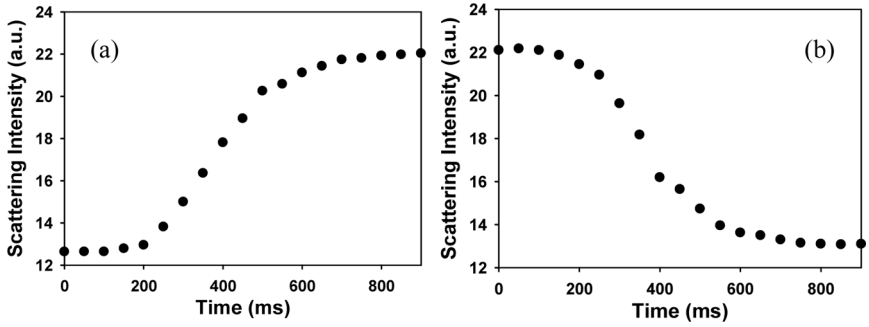

FIGURE 4 The electro-optic response curves of the dual particle electrophoretic display system measured during (a) red-to-white and (b) white-to-red color change.

applied to the front electrode. Delay time of ~200 ms was observed for the reversible color change between red and white. Response time is strongly affected by the packing of the particles to the electrode and the specific gravity matching of the two colored particles [13]. The shape of the electro-optic response curve again reflects this packing process [12], which is based on the sequential electrophoretic motion of charged particles to the electrodes. The response time can be improved if the zeta potential of the particles is further increased and/or the densities of the particles and the dielectric medium are more closely matched.

CONCLUSION REMARKS

We demonstrated a dual particle electrophoretic display (DPEPD) system with red and white contrast by using the positively charged PS-encapsulated red pigment particles and the negatively charged white particles of rutile titanium dioxide. This approach of dual particle system to multi-color display applications may provide a pathway to realize a full-color EPD system without adopting the conventional color filter technique developed for LCD.

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