Understanding the Mechanisms of E-ink Operation

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ABSTRACT

Owing to the unique features of electrophoretic E-ink displays, including the bistability, paper-like appearance, and sunlight visibility, E-ink has been applied in many IoT environments. We will summarize the mechanisms frequently used while designing the E-ink displays, which may facilitate the new beginners to start their research in E-ink fields.

1. Introduction

Because of the special advantages of bistability, paper-like appearance, and sunlight visibility, electrophoretic displays (EPDs) have been widely used in the e-reader, electric shelf label, smart bus stop signage, and so on. Recently, EPDs were further applied for IoT devices. Because in IoT, AI, and Smart Environments, people need very large quantity of terminal sensors to collect data (aka Big Data), which is crucial to cultivate the AI's central brain and consciousness. Imagining that each sensor has at least a display to communicate with users, the tremendous number of sensors would consume so much electricity, as well as manpower to replace the battery, and do the maintenance. As a result, EPD, with the inherent advantage of low power consumption, is regarded as one of the most important display technologies for future IoT environment.

However, E-ink is a kind of display technology whose operational principle is very different from the conventional LCDs and OLEDs [1, 2]. The charging process, driving scheme, and bistability mechanisms were not systematically established for the new beginners to do their research on E-ink. Therefore, to encourage more enthusiasts involve with the research of E-ink, we try to summarize what we think important for the EPD research beginners.

2. General view of E-ink operation

E-ink contains pigment particles, charge controlling agent (CCA), solvent, and various additives. The particles are usually surface treated and charged by CCA, thus they can be driven by external electric field. Therefore, specific distribution of pigment particles can be formed by designed waveform to show the designated grey level.
To explain the particles' behavior under different stage, the optical trace of these particles during the driving process are shown in Figure.1. In a typical driving waveform, particles are firstly shaken by alternating voltage, which makes particles activated. Then, particles are driven to the upper and bottom boundaries, which helps to erase the image history. Actually, the controlling of grey level in E-paper is not perfect enough, causing tiny difference of grey level, which is termed "ghosting". It worth noting that ghosting is usually related with the previous grey level of E-paper.

After removing the external driving voltage, the distribution of particles supposedly should not change due to the bistability characteristics of E-paper. But actually, the distribution of particles is still influenced by some factors, for example, built-in electric field, causing the variation of grey level of E-paper, which is called degeneration of grey level.

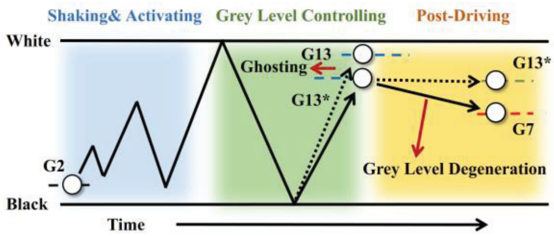

Figure 1. Optical trace of particle in PWM waveform.

By controlling the voltage applied between the two electrodes of the e-paper and the duration of applying the voltage, we can realize the multi-gray scale display of the e-paper. Generally speaking, as shown in Figure. 2, people use pulse width modulation (PWM) to control the movement of electrophoretic particles by controlling the polarity and duration of the voltage applied to the two electrodes of the e-paper, so that the spatial distribution of electrophoretic particles is different, and how to realize the grayscale display of the e-paper [3-6].

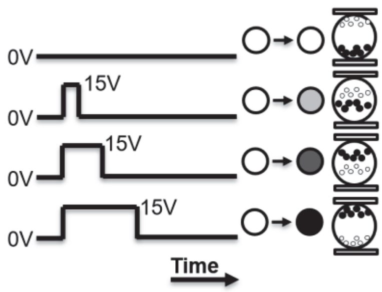

Figure 2. PWM waveform drive EPD.

3. Charging mechanism

The hydrophobic side of the surfactant dissolves and disperses in non-polar solvents and the hydrophilic side is adsorbed to the color particles because of its repulsion. Surfactants provide dispersity and suspension to particles while surfactants assemble together in micelles. In this process, some surfactants (CCA) endow the particles and micelles with charges [7, 8]. Except of friction factor between particles and solvent, the charge of the electrophoretic particle depends on modification of particles and functional group of CCAs.

Some particles which were modified by quaternization or polymerization of unsaturated fatty acid salts were charged by desorption of ions physically, as shown in Figure. 3 It is more common that Lewis acid-base reaction between CCAs and particles. CCAs with hydroxyl, carboxyl, sulfonate or phosphate will donate hydrogen atoms to particles with amino and accept electrons from particles, which makes particles positively electrificated and micelles negatively electrificated, as shown in Figure. 3.

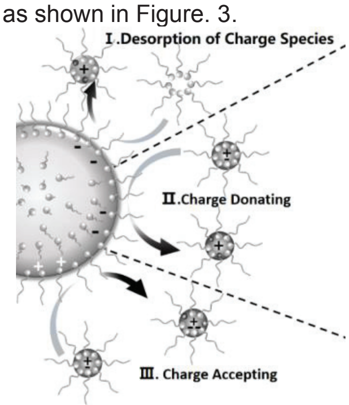

Figure 3. Charging mechanism of EPD.

4. Rheological effects during driving

To study the solvent's viscosity effect, iso-alkane in aliphatic hydrocarbons is used, where the solvents A-B represents solvents with different viscosity from low to high. We designed a new setup to gradually increase the applied voltage to see the optical response with varied external fields. The solvents are with different viscosity. It's suggested that the viscosity of solvent had a great impact on the electrophoretic velocity of particles. The lower viscosity means that the particles experience less resistance and greater velocity when moving, thus having a faster response speed, as shown in Figure. 4. [9,10]

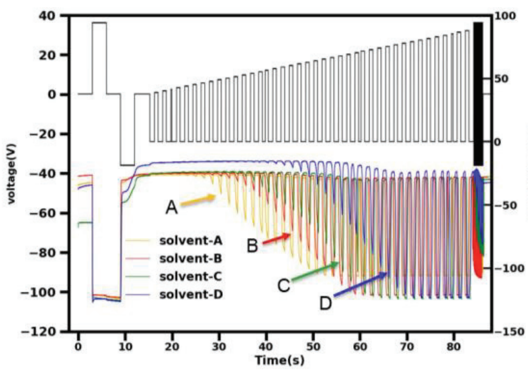

Figure 4. Optical response of various solvent viscosity

Furthermore, there is a phenomenon, which leads the viscosity reduced with the increasing applied voltage. It is also known as inversed electrorheological（IER） effect. One of the possible mechanism was proposed that the rotation of particles under application of a voltage in a liquid , i.e. Quincke rotation, could reduce viscosity by driving the surrounding liquid and inducing a IER effect. Particles are polarized under an electric field. After that, charges in the solvent system accumulate on the surface of particles due to coulombic forces, as shown in Figure.5.

Under shear force, the particle rotates in a random direction, so the total effects is zero. When there is a certain shear force, particles will tend to rotate along with the direction of shear force, so that most of the particles will rotate in the same direction to form the flow field or enhance the original flow field, thereby reducing the viscosity of the solution.

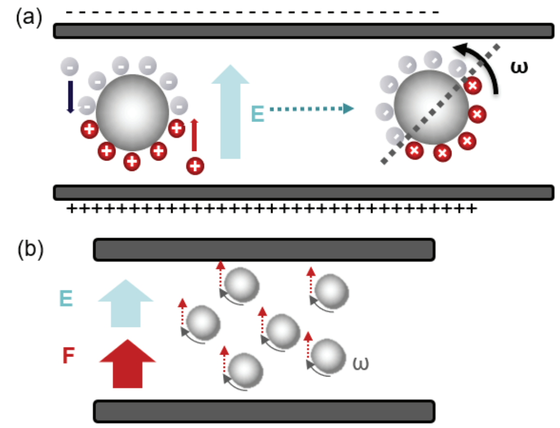

Figure 5.(a) Quincke rotation (b) Quincke rotation in EPD.

Generally, E-ink behaves like the pseudoplastic fluid (non-Newtonian fluid) [11]. As shown in Figure 6, under the same shear stress, the shear rate increases (shear thinning). Similar to E-ink operation, we usually use a shaking waveform to shake the particles, and then make the particles move faster increasingly.

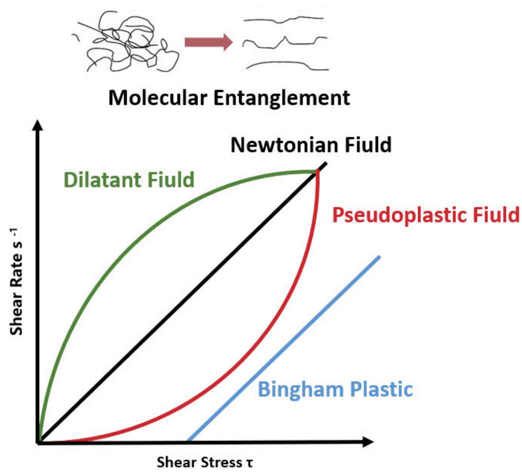

Figure 6. Influence of various viscosity on optical response.

The fluid behavior also varies with temperatures. As shown in Figure 7, owing to the high viscosity of solvent, the optical response under 5C was smaller than that of 25C [12-14]. While further increasing the temperature to

60C, the optical response dropped again, which is believed to be attributed to the desorption of CCAs or the less exchanging between the particles and CCAs, under the effect of high temperature Brownian motion.

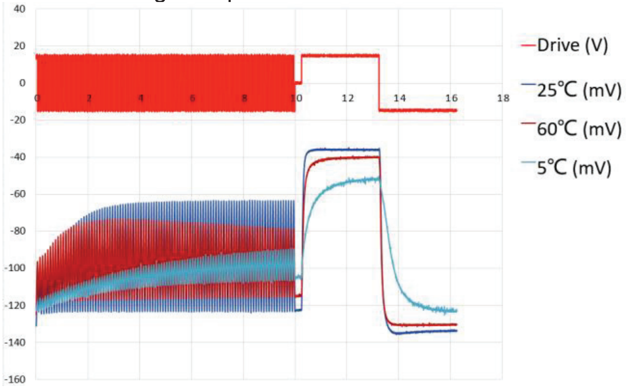

Figure 7. Activation of particles with various temperature in EPD.

5. Bistability after removing external fields

After removing the external fields, the particles tend to stay under the force balance. As shown in Figure. 8, there many forces acting on the particles to balance each other, such as the Buoyancy, Vander Waal force, coulombic force, frictional force, gravity, and solubility force. This mechanism is called “bistability”, which is the reason why particles can stay at the same place while removing the fields. Also, this leads to low power consumption of EPD related products. To further increase the bistability, a plausible way is to add some nano-particles or free polymers to induce the so-called delption flocculation effect. This effect makes the osmotic force to attract the particles tightly together, while still can be separated upon external field applied [15, 16].

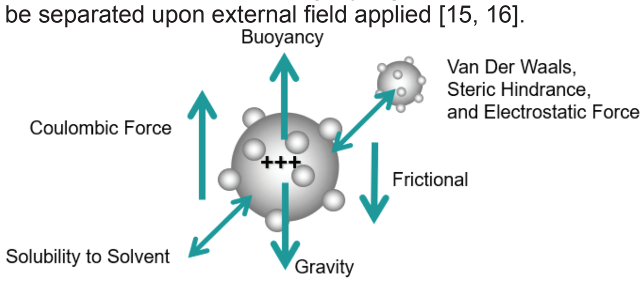

Figure 8. Forces in EPD.

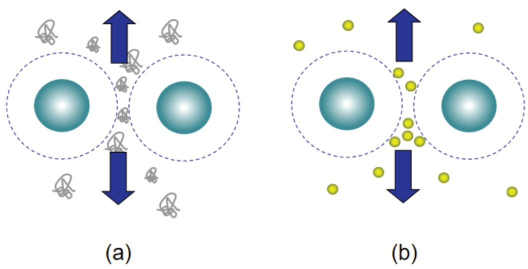

Figure 9. Depletion Flocculation for Bistability. (a) with free polymers and (b) with nan-particles.

6. Conclusion

In this paper, we reviewed and summarized the mechanisms usually used while researching the EPD driving scheme and materials design. The detailed description of the mechanisms will be explained during the presentation.

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