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Progress on Color Electrophoretic Displays

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Abstract. Electrophoretic display (EPD), also known as E-paper, is a reflective display whose mechanism is different from active emission display such as organic light emission display (OLED) and liquid crystal display (LCD). The commercially available EPDs are mainly black-and-white ones which are used as price tags and e-readers. Herein, some strategies for realizing a full-color EPD are reviewed. A full-color EPD would be a promising candidate in wearable electronics for information display due to its light-weight, flexible, and ultra-low power consumption.

Keywords: Electrophoretic display; wearable electronics; E-paper; full-color electrophoretic display.

1. Introduction

Information display technology is in a very mature stage and is now coming to a flexible era. Nevertheless, people still have the demand for paper as an information carrier. Conventional paper has the advantages of good flexibility, light weight, low cost and not easy to visual fatigue. However, after being printed or written, paper loses its function for displaying new information. The result of using paper as an information carrier is a waste of resources. Therefore, people try to develop a paper-like display that is also named as E-paper. A variety of technologies including rotating ball [1], cholesteric liquid crystal [2], Micro-electromechanical Systems (MEMS) [3], electrowetting [4] are used in the research and development of E-paper, but these technologies are limited by their respective technical bottlenecks and cannot achieve mass production or commercialization. Electrophoretic technology based on microcapsules [5] is the most mature commercial E-paper technology. Its products are widely used in E-readers, commercial tags and billboards. In addition, the application of E-paper as an information terminal in the field of Internet of Things (IoT) is thriving, and E-paper readers entered students' classrooms, which is expected to replace traditional textbooks and reduce the burden of schoolbags for students.

2. The mechanism of EPD

Micro-capsulated electrophoretic display (EPD), is a paper-like display technology, which is different from liquid crystal display technology (LCD) with backlight and organic light emitting diode (OLED). EPDs display the picture by reflecting ambient light. In contrast to the LCD, the EPD is clearer outdoors under the sunshine, and this reflective display has the visual experience of conventional paper and is not easy to have visual fatigue. In terms of device structure, the display film of EPD is closely arranged by a large number of microcapsules with particle size of 30 to 80 microns. A single microcapsule is composed of a capsule core and a capsule wall. The capsule core is an electrophoretic solution system, which is encapsulated by the capsule wall. The electrophoretic solution system includes dispersion medium, electrophoretic particles, charge control agent, dye, background pigments, stabilizer and other components. The early developed EPD was not divided into a large number of small units by capsules or micro cells, but connected between the two electrodes. Agglomeration and caking sedimentation of electrophoretic particles are the main factors affecting the performance of early EPDs. But with the emergence of microcapsules and microgrids, this problem was solved. It can be seen that dividing the electrophoresis system into

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small units is conducive to the local stability of the electrophoresis system. In the components of the electrophoretic solution system, the dispersion medium is liquid oil phase (non-polar solvent), and the electrophoretic particles play a role in color rendering in the display. The physical parameters such as viscosity, density, dielectric constant of oil phase, volume and charge of particles should be matched between the dispersion medium and electrophoretic particles in order to realize the bistable characteristics of EPDs. The dispersion medium and electrophoretic particles constitute the main body of the electrophoretic system. The charge on the particle surface is selectively and preferentially adsorbed by the particle surface, and the role of charge control agent is to increase the charge on the surface of pigment particles [6]. Dyes were used as background color in microcapsules in the early days. The scattering of light by white particles forms a white state, while dark dyed solution forms a dark state as the background color. However, the dyed solution exists in the gap between white particles, resulting in impure white color development. The introduction of two particle system solved this problem. Black particles replace dyes to form a dark state. Although the two-color particle system is more complex than the single particle system, it does help to improve the contrast of the display. The stabilizer is generally a surfactant, which makes the electrophoretic particles evenly and stably dispersed in the medium and prevents the agglomeration between particles or deposition on the capsule wall. The display mechanism of EPD is shown in Figure 1.

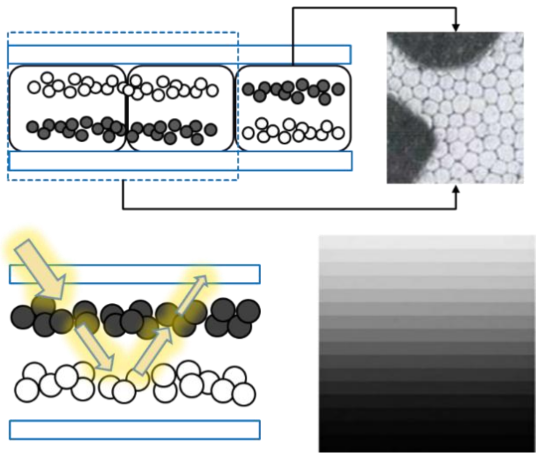

Figure1. The display mechanism of EPD, and the relative position of black-white particles determines a certain greyscale.

3. Colorization strategies

The main color of E-paper is black-and-white. Colored E-paper can render more information and enrich the picture. Researchers have also devoted many efforts to its research and development. The colorization technology for EPD can be roughly divided into color filter scheme, lateral driving scheme, multi-particle dispersion system and microcapsule sub-pixel scheme, as shown in Figure 2.

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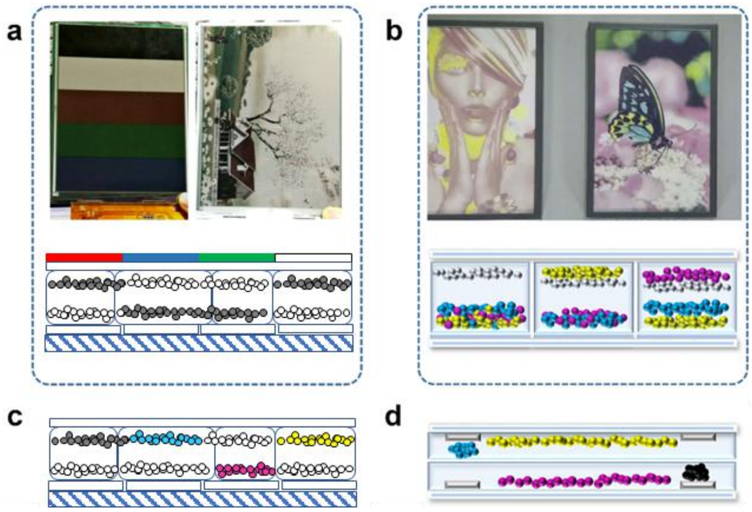

Figure2. The four color EPD strategies.

In the above schemes, the color filter is the most mature mass production technology. The color filter array formed by lithography process is added to the black-and-white microcapsule film as shown in Figure 2a. However, the color filter subtracts two-thirds of the reflected light and reduce the whiteness from 50% to 15% [7-8]. Multi-particle system has always been the focus of research and development in industry (Figure 2b). After the launch of three particle system consisting of red, white and black particles [9], the corporation E Ink launched the advanced color e-paper (ACeP) [10] at SID exhibition in 2016, in which two particles are positively charged and two are negatively charged. This prototype presents full-color images, which is because it follows the subtractive color mixing principle and avoids the reduction of brightness, color saturation and resolution caused by sub-pixel color mixing scheme in reflective display. However, the complexity of the system inevitably makes the driving waveform complicated, and the time to refresh the picture has reached the order of 10 seconds. Color microcapsule subpixel (Figure 2c) is a compromise scheme, which uses three primary color-black microcapsules and white-black microcapsules to replace the color filters. Although this scheme retains the sub-pixel structure, it uses the two-particle system of black-white microcapsules, and the picture updates quickly. Moreover, different from the absorption of reflected light by color filter film, microcapsules present color directly by color particles, which means no more light will be lost. For the lateral driving scheme (Figure 2d), the color charged particles are driven by the lateral electric field. However, there are still many problems to be solved in the aspects of complex electrode constructing, particle agglomeration, small opening ratio and particle control.

4. Conclusion

On the road to commercial application, some technical problems of color EPDs need to be further solved. In addition, the market demand for color EPD remains to be studied. In addition to the display for advertisements, tags, and reading, the emerging demand in the IoT era is a great driving force to promote the commercialization of color EPD. At present, multi-particle EPD is making efforts in the consumer electronics market. It is believed that color EPD will be widely available in the near future.

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