Electro-Optical Characteristics of Mobile Fine Particle Display with Liquid Crystal

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Abstract

We proposed a new type of display called Mobile Fine Particle Display (MFPD) with liquid crystal (LC). In MFPD cell, fine particles are doped and dispersed within nematic LCs and the display changes because of the horizontal movement of the fine particles. It is found that the fine particle migration of MFPD is different depending on the type of fine particle. In addition, the influence of doping a charge transfer complex (CTC) on the performance of MFPD cells has been experimentally investigated.

Introduction

It is evident that the ever-increasing amount of paper consumed by our society contributes significantly to some of the world's most serious environmental problems such as deforestation, the depletion of the ozone layer and garbage disposal. Therefore it is becoming increasingly urgent to find alternatives to paper in order to significantly reduce environmental damage. We must strive to become a "paperless" society. Displays as an alternative to paper are an ideal solution. In addition, legible displays are required in the aging society. From these social conditions, it is predicted that the electronic paper displays will become more and more popular.

Recently, various electronic paper display modes are proposed; such as an in-plane electrophoretic display [1,2], a microencapsulated electrophoretic display [3,4], a twisting ball display [5], a toner display [6,7], and an electrodeposition device [8]. It is required that such electronic paper displays are characterized by display memory function, rewritability, convenience, low manufacturing cost and high legibility. In order to approach these performances, we proposed an MFPD (Mobile Fine Particle Display) using nematic liquid crystal doped and dispersed with special fine particles [9,10]. In the MFPD cell, the fine particles are moved to a horizontal position for switching the display by the applied electric field.

Principle of MFPD Mode

Figure 1 shows fundamental cross section structure of MFPD cell (1 pixel). The opaque electrode is formed in the upper substrate, and the light absorption layer and the transparent electrode are formed in the bottom substrate. The nematic liquid crystal, which is mixed at 10-25 wt% with white color fine particles (2-20 μm diameters), is used for this display. Thickness of the MFPD cell is 50-200 μm. A vertical orientation film has been formed on the surface of both substrates, and liquid crystal molecules are orientated in the direction which is vertical from the substrate plane. The position of the fine particles-group in each pixel can be controlled by the applied electric field, which is a DC field or a biased AC field.

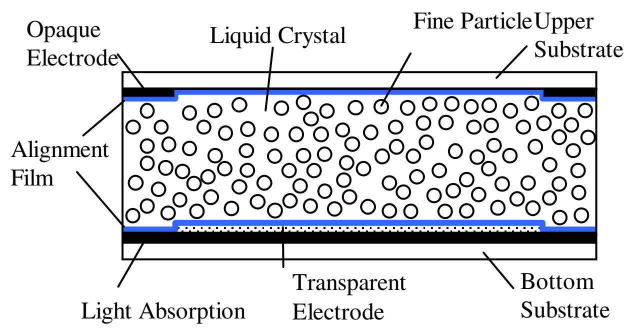
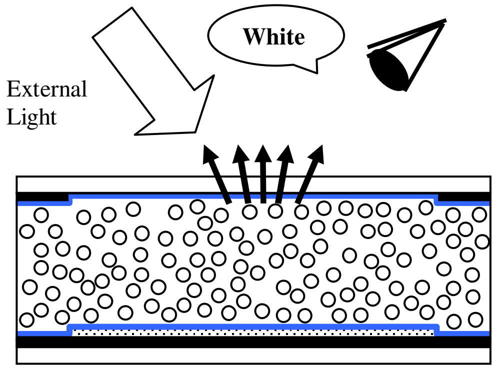
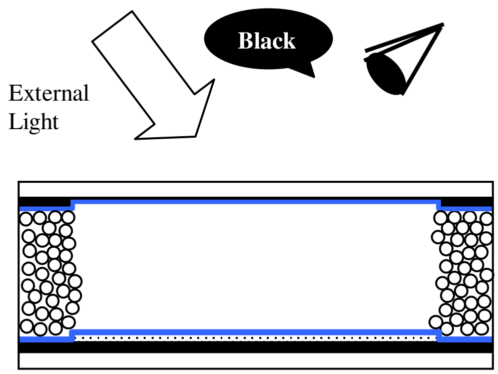


Figure 1. *The structure of MFPD (fundamental structure).*

The display switching principle of the MFPD cell is shown in Figures 2 and microphotographs of actual MFPD cell are shown in Figures 3. Figure 2 (a) shows the white display condition. In the white display, the white fine particles disperse in the pixel and the white fine particles scatter the external light. Then the bright white display is obtained (Figure 3 (a)). In Figure 2 (b), the white fine particles move under the opaque electrode pattern of the upper substrate. Then, the external light penetrates the liquid crystal layer, and is absorbed in the light absorption layer. Therefore, the black display is obtained (Figure 3 (b)).

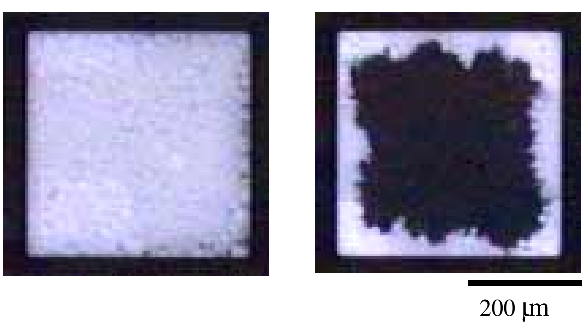


(a) *White display*



(b) *Black display*

Figure 2. *Display switching principle of the MFPD cell.*



(a) White display *(b) Black Display*

Figure 3. *Microphotographs of the MFPD cell.*

Fine Particle Migration in MFPD

The example of observing the fine particle migration in MFPD is shown in Figures 4.

From Figures 4 (a)-(d), it is clear that the fine particles are moved in a horizontal direction by applying DC voltage. Transfer directions of the fine particles are decided by the polarity of DC voltage. We confirmed that the transfer of the fine particles is repeatedly possible. After the DC voltage is turn off, the fine particles do not move for over several months in the position. This indicates display memory of MFPD is fairly high. It is considered that the high memory of MFPD originates from the self-orientation of liquid crystal. Orientated liquid crystal molecules retains the fine particles for a long time.

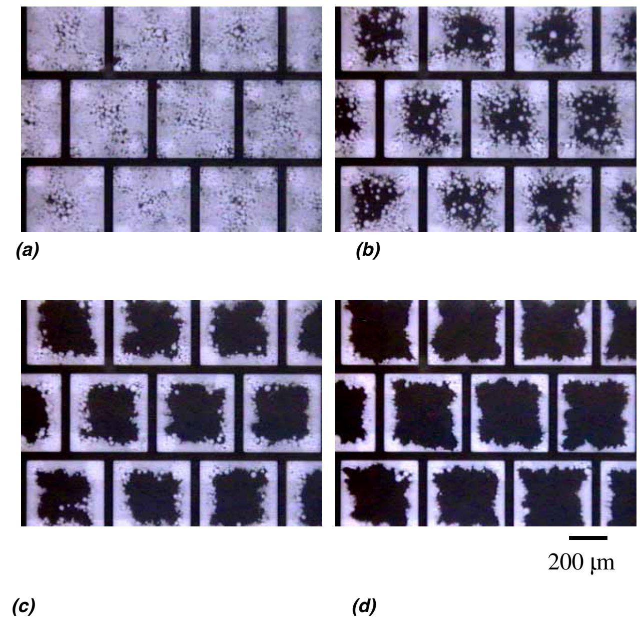


Figure 4. *The example of fine particle migration.*

Effect by Adding Charge Transfer Complex (CTC) Dopant in MFPD

The mechanism of the fine particles migration in groups in the MFPD cell is not yet clarified. However, we confirmed that the flow of the liquid crystal is generated in an MFPD cell without containing the fine particles by applying the electric field to the liquid crystal cell [9]. The improvement of the LC flow speed is connected for the improvement of the response speed of MFPD.

In this study, the effect of doping a CTC into the LC on the LC flow was investigated. Only LC without fine particles was injected into the MFPD test cell. The test cells substituted to the measurement have 75µm thickness. Substrate surfaces were coated by vertical orientation film. Figure 5 shows the molecular structure of CTC which we used in this experiment. The behavior of nematic LC having $\Delta\varepsilon>0$, doped with CTC dopant, was observed by a polarizing microscope when the DC voltage applied to the cell.

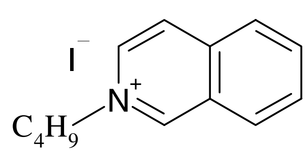


Figure 5. *Chemical structure of Charge Transfer Complex (CTC).*

By applying DC voltage to the LC cell, the flow of LC is observed, and the director of LC changes with the LC flow. We confirmed the flow of LC by observing in the LC cell under the polarizing microscope. Figure 6 show the examples of photographs of LC cell under the polarizing microscope when the applied DC voltage was changed. The brightness of the image corresponds to the behavior of the LC director. In Figure 6, which shows images for the changes of the optical pattern due to the LC flow, the behavior of the LC became more actively as the applied voltage was higher. In order to evaluate the speed of the LC flow, we noticed the changing speed of the optical image pattern corresponding to the activity of the LC under the polarizing microscope. The image data from the polarizing microscope were sent to the PC through the CCD. The evaluation was done to count the total number of pixel on the PC screen image that the brightness changed in every frame time interval by original software. The observed region was about 1mmϕ

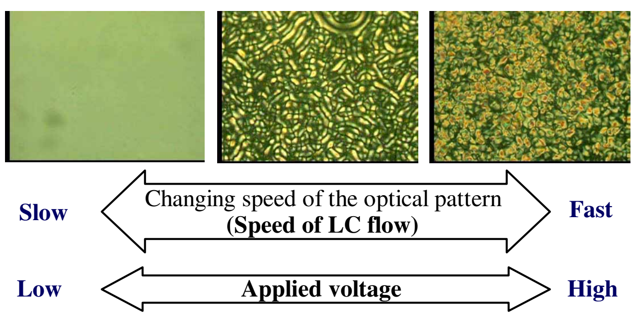


Figure 6. *Example of the polarizing microscope photograph of the LC cell.*

Figure 7 shows the changing speed of the polarizing microscope image dependent on the applied DC voltage. In Figure 7, the amount of doped CTC dopant was varied as 0%, 0.007wt% and 0.038wt%. It was proven that the movement (flow) of the LC became active, when the amount of doped CTC dopant was increased.

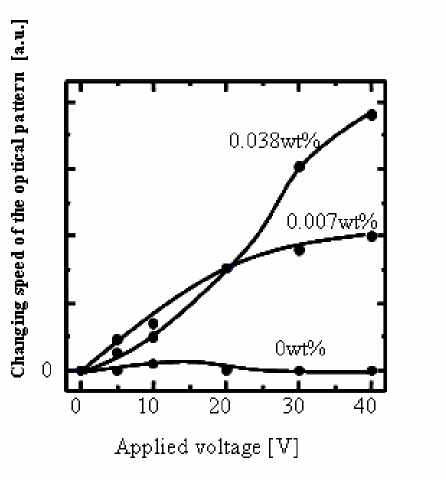


Figure 7. *Activity of LC vs. applied voltage, amount of CTC is varied.*

Figure 8 shows the relationship between the velocity of fine particles and applied voltage. It shows the movement of the fine particle depends on amount of the CTC, as expected. From this result, it was clear that the flow of LC contributed to the driving force of fine particles in the MFPD cell.

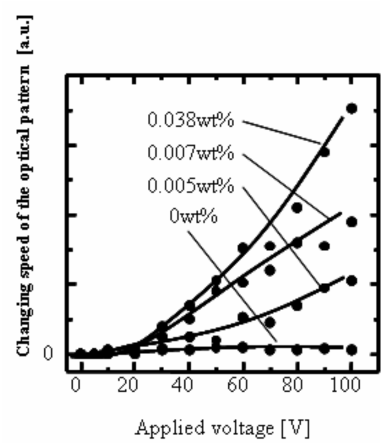


Figure 8. *Activity of LC and particles vs. applied voltage, amount of CTC is varied.*

Effect by Electric Charge of Fine Particle in MFPD

On the other hand, fine particle migration of MFPD is different depending on the type of fine particle. Figure 9 shows the characteristics between the velocity of fine particles and applied voltage in the MFPD cells. The parameter is an electric charge of the fine particle. It is recognized that the moving speed is faster as the rate of the electric charge of the particles becomes larger.

From Figure 9, the moving force of the fine particles in the MFPD cell is affected by not only the effect of the flow of the liquid crystal but also the effect of the electrophoretic with charged particles. Then it is considered that the fine particles in MFPD cell can be moved by the synergistic effect of the flow of liquid crystal and the electrophoresis of the fine particles.

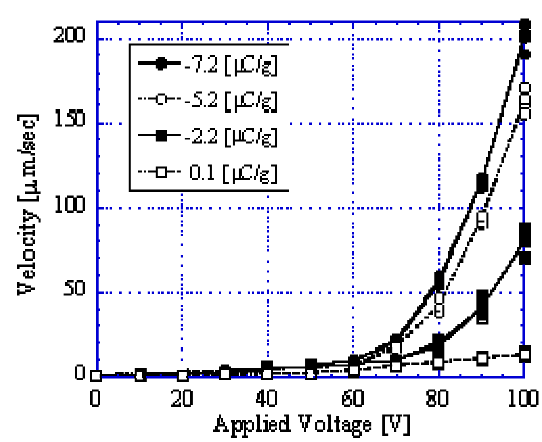


Figure 9. *Velocity of the fine particles (dependence of the particle charge).*

Reflective-Viewing Characteristics of MFPD

Figure 10 shows the measurement of reflective-viewing characteristics of the display pixel area in the MFPD cell. The 100% level is a reflection of the standard white plate. On measurement, the incident light used was diffused light source by integrating sphere, and the angle of the detector was changed from 0 degrees to 55 degrees.

Figure 10 shows that the high reflective property (white state) and excellent dark condition (black state) are obtained through the entire region of measured viewing angle. Characteristics of Figure 10 indicate that a display having excellent visibility that is equal to the newspaper can be realized in MFPD.

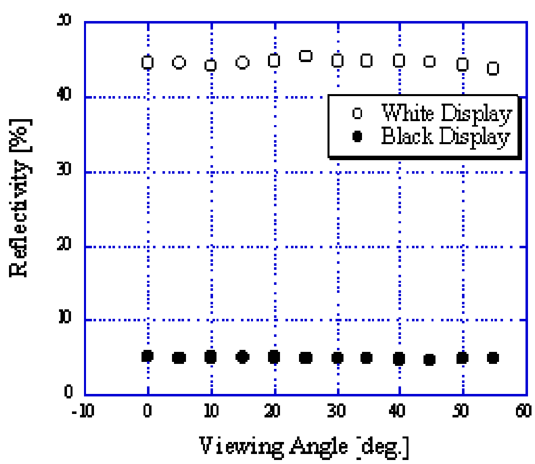


Figure 10. *Viewing angle characteristics of the MFPD cell.*

Conclusions

We developed a new type of display, which is called a Mobile Fine Particle Display (MFPD). The MFPD uses the LC mixture as fine particle dispersion medium. It was confirmed that the migration of the fine particles in the MFPD cell became fast by doping the CTC in the LC mixture and/or by charging the fine particles. It was clarified that the fine particles are moved by the synergistic effect of the flow of liquid crystal and the electrophoresis of the fine particles.

In MFPD, the fine particles are moved to a horizontal direction, then the MFPD shows a high contrast ratio and a good display memory function. The MFPD is able to realize fast response property and excellent legible display simultaneously.

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Author Biography

Yasuo Toko received his B.S. degree in Electrical Engineering from the Hiroshima University in 1985 and a Ph.D. in Electrical Engineering from Nagaoka University of Technology in 1998. Since 1985 he has worked in the R&D laboratory at Stanley Electric Corporation in Yokohama. His work is research and development of the display device technology mainly on liquid crystal.