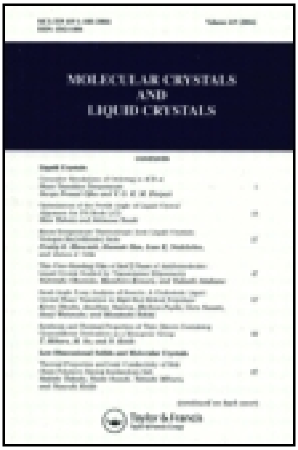

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Improvement of Response Speed for Mobile Fine Particle Display Cells by Adding Charge Transfer Complex Dopant

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The influence of doping a charge transfer complex (CTC) on the performance of MFPD cells proposed by our group has been experimentally investigated. The increase of flow speed of liquid crystal (LC) was observed as the concentration on the CTC in LC was increased. Due to the doping of the CTC, the improvement of the response property and contrast ratio of MFPD cells was confirmed from the observation with optical microscope.

Keywords: charge transfer complex; electronic paper; fine particle; nematic liquid crystal

1. INTRODUCTION

Recently, some studies from the aim of electronic paper displays using several kinds principles are reported from several research institutes and companies [1–5]. It is required that such electronic paper displays

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are characterized by memory function, rewritability, a high legibility, convenient (as like paper), low cost performance, and so on. In order to approach this performance, we proposed a novel display mode, which is called a Mobile Fine Particle Display (MFPD) with nematic liquid crystal (LC) [6]. In the MFPD cell, the fine particles are moved to horizontal direction for switching the display by the applied electric field.

In the electronic paper display, movie image is not always. Therefore, the response property is not important in many cases. However, since the response time corresponds to the time which turns the page of the conventional paper book, the improvement of the response speed is required.

In this report, improvement of response speed for our MFPD cells doped with the charge transfer complex (CTC) is described.

2. PRINCIPLE OF MFPD MODE

Figure 1 shows fundamental cross section structure of MFPD cell (1 pixel). The opaque electrode is formed on the upper substrate, and the light absorption layer and the transparent electrode are formed on the lower substrate. The nematic LC, which is mixed by 10–25 wt% with white fine particles (2–20 μm diameters), is used for this display. The thickness of the LC layer is 50–150 μm. A vertical orientation film has been formed on the surface of both substrates and LC molecules are orientated vertical to the substrate plane, to obtain a weaker azimuthal anchoring strength is realized on surfaces compared with using the horizontal orientation. 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.

The display switching principle of the MFPD cell is shown in Figure 2 and microphotographs of the actual MFPD cell are shown in Figure 3.

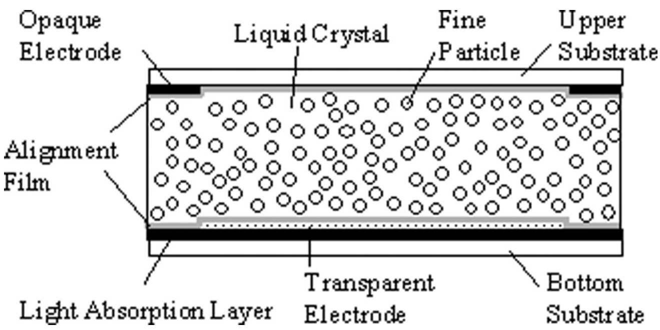

FIGURE 1 The fundamental structure of MFPD.

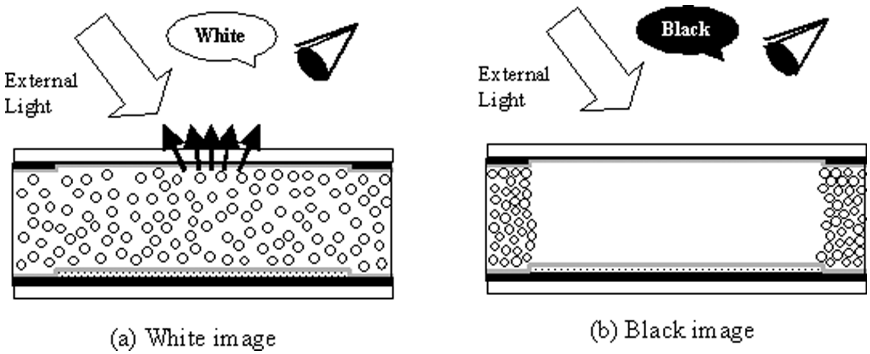

FIGURE 2 Image switching principle of the MFPD cell.

Figure 2(a) shows the state of displaying the white image. In the white image, the white fine particles disperse in the pixel and the white fine particles scatter the external light. Then the bright white image is obtained (Fig. 3(a)). In Figure 2(b), the white fine particles move to the under of the opaque electrode pattern of the top substrate. Then, the external light penetrates the LC layer, and is absorbed in the light absorption layer. Therefore, the black image is obtained (Fig. 3(b)).

3. FINE PARTICLE MIGRATION IN MFPD

3.1 Migration Condition of the Fine Particle

A example of the fine particle migration observed in the MFPD is shown in Figure 4. From Figures 4(a)–(d), it is clear that the fine

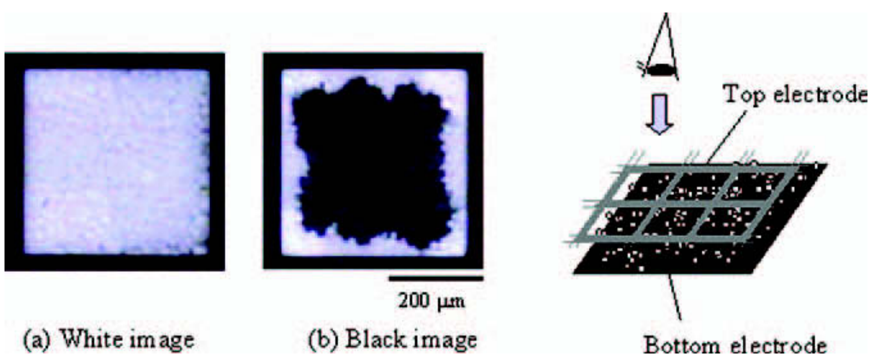

FIGURE 3 Microphotographs of the pixel in the MFPD cell.

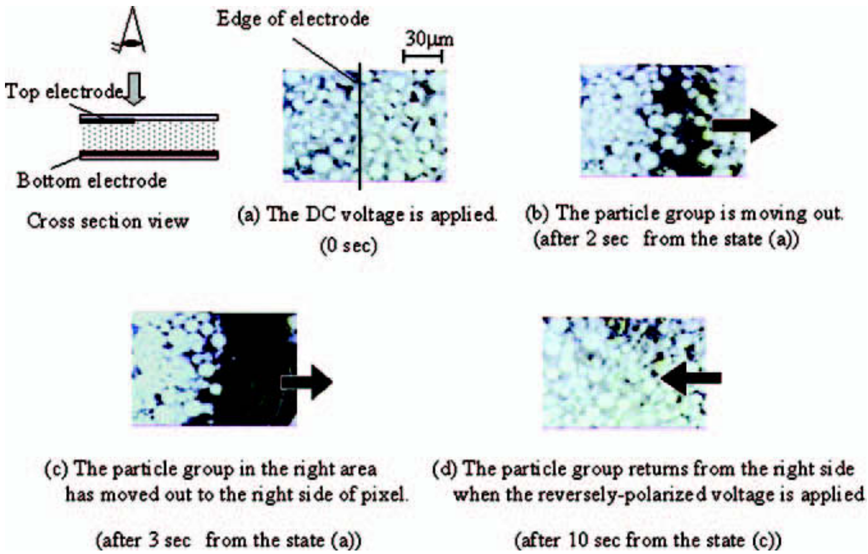

FIGURE 4 The movements of fine particles under applying DC electric field. It was measured by the reflection mode.

particles move parallel to the substrate surface by applying DC voltage. Transfer directions of the fine particles are controlled by the polarity of DC voltage. We confirmed that the transfer of the fine particles is repeatable. After the DC voltage is turned off, the fine particles do not move for over several months in this position. This indicates that the MFPD has fairly high memory effect. It is considered that the high memory of MFPD cell due to the properties of nematics, such as a high order parameter, a high viscosity, a low diffusion constants, an appropriate specific gravity so on.

3.2 Flow of the Liquid Crystal

The mechanism of the fine particles migration in groups in the MFPD cell is not yet clarified. In the MFPD cell without containing the fine particles (LC cell), the flow of LC is generated when the electric field of DC or alternating current adding DC offset is applied. With this factor, it is considered that the fine particle is put in flow by the impurity ion in the LC [7,8], by a back-flow effect in the LC cell with the switching, and moreover, by the electrification of fine particles which is made to draw them into the electrode (electrophoresis-like).

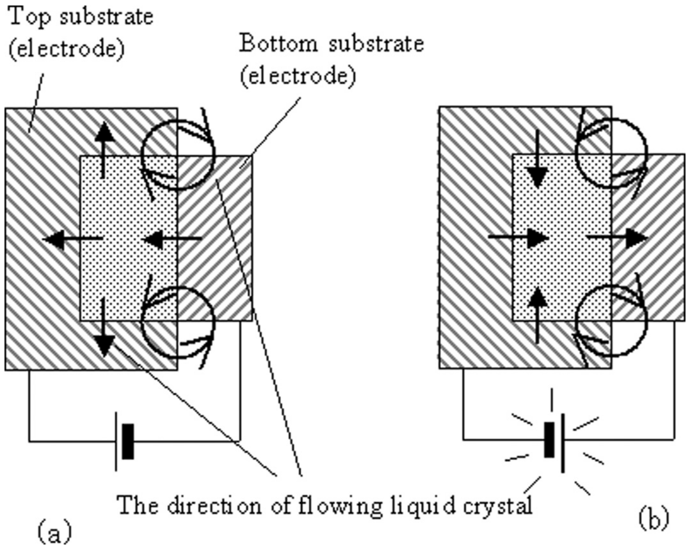

FIGURE 5 The flow direction of liquid crystal (particles) is dependent on the polarity of the electric field.

The LC flow patterns without any fine particles observed using the polarizing microscope under the DC voltage application are depicted in Figure 5 by arrows together with the top and bottom electrode patterns (ITO). The cell thickness was 50–70 μm, excluding an alignment layer on the cell surfaces. The nematic LC, ZLI-2232 ($\Delta\varepsilon > 0$) (Merck), which we used for this experiment showed the flow together when the DC electric field was continuously applied as shown in Figure 5. In these LC material, the stream could be considered flowing from the cathode to the anode. In the current stage, the clear factor of this flow is not proven, and it may have been caused by the impurity ion in LC material. The flow direction of LC was same with the moving direction of the fine particle in the cell. Therefore, it was considered that the flow of LC was a factor contributing to the fine particles migration in the MFPD cell. In the case of the solvent that has been widely used in electrophoretic displays, the particles also moved, however, the migration distance is much shorter than in the case of using LC.

3.3 Velocity of Fine Particles

Figure 6 shows the characteristics between the velocity of fine particles and applied voltage in the MFPD cells. The parameter is an

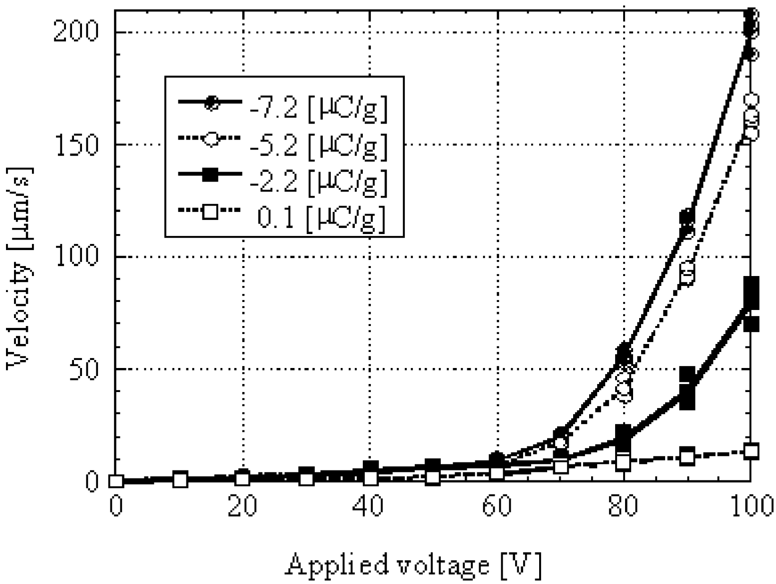

FIGURE 6 Surface charge dependence of velocity of the fine particles-group.

electric charge of the fine particle. In this case, diameter of all fine particles is 6 μm. It is recognized that the moving speed is faster as the rate of the electric charge of the fine particles becomes larger.

From Figure 6, the moving force of the fine particles in the MFPD cell is affected by not only the effect of the flow of LC but also the effect of the electrophoretic with charged fine particles.

4. EFFECT BY ADDING THE CHARGE TRANSFER COMPLEX (CTC) DOPANT IN MFPD

4.1 Flow of the Liquid Crystal by Adding the CTC

It is considered that the fine particles in the MFPD cell can be moved by the synergistic effect of the flow of LC and the electrophoresis of the fine particles. Therefore, 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 the CTC into the LC on the LC flow was investigated.

In the MFPD test cell, the top and bottom ITO electrodes were arranged as shown in Figure 5. Only LC without fine particles was injected into the cell. The sample cells substituted to the measurement

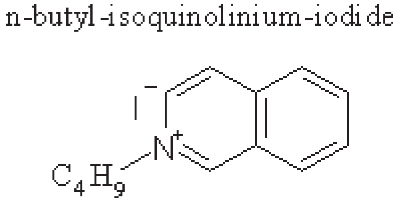

FIGURE 7 The chemical structure of Charge Transfer Complex (CTC).

have 75 μm thickness. Substrate surfaces were coated by vertical orientation film. Figure 7 shows the molecular structure of CTC which we used in this experiment. The behavior of nematic LC, doped with CTC dopant, was observed by a polarizing microscope when the DC voltage applied to the cell.

By applying DC voltage to the LC cell, the dynamic flow of LC is observed. Figure 8 show the examples of photographs of LC flow when the applied DC voltage was changed. The brightness of the image corresponds to the behavior of the LC director. In Figure 8, 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

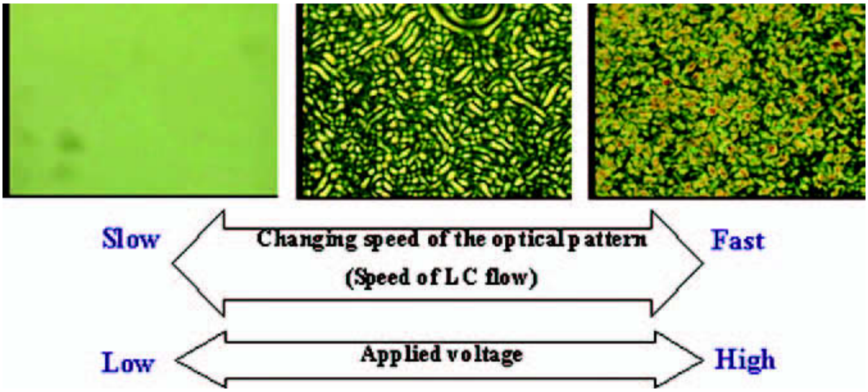

FIGURE 8 Example of the polarizing microscope photograph of the LC cell.

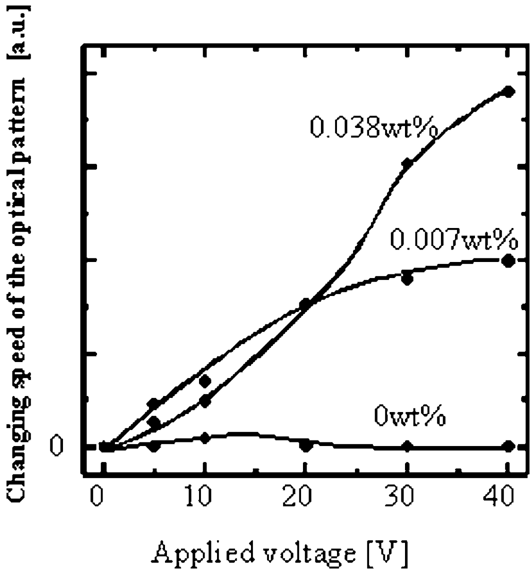

FIGURE 9 Activity of LC vs. applied voltage, amount of CTC is varied.

in every frame time interval by original software. The observed region was approximately 1 mmϕ. Figure 9 shows the changing speed of the polarizing microscope image dependent on the applied DC voltage. In Figure 9, the amount of doped CTC dopant was varied as 0%, 0.007 wt% and 0.038 wt%. It was proven that the movement (flow) of the LC became active, when the amount of doped CTC dopant was increased.

4.2 Changes of Velocity for Fine Particle by Adding the CTC

We anticipated that the moving speed of fine particles will be dramatically improved, when the fine particles were mixed in the LC doped with the CTC. The ratio of fine particles, diameter was about 6 μm, mixed with the LC was 0.2 wt%. The cell thickness was 75 μm, excluding vertical alignment layer on the cell surfaces. The test cell having electrode patterns, of which the oblique electric field could be applied, as shown in Figure 10, was used. We observed the movement of the fine particle in the measurement area by using microscope.

Figure 10 shows the relationship between the velocity of fine particles and applied voltage. It shows the movement of the fine particle

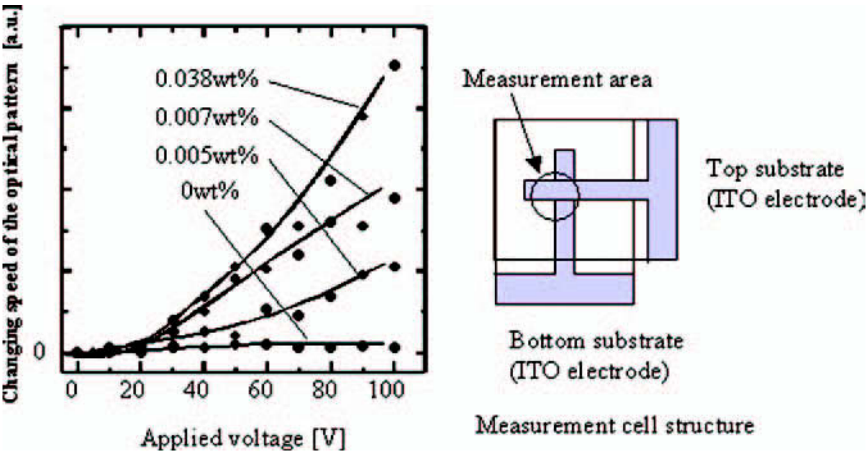

FIGURE 10 Activity of LC vs. applied voltage, amount of CTC is varied.

depends on amount of the CTC, as expected. From this result, it was clear that not only the Coulomb's force between the electric field and particles but also the flow of LC contributed to the driving force (mechanism) of fine particles in the MFPD cell.

4.3 Effect on the Response Speed of MFPD of Adding the CTC

Finally, we confirmed the effect of doping the CTC to MFPD cells. The MFPD cell structure shows in Figure 11. The MFPD cells had 75 μm thickness. Substrate surfaces in those cells were coated by vertical

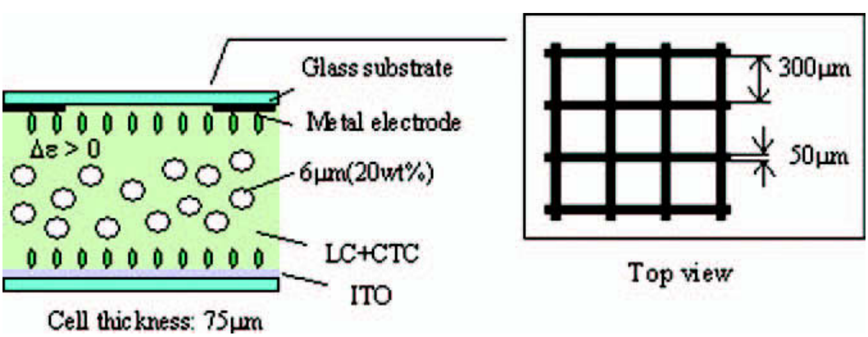

FIGURE 11 The structure of test cell.

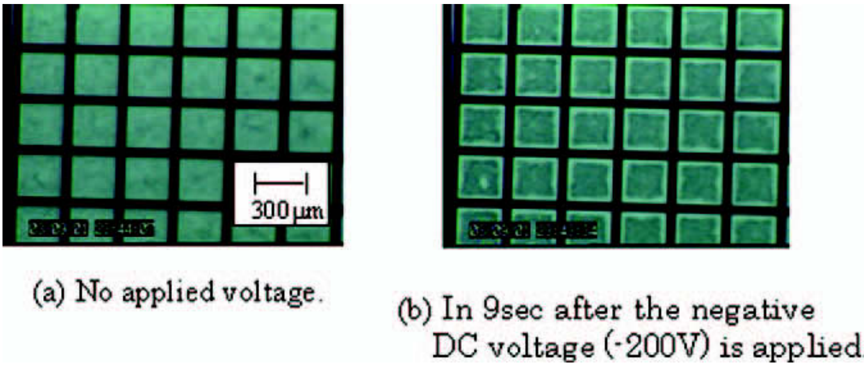

FIGURE 12 Photomicrograph of MFPD cell without doping CTC dopant.

orientation film. The lattice metal electrode was formed on the upper substrate, and the common ITO electrode was formed on the lower substrate. The ratio of fine particles mixed with the LC was 20 wt%.

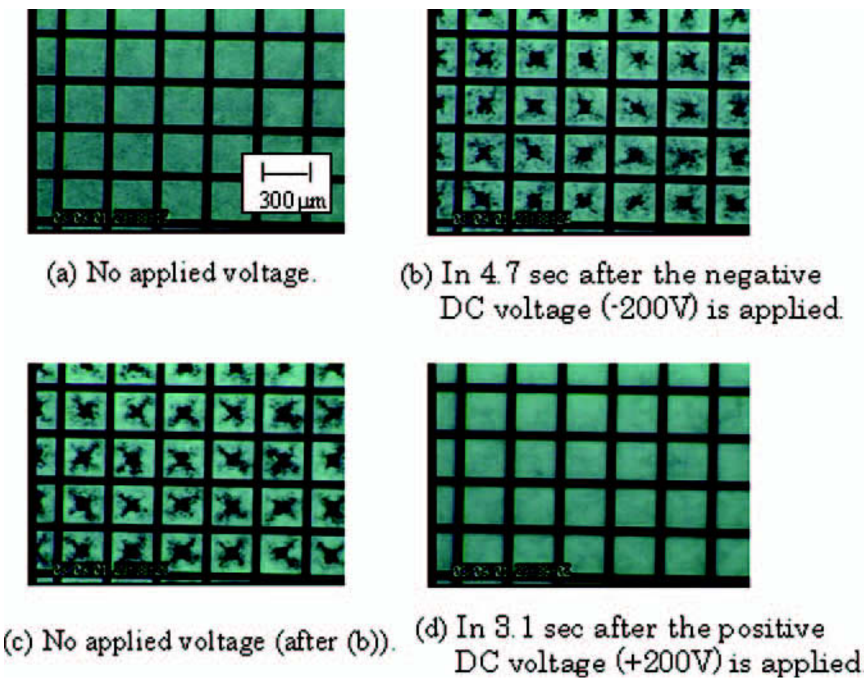

FIGURE 13 Photomicrograph of MFPD cell doped with CTC dopant by 0.005 wt%.

Each MFPD cell was produced by changing the amount of doped CTC dopant. The movement of fine particle in the MFPD cell was observed by the reflecting microscope.

As shown in Figure 12, when no CTC was doped with the LC, the migration of particles hardly could be observed in 9 sec after applying the DC voltage (−200 V), due to the voltage was not sufficient for moving the fine particle.

The case of including 0.005 wt% and 0.038 wt% of the CTC in LC are shown in Figures 13 and 14, respectively. It was confirmed that the fine particles near the pixel center could be moved by the applied voltage. It can be considered that this fine particle migration was caused by the increase of the flow of LC by doping CTC. This indicated that the low-voltage driving and high contrast ratio in our MFPD cell could be realized by using CTC. From Figures 13 and 14, it was clear that the migration speed of fine particle was faster, as the amount of doped CTC dopant was increased.

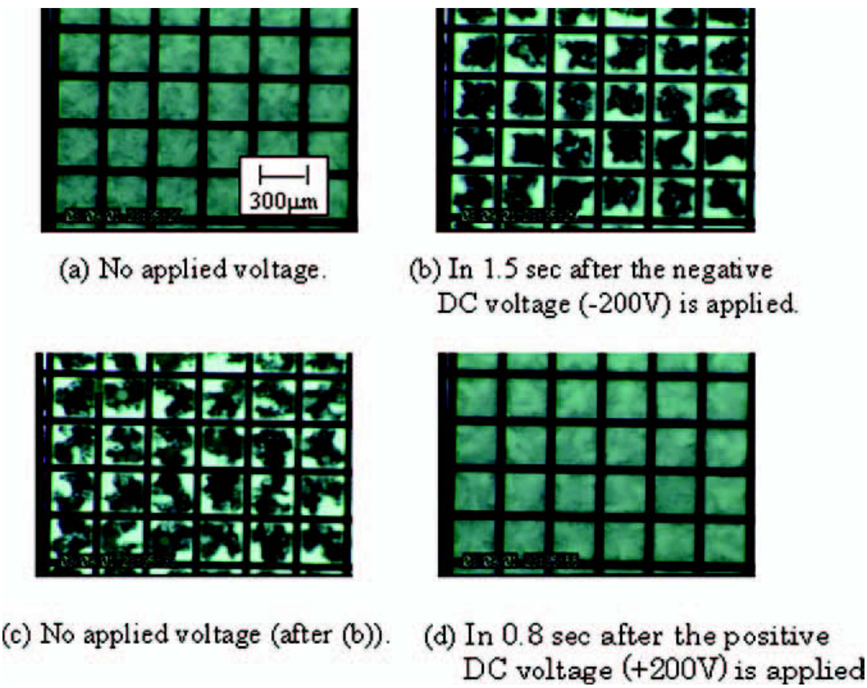

FIGURE 14 Photomicrograph of MFPD cell doped with CTC dopant by 0.038 wt%.

5. CONCLUSIONS

We developed a new type of display, which is called a Mobile Fine Particle Display (MFPD). The MFPD uses the LC as fine particle dispersion medium. In our MFPD cell, the fine particles can be moved by the synergistic effect of the flow of LC and the electrophoresis of the fine particles. Therefore, the MFPD has following features: the driving voltage for moving fine particles is lower and the migration length of the fine particles is longer than those of conventional electrophoretic displays which use other solvent as fine particle dispersion medium.

In the LC cell, the increase of the flow speed of LC was observed under the applying dc voltage, when the small amount of CTC was added in the LC. In addition, it was confirmed that the migration of the fine particles in the MFPD cell also became fast due to doping the CTC. It was clarified that the flow of the LC greatly contributes in the transfer of the fine particle. By doping the CTC dopant, the response speed of particles in our MFPD cell was improved. Furthermore, the improvement of the contrast ratio and driving voltage for display are also achievable, because the fine particle surely moves at the under of metal (opaque) electrodes in the low-voltage condition.

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