

Development of Reflective Paper-like Display with Triboelectrically Charged-polymer Particles

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Abstract

We have developed a paper-like display using polymer particles charged triboelectrically. By using a toner-type display with a simple structure, we confirmed that polymer particle movement is controlled by only a voltage difference between scan and data electrode. We fabricated a diagonal 2.4 inch panel on the glass substrate and successfully produced an image by the passive driving method with operating voltages of about ± 120 V. The contrast ratio was 4:1.

Keywords : paper-like display, polymer particle, triboelectric, passive driving

1. Introduction

In the viewpoint of approach as the display, the paper has high legibility, is thin, flexible and easy to handle. Thus, it may record the information to be semi-permanent. Paper has been used by the media to record and transport information for a very long time. However, it has shown some limitations in terms of the diffuculty in rewriting information repeatedly.

Digital information has made it possible to access a large volume of useful information quickly and also do so at any location, be it at the office or at home. With the advancement of digital networking of information in addition to the basic paper concept, there have been great demand for the development of outstanding mobile display such as electronic paper (e-paper) as discussed herein. Reflective-type e-paper is suitable for displaying a large volume of useful information. It makes it possible to rewrite digital information due to the low-power consumption and bistability (or nonvolatility without power). Several re-flective types of e-paper have been proposed such as electro-phoretic type [1, 2], cholesteric LCD [3, 4], electrochromic [5, 6], electrowetting [7] and toner-type [8-15]. Especially, e-paper of the electrophoretic type displays (EPDs) makes it possible to develop commercial products, for example e-book, rollable digital clock, wall-newspaper and low-power portable displays.

E-paper or paper-like display (PLD) that uses charged particles can be divided largely into two categories - electrophoretic and toner-type displays. If the charged particle moves in liquid condition, we call it an electrophoretic (or wet) type, whereas if the particle moves in air, it is called a toner (or dry) type. The particle movement mechanism of both types is the same, but they show different response characteristics depending on the change of the voltage. EPDs are the most proceeding candidate in the e-paper market at present and exhibit attractive features such as good optical property and bistability. Meanwhile, they have some intrinsic problems such as the lack of a well-defined threshold at the same time. It is difficult to drive EPDs with a passive matrix (PM) addressing because of the slow response time. In other words, the addressing time of the entire panel takes too long. Unlike the EPDs, a toner-type display has distinctive features, an appropriate threshold and fast response time because the particle moves in air such that it can form images simply through PM addressing. Compared to the EPDs with the thin film transistor (TFT) device, the toner-type display can be manufactured cheap and use the flexible substrate easily because of its simple structure.

This paper investigates the characteristics of the PM addressing PLD. In order to find out the key points in making an image using the toner-type PLD panel, we firstly applied to the glass substrate. Also, the basic charging principle of the particles, display principle, panel structure

Manuscript received August 5, 2005; accepted for publication September 9, 2005.
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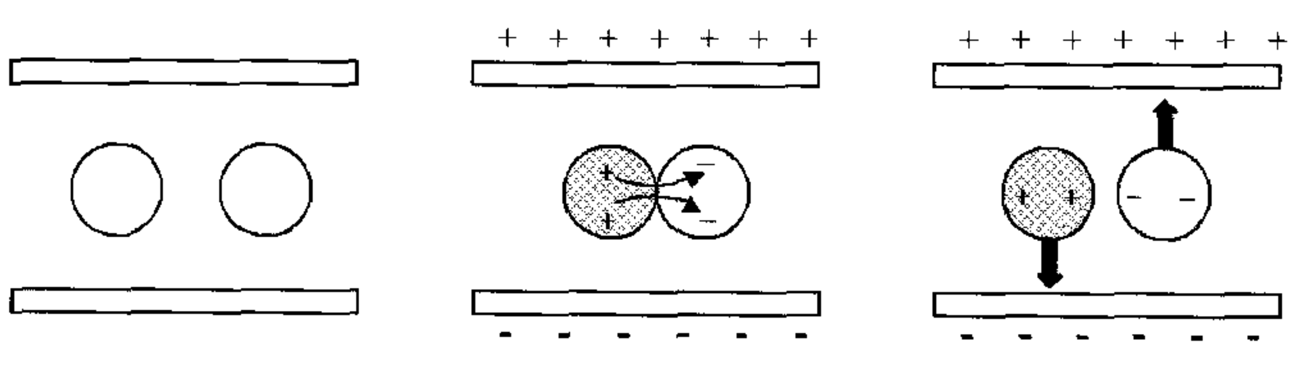
and fabrication method are described.

2. Principles

2.1 Principle of particle charging

The electrophoretic and toner-type displays are associated with the paper-like display typically due to the way in which the charged particles move in liquid and air, respectively [1, 2, 8-15]. Therefore, it is important to know about the principle of tribocharging [16]. For a long time, rubbing elec-trification has been well known by experiences. In fact, there have been extensive research conducted on have been reported [16-21]. Fig. 1 illustrates a simplified model of the way in which charge is exchanged between two particles. When two different polymer particles collide with each other, electrons are separated from the surface of the neutral particle, causing the electrons to move by the work function difference between the two particles, so called a charging process. That is, electrons are moved from low to high work function of the particle until the Fermi levels are equal (Fig. 1 (b)). Basically, when two particles are separated from each other, it occurs either due to the lack of or excess of electrons. And then neutral particles gain or lose electric charge, depending on the magnitude of work function. One polymer particle having higher work function displays an excess of negative charge, while the other with lower work function donates electron to become a positive charge. That is, the relative positions of electronic energy levels in each polymer particle determine the direction in which electronic transfer will take place. After the transfer, positively charged particle moves toward the minus electrode and negatively charged particle moves toward the plus electrode, respectively (Fig. 1 (c)).



(a) Uncharged (b) Charging (c) Charged

Fig. 1. Charging process of the polymer particles.

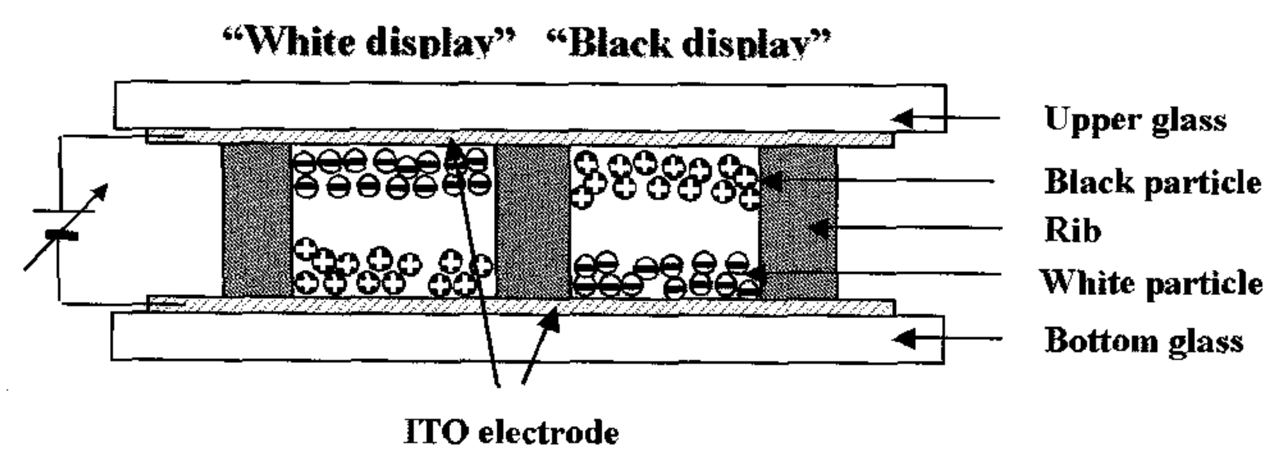


Fig. 2. Schematic cross-section of the PLD.

2.2 Display principle of the toner-type PLD

Fig. 2 illustrates the principle of the toner-type PLD. Each pixel indicates a white or black display. The two types of particles have completely different optical properties and opposite electric polarity. When we apply to the voltage between the two transparent electrodes, the triboelectrically charged particles move to the opposite direction by electric polarity. White particles charged negatively are drawn into the plus electrode by the electrostatic (or coulombic) force and simultaneously black particles charged positively are drawn to the minus electrode. These particles stick to the transparent electrode and the reflected lights from particles are either black and white. Then if the polarity of applied voltage is changed, the black and white particles move to the opposite direction simultaneously. Black and white images are displayed by the switch of polarity of the only applied voltage [8-15].

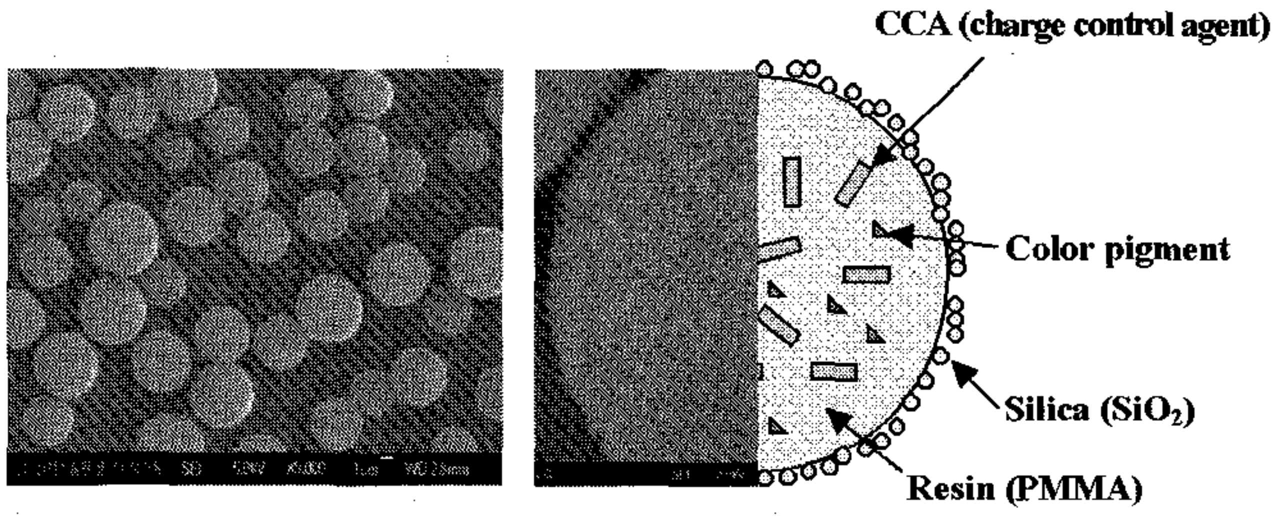
In order to operate or drive the PLD panel, the charged particles must be detached from or addicted to the electrode. If there is no electric field between the electrodes, the image charging force due to the polarization of the electrode is formed. On the other hand, if there is an electric field between the electrodes, the charged particle can move from one surface to another only by a coulombic force that is strong enough to overcome the attractive force between the charged particle and original substrate. The repulsive force created by the electric field detaches the charged particles from the electrode and appears to the threshold phenomenon in the driving characteristic curve.

The attractive force between the particle and electrode is the origin of its bistability [14, 15], also a unique characteristic in fields of the PLD. In order words, a PLD can display an image, does not disappear after its power supply has been turned off. This is called the memory effect. It retains stationary images because of the image charging or Van der Waals force between the particle and electrode at the electrode surface [17-19].

3. Experimentals

3.1 Particle configuration

Fig. 3 (a) shows the polymer particles, having uniform size distribution. The mean diameter of the particle was measured to be about 5 μm and the standard deviation was the 1.6 μm. Fig. 3 (b) shows components of the particle, we used. There are charge control agent (CCA), color pigment and resin with silica. Resin is made of the poly methyl methacrylate (PMMA). Black particles include the carbon black while white particles include the titanium oxide into the resin respectively. To polarize the particle, we added a positive/negative CCA into the resin. Especially, to avoid the agglomeration of the particles, we applied a few of the silica to the resin particle shell by the mixing. Fig. 3 (b) shows a SEM image of the particle after the silica coating. A role of added silica is presumably serves as asperities that reduce adhesion force by roughening the surface and preventing any contact from occurring between particles [20, 21]. The polarity of the whole particle is mainly determined by the CCA and independent of the color pigment. One particle with (+) CCA develops a positive charge, while the other particle with (-) CCA develops a negative one, respectively.



(a) (b)

Fig. 3. Polymer particle. a) SEM image of the sphere particles, b) surface morphology of the particle with nano-sized silica (in left side) and cross sectional view of the inside particle (in right side).

3.2 Panel structure and manufacturing process

The toner-type of the PLD structure consists of two electrodes: barrier rib and charged-polymer particles as shown in the Figs. 2 and 4. Charged-polymer particles between the upper and bottom transparent electrodes are enclosed by the barrier ribs. In comparison to the EPD with the TFT process, our panel structure is very simple.

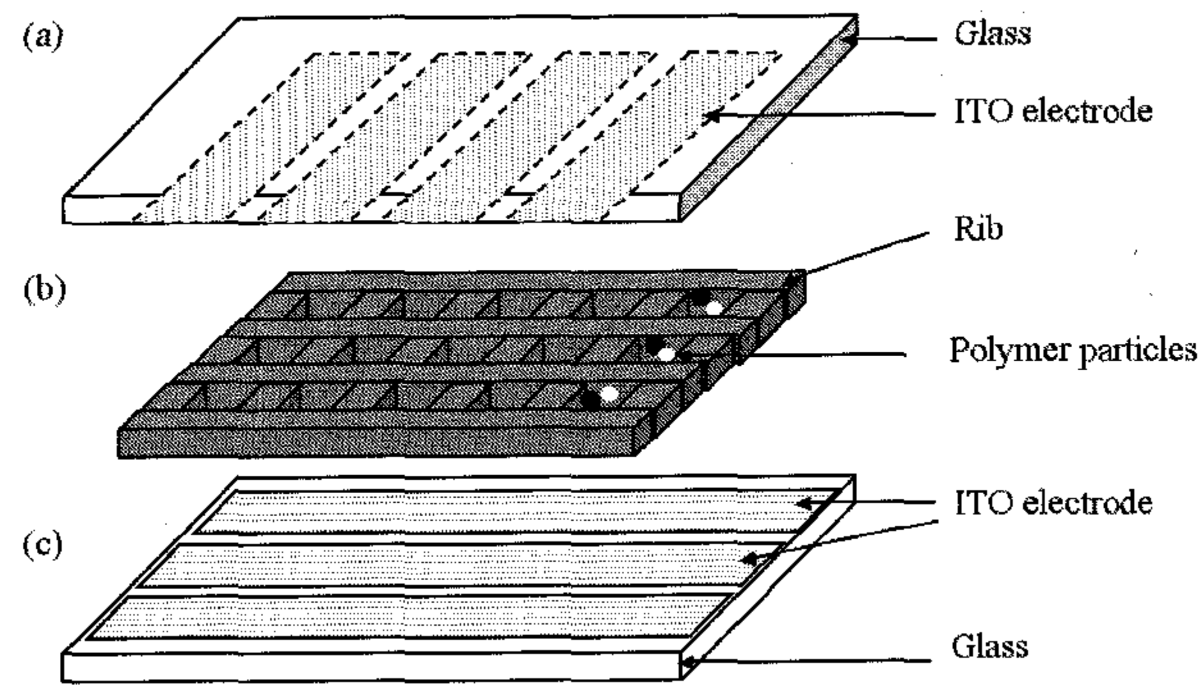


Fig. 4. Fabrication process of the PLD panel. a) The ITO patterned upper plate, b) The patterned rib with the polymer particles, c) The ITO patterned bottom plate.

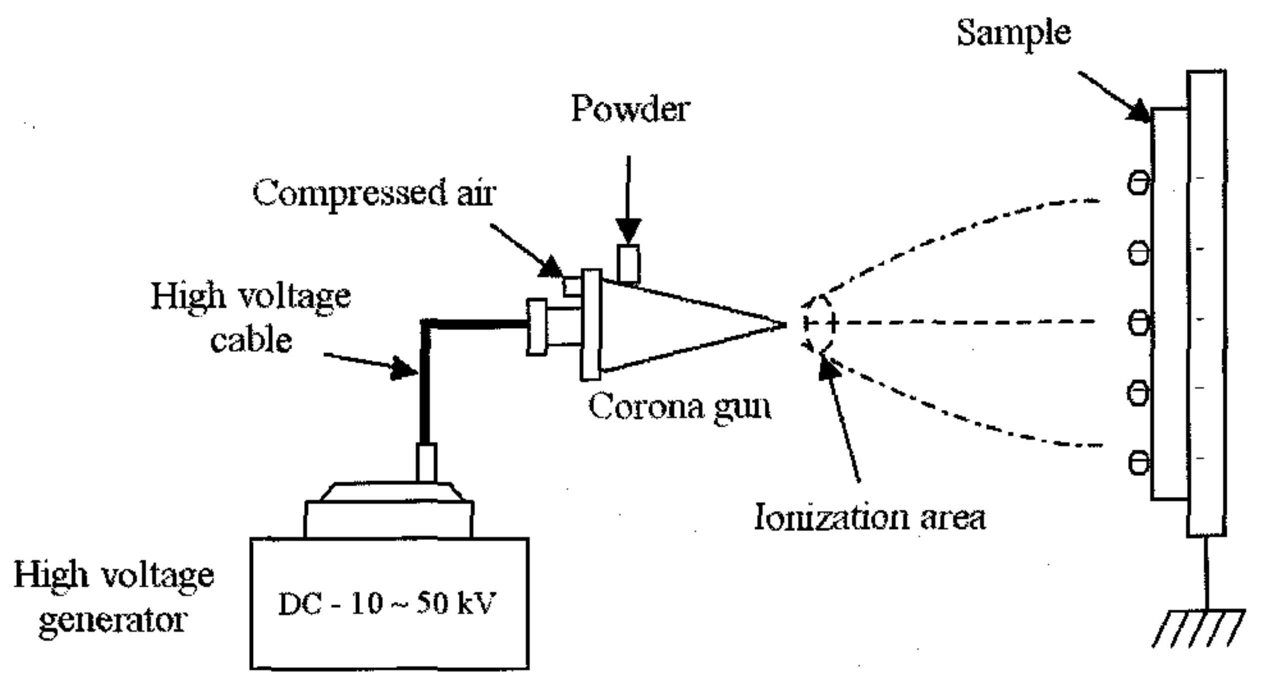


Fig. 5. Schematic of the particle injection.

Fig. 4 shows the manufacturing process of the PLD panel. The substrates include all the glasses with stripe-patterned ITO electrodes (Figs. 4 (a) and (c)). As the reflective display, the electrode must be transparent because lights reflected from the particle have to pass through the electrode on the substrate. The upper and lower ITO electrodes are perpendicularly intersected. The barrier ribs, located between the electrodes (Figs. 4(b)) are made of a thick photoresist which is especially useful for thick and high resolution of the ribs. Then, the upper plate is assembled on the bottom plate with the patterned rib. A high-temperature process is not required for making the panel.

Fig. 5 shows a schematic of the particle injection equipment, used in corona discharging. This is perhaps the most widely used method for particle charging and injection in powder coating applications. In its simplest embodiment, the charging electrode may be a sharp pointed electrode. The electrode is connected directly to high voltage generator. It is due to the electrode geometry that the local electric field at the pointed electrode is greatly enhanced. Strong electric field surrounding the electrode makes particles to become ionized. These ionized particles, colliding with the compressed air, move and stick to the opposite sample that is earthed.

In this experiment, charged particles of black and white were mixed in 1:1 by the weight ratio. The volume percent of occupied particles per pixel was about a half percent.

3.3 Aging process

Even though we put charged particles into the pixel through corona discharging, it was still not sufficient to charge all of the particles. There are some particles that do not contribute in any way to the image, consequently lowering the contrast ratio. Thus, after putting the mixing particles into the pixel, we executed the aging process. When DC pulse voltages of about 400 V applied both electrodes in turns, the particles was charged triboelectrically. We stopped the aging process when all the pixels exhibited fully black or white images and, at the same time, showed the maximum contrast ratio. The purpose of this process is to confirm the uniform display quality and look for the maximum contrast of a whole PLD panel.

4. Results and Discussion

Fig. 6 shows a typical voltage-reflectivity curve of the PLD. After the aging process was completed, we measured the reflectivity of the panel. When the white lights

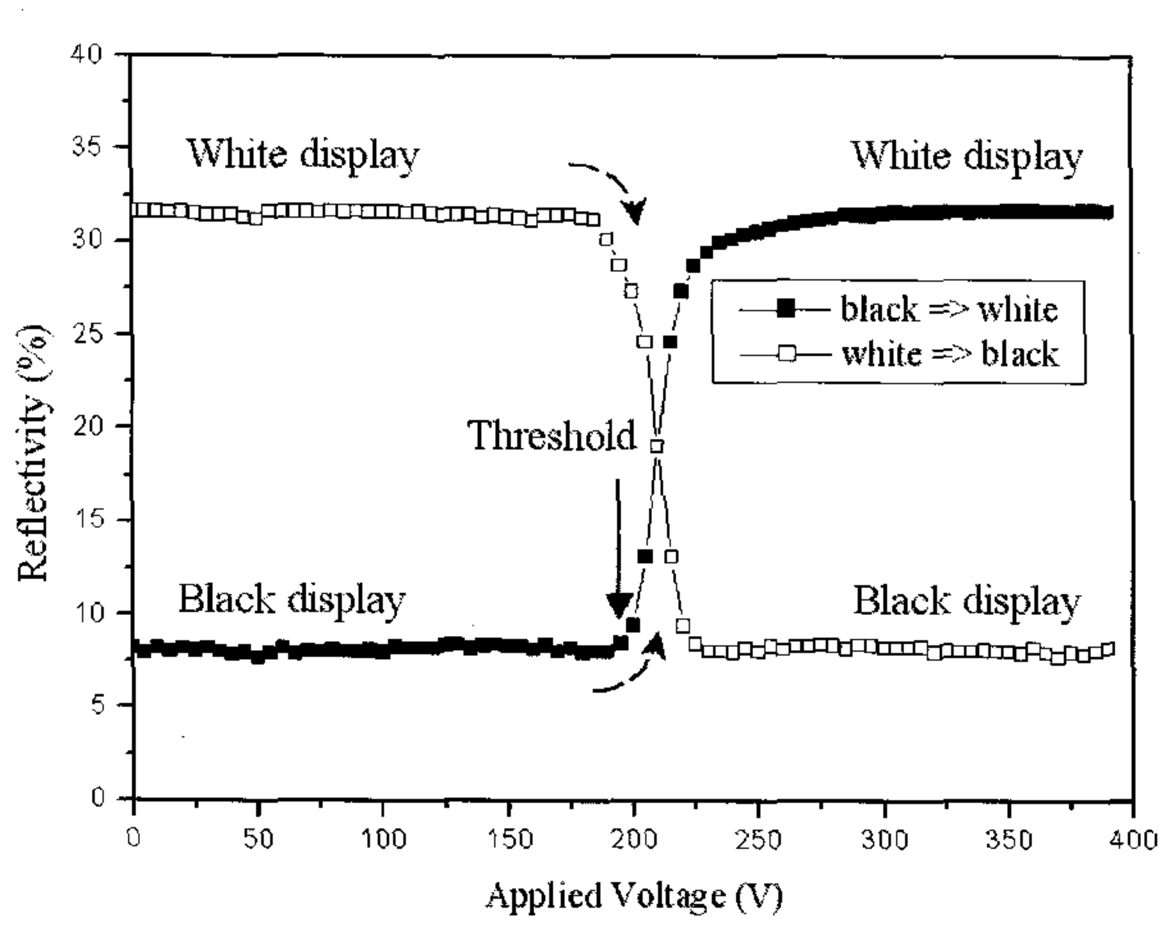
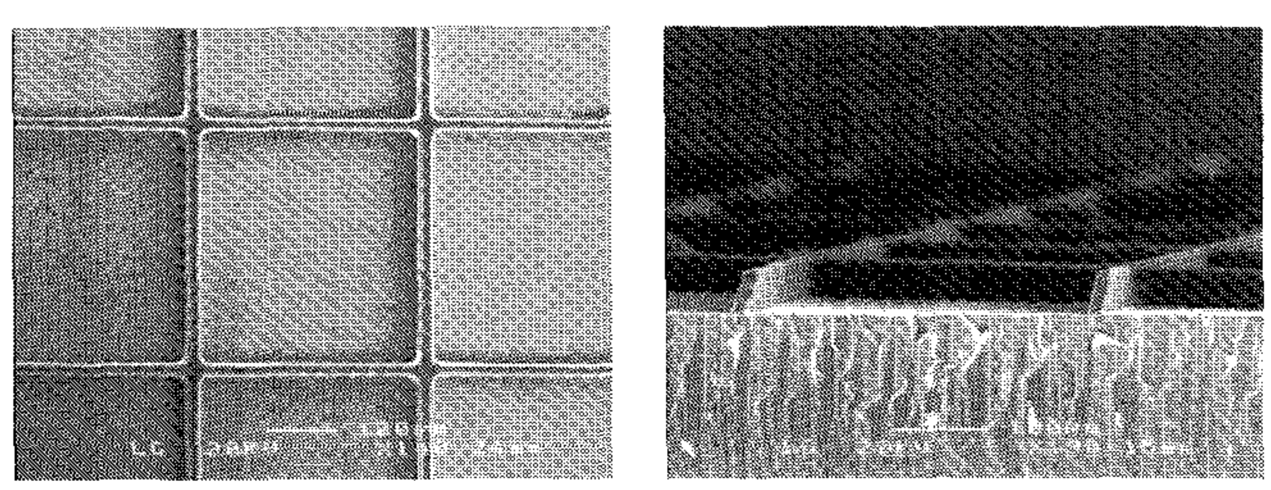


Fig. 6. Relationship between applied voltage and reflectivity.

illuminate the panel, reflectivity, which is the amount of the lights reflected from the PLD panel was obtained. The state of "White display" means that the front view of the PLD panel is composed of totally white particles. The value of "White display" indicates white reflectivity of the panel that is 32 %, when white reflectivity of the standard sample (white paper) is 100 %. The reflectivity of the "Black display" was about 8 %. Therefore, the contrast ratio of the white to black reflectivity was about 4:1.

The curve is in the form of an "S"- shape and does not show any reflectivity difference between the measuring direction from black to white display and the opposite direction. The curve rises or drops rapidly according to the applied voltage, saturated above the 250 V and indicated a completely white or black appearance. It did not change the reflectivity after saturation because the white or black particles stopped increasing in number. The curve also has a well-defined threshold voltage of about 200 V, which is higher than the scan or data drive voltage of 120 V. This curve tells us that only the scan or data voltage could not appear the image, but also, it is possible to drive by the passive addressing because of the threshold. Even though the level of threshold voltage is still high, there is still room to improve it further. However, to lower the threshold voltage, the amount of the particle charging according to the coulomb's law must be increased. In order to increase the amount of particle charging, we can try to change the type of resin or adjust the content and polarity of the CCA. This is essential to conduct a more detail research about the particle configuration.

Fig. 7 shows the structure of the rib. The width of rib is about 20 μm (Fig. 7(a)) and the height is about 50 μm (Fig. 7(b)). The shape of the rib is a square and one lattice corresponds to a pixel so as to limit lateral particle



(a) (b)

Fig. 7. Rib structure. a) cross stripe pattern, b) cross sectional of fracture plane.

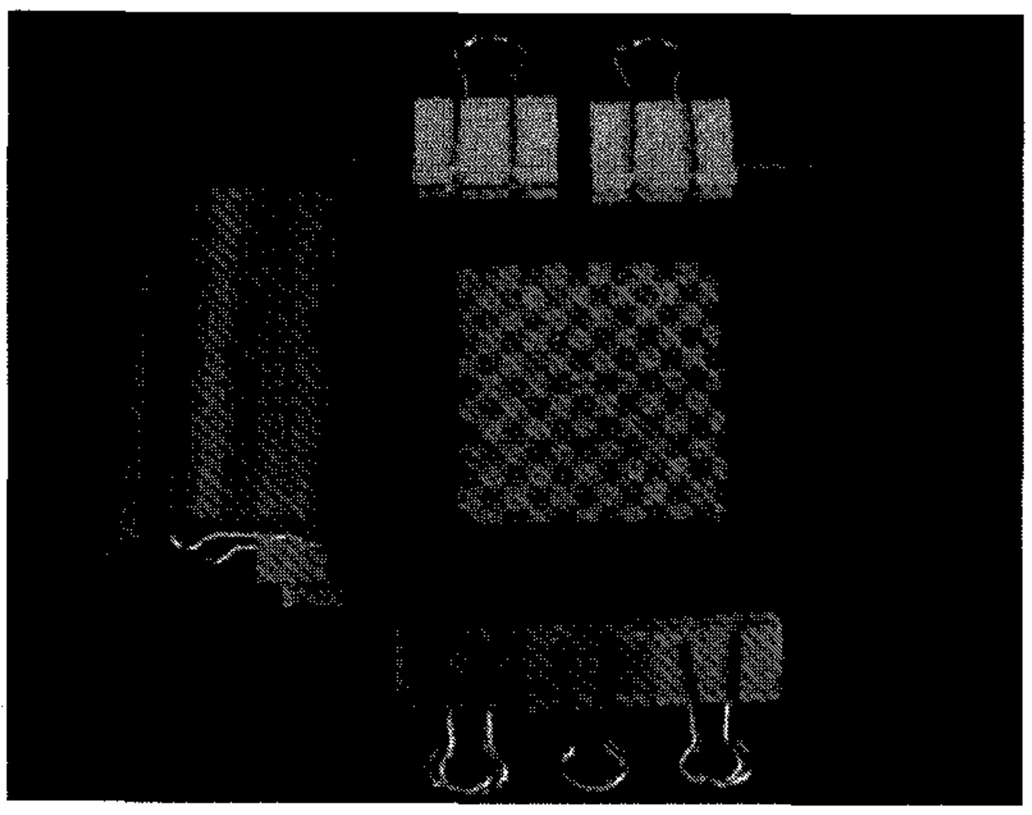


Fig. 8. Picture of the 2.4 inch PLD panel.

migration. A pitch of the electrode is a 360 μm and the resolution of our panel is the about 70 pixel per inch (ppi). The aperture ratio is above 80% and can be calculated as shown in Fig. 7. The aperture ratio of the PLD panel is determined by the width of the rib and electrode. Therefore, the width of the rib must be narrow for the high aspect ratio. This high aspect ratio of the rib can be obtained by using the photolithographic process, which is easy to perform and reliable.

With respect to the height of the rib, it should be designed by considering the magnitude of the driving voltage and contrast ratio that put reservely in relationship of competition to each other. If the height of the rib is low, the driving voltage can be low. It is also possible that in this case that the number of particles entering the pixel can also be low, hence causing the contrast of the panel to drop. It was predicted that contrast ratio is proportionate to the aperture ratio of the pixel. This ultimately means that an the rib should have an optimum heright.

Fig. 8 shows a check pattern with PM driving mode. The demonstration of block emission under the normal light ambient can be seen from a 2.4 inch panel. The scan and data voltage were about 120 V and the reset voltage was used to ensure the image quality was above 250 V [8]. The active area, which produces a relatively bright and good contrast image, was maintained over several months without any electric power supply. And hence we can realize to chance the commercialization.

In comparison with the EPD which the TFT device needs to drive, our toner-type panel with PM addressing has merits as follows. Passive addressing does not require any active electrical elements on the bottom plate. This means that manufacturing cost of the panel can be lowered compared to that for an active matrix counterpart. In addition, it can simplify the transfer to flexible substrates and be easily applied to the large size displays. The toner-type PLD is very suitable for outdoor or mobile applications due to the very low power consumption of a few micro-amperes.

While many researches [8-15] have been conducted on the toner-type PLD, there are still several issues such as the high contrast ratio, color imaging and low-voltage driving for mobile equipment that need to be investigated and resolved. We plan to realize the high contrast image and improve the resolution to more than 70 ppi on the flexible substrate.

5. Conclusions

We fabricated a diagonal 2.4 inch competitive PLD panel, driven by the PM addressing and used the electrostatic effect of the charged particle. In addition, we considered about the possibility of the first stage of the commercialization at the glass substrate. This simple structure allows us to make the fabrication process easier. The display application of the triboelectricity on the separation of the black and white particle was discussed. The proposed toner-type reflective PLD with the memory effect has a 120 X 120 array of pixels, a resolution of 70 ppi and contrast ratio of 4:1.

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