Novel Type of Bistable Reflective Display (QR-LPD®) and Material Design of Electronic Liquid Powder®

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Abstract

A novel reflective display; Quick-Response Liquid Powder Display (QR-LPD®), has been developed in this study. The new display shows the advantages of outstanding image stability, easy viewing, low-power consumption and a fast-response time. A highly fluidizing powder is used for producing paper like images. In this paper the material design of the powders for the display is described and the electrostatic features are discussed. Some of the recent products using QR-LPD® will also be demonstrated.

Introduction

As electric information technologies have progressed, there have been many different types of displays proposed for practical forms of electronic paper. These displays are designed for reading but not for watching moving pictures. The electronic paper displays are expected to possess "Paper-like usage", such as readability, robustness of stored images, flexibility, ultra low power consumption, lightweight and affordable price. We reported that the Quick-Response Liquid Powder Display (QR-LPD®) is an attractive technology for multi-stable and reflective displays.[1,2] Many kinds of polymer materials are used in this display, such as powders, grid ribs, a bonding agent. Furthermore, in the case of flexible displays the substrates are also made of polymer materials. Among these materials, the powder is the most critical component and should be designed to be of high fluidity and controlled electrostatic features necessary for producing high quality images. We named this powder as "Electronic Liquid Powder®" according to its characteristics described above. The material design and performance of Electronic Liquid Powder® will be discussed in this paper. In addition, concept models of new applications of QR-LPD® such as color display and flexible panel display are also proposed.

Over view of QR-LPD®

Figure 1 shows the cross sectional structure and the operational principle of QR-LPD®. Two types of "electronic liquid powder®," (one is negatively charged and colored white, and the other is positively charged and colored black) are filled into the space between a pair of patterned substrates. The rib forms a cell gap and prevents non-uniform distribution of the powders. The rest of the space is filled with air.

When a negative voltage is applied to the upper ITO electrode the positively charged black powder moves to the upper electrode bringing about a black appearance. In the oppositely biased case, the negatively charged white powder is attracted to the upper electrode showing a white appearance. Each cell corresponds to a picture pixel. By controlling the bias voltage of each pixel, specific information can be displayed as shown in Fig.2.

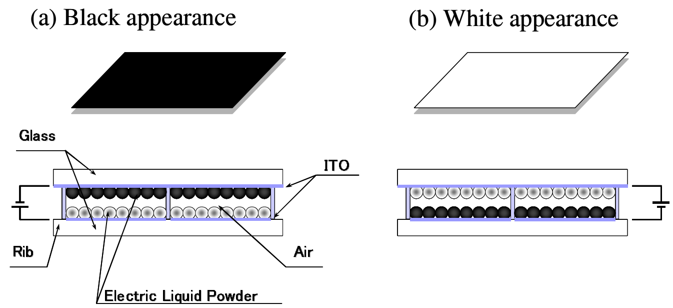

Figure 1. *Schematic diagram of the operational principle of QR-LPD®.*

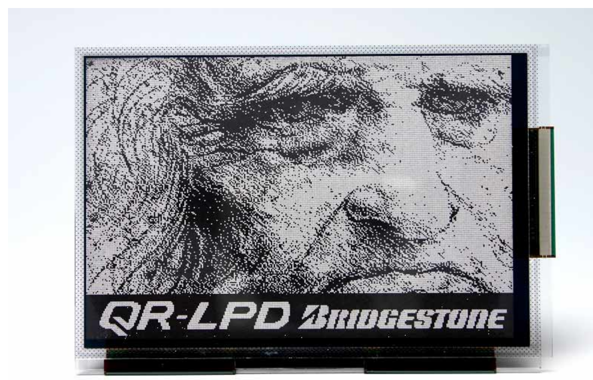

Figure 2. *An example of an image of QR-LPD®.*

The structure of QR-LPD® is very simple. It consists of a pair of electrodes, ribs and electronic liquid powder®. Compared with a LCD, this display does not require a polarizer layer, an orientation layer or a reflective layer. In addition, The QR-LPD® gives a clear image without TFT arrays as a result of the threshold development characteristics of the electronic liquid powder.

The white appearance of QR-LPD® is derived from the light reflection at the surface of electronic liquid powder® on the upper substrate. This leads to a paper-like appearance and a wide viewing angle. This feature is one of the most important specifications for comfortable reading. Furthermore, its fast response time and its sensitive threshold voltage feature enable passive matrix driving of QR-LPD®. In addition, the attractive forces (electrical and non electrical) between the electrodes and electronic liquid powder® enable us to store the image with "no electric power". We expect that this property could be a solution to satisfying the demand for ultra low power consumption displays such as electronic paper.

Fabrication process

The fabrication process of QR-LPD® is shown in Fig.3. The ITO was patterned on a glass substrate in a striped shape to a targeted resolution (a). Ribs were then formed onto this plate with a photo lithographic process (b). Then an appropriate amount of both types of powder are put into the space surrounded by the ribs (c). Finally the upper glass plate with ITO electrodes is assembled onto the upper plate (d). This fabrication process is very simple and suggests that QR-LPD® can be produced with high through-put and high yield during the manufacturing process. In addition, it does not require high-temperatures in the fabrication process (e.g. building TFT arrays), and thus allows the possible use of plastic substrates.

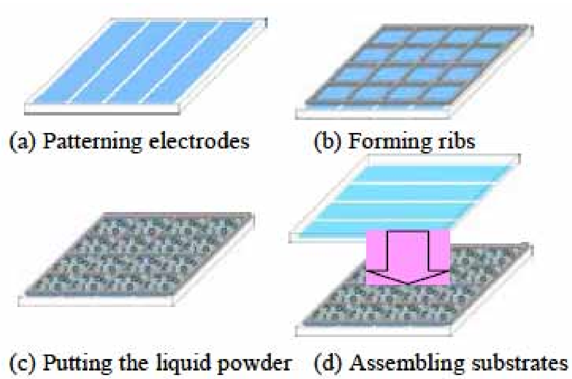

Figure 3. *Fabrication process of QR-LPD®.*

Principle of powder transportation

A schematic showing the principle of powder transportation is shown in Fig.4. The curved line indicates the adhesion force between the powder and the substrate as a function of charge density. The powder is attached to the substrate by both a "non-electric forces" and "electric force". The non-electric forces originate from molecular force, liquid cross linking force, etc. These forces do not depend on the powder charge density, thus it has a non zero intercept with the vertical axis. The electric force can be described as a mirror image force originating from the electrostatic charge of the powder itself. The mirror image force is proportional to the square of the powder charge density. As a result, the adhesion force between powder and substrate can be described as a quadratic line with an intercept at the point of zero charge density.

In the case of applying a bias voltage between the substrates, a Coulomb force acts on the powder. The Coulomb force is directly proportional to the charge density and the electric field produced by the bias voltage between the substrates. Thus the force tending to move the powder from the substrate can be described as a straight line intersecting with the origin. As shown in Fig.4, the powder can be transported from the substrate to the opposite side substrate if the removing force becomes larger than the adhesion force. The difference between these forces is the driving force for powder transportation. This suggests that the powder has to be designed to have proper charge density for giving good black and white images.

Unlike some systems, the QR-LPD® does not require the use oil or liquid in the space between the pair of substrates and this space consists only of air. Since the powder jumps through the air between the substrates, this results in a very fast response as shown in Fig.5. The observed response time is 0.2 ms, which is one of the special features of QR-LPD®.

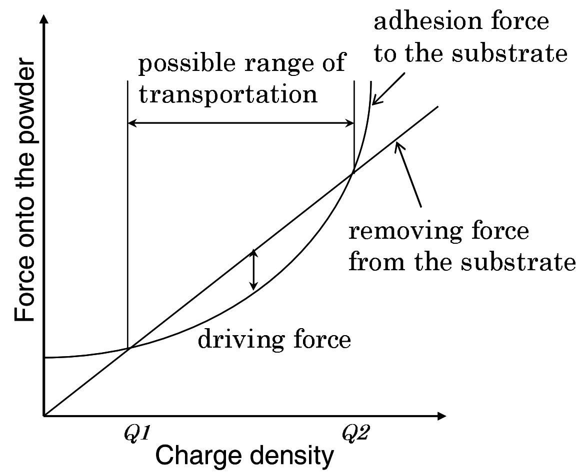

Figure 4. *Schematic figure of the theory of powder transportation.*

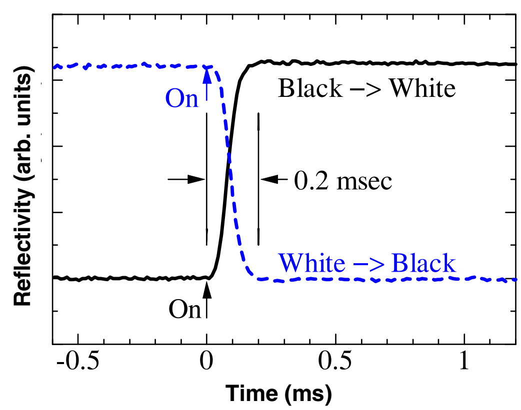

Figure 5. *Response of reflectivity.*

Electronic Liquid Powder®

Electronic Liquid Powder® mainly consists of base resin, pigment and a charge control agent. The average diameter is around 10μm and has a narrow size distribution. Examples of SEM images are shown in Fig.6. The Electronic Liquid Powder® can be produced either by the conventional pulverized process or the polymerization process as shown in Figs. 6(a) and (b), respectively. Figure 6(c) shows an example of a porous polymerization type, and Fig. 6(d) shows a powder with a chemical treatment (sol-gel method) on the surface for improving the characteristics required for the Electronic Liquid Powder®.

The design of this powder is very similar to an electrophotographic toner such as used in laser beam printers. However toners are usually designed to be suitable for heat fusing to form a permanent image on a paper. In this case further characteristics such as heat durability for keeping the shape, charge properties, etc. are required to enable this powder to be used for long time displays. For this reason, high strength materials are selected for the powder design.

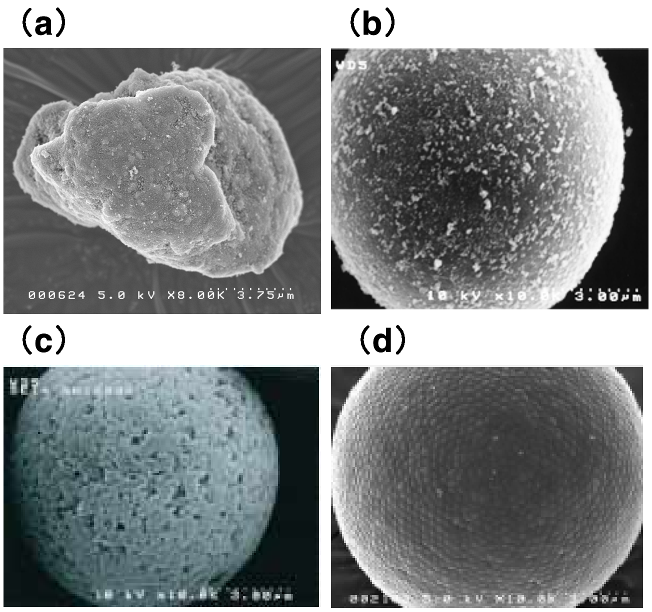

Figure 6. *SEM images of powder examples. (a) pulverized type, (b) polymerized type, (c) porous type, (d) surface treatment type.*

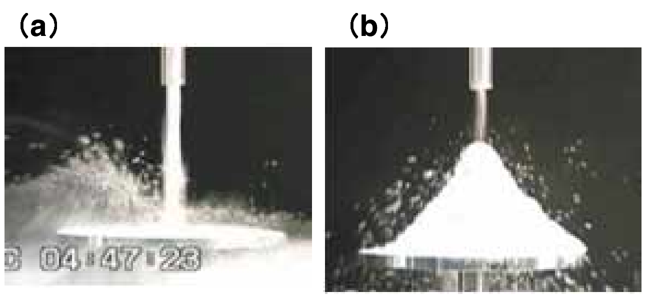

Figure 7. *Behavior of (a) electronic liquid powder (this work) and (b) a conventional powder.*

Improving the fluidity by reducing adhesion forces between the powder and the substrate is another big issue. External additives such as SiO_2 or TiO_2 can be attached onto the surface for this purpose. The control of surface roughness such as shown in Figs.6 (c) and (d) may also be effective for improving these properties. Figure 7 shows pictures of comparing the fluidity of the Electronic Liquid Powder® and a conventional resin powder. For the case of the Electronic Liquid Powder®. It can be seen that the angle of repose is zero because of its high fluidity. By controlling all the materials, particle shape and surface properties, the Electric Liquid Powder® achieves proper charging, fluidity and stability.

Evaluation of charge properties and design of Electronic Liquid Powder®

The most important property of the powder is the charging characteristic. Once the powder is filled in the panel and displays the images, the powder is required on occasion both to move and to remain stationary in contact with a substrate. When moving it contacts and collides with other particles and surfaces. When stationary, it must retain sufficient charge to maintain its characteristics. In other words, the charge of the powder is always changing. A schematic showing the nature of the powder charge transition is given in Fig. 8. In the case of updating an image, the powder gets additional tribo-charge and the charge density increases. In the case of powder in contact with the conducting substrate the charge relaxes and charge density decreases.

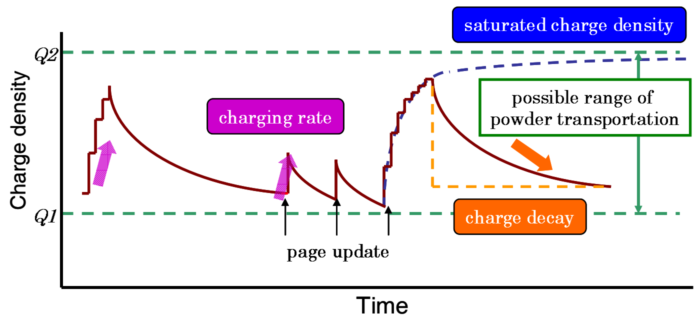

Figure 8. *Schematic figure of the charge retention of the powder applied to QR-LPD®.*

As shown in Fig. 4, powder cannot be transported if the charge density is either too large or too small. Thus the charge density has to be controlled in a proper range (*Q1* to *Q2*) under every condition. According to Fig.8, the charging characteristic can be described by the following three properties, (1) charging rate, (2) saturated charge density, and (3) charge decay.

It is very important to measure each of these charging properties of the powder. In the case of (1) and (2) they can be measured by conventional methods. The blow-off method, in which the powder is mixed with a ferrite carrier, is one of the more convenient ways to measure the charging rate and the charge saturation. Furthermore charge distribution is also a very important factor. Checking the transition of the charge distribution as a function of mixing time provides important information for designing the powder.

The charge relaxation is the other important factor, although the measurement techniques for this are not as yet as established. For measuring charge relaxation properties as functions of time and temperature, the surface potential method [3] and thermally simulated current method (TSC) [4] have been adopted here. Examples of the TSC measurements are shown in Fig.9. Once the powder is charged by a corona charger, charge relaxation as a function of increasing temperature is observed as an infinitesimal current. In this case, the current profile for powder B occurs at the higher temperature range comparing with that of powder A. These results suggest that the charge stability of powder B is better than powder A, which means that the powder charge can be maintained in the case of non image update condition. The mechanism of determining TSC result is very complex. All the factors such as material properties (especially Tg), filler dispersion, surface roughness, etc. influence charge relaxation. It has been found that the most important point for designing the powders to produce the proper charging characteristic is the necessity of using various materials in combination.

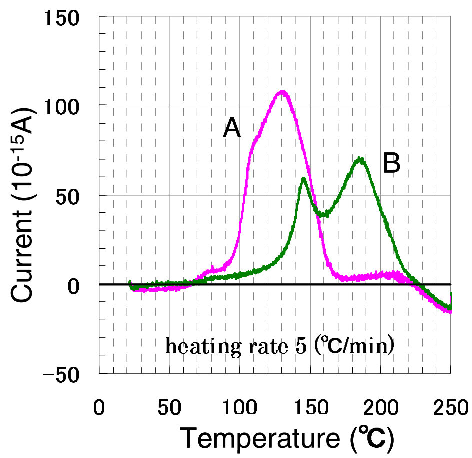

Figure 9. *Example of the results of TSC measurement. Powder sample A, B.*

Proposal of further products

Black and white display panels have been commercially released, especially for electric price tags and information boards. Corresponding to the wider requirements of electronic paper such as the display market, new prototypes of QR-LPD® have been developed. One of the big demands is color appearance. We have proposed two types of color display, one is area color and the other is a full color display. Color Electronic Liquid Powder® is prepared by using color pigment instead of carbon black or titanium oxide. This type of display can produce vivid color appearance because the observer can see the powder color directly without needing a filter.

A full color display has been also been developed by using color filters with B/W powders and gray scale level technologies. A R/B/G color filter is fabricated into the upper substrate. Gray scale can be produced by changing the B/W powder ratio of transport by controlling the bias voltage and driving logic. The prototype model provides 16 gray scale levels and a 4096 color appearance.

Flexibility becomes another big demand from the standpoint view of future electric paper like displays. As described above, the QR-LPD® fabrication process doesn't need high temperatures and thus it is suitable for film type production. Figure 10 shows the prototype model of a film type QR-LPD®. [5] The substrates are made of transparent plastic film and thin metal electrodes. It was made by a newly developed roll-to-roll process.

Figure 10. *Flexible type QR-LPD®.*

Conclusion

A novel type of electric paper like display QR-LPD® and its key component, Electronic Liquid Powder® are introduced. The QR-LPD® is a novel reflective display that has a paper like appearance and a multi-stable property that results in ultra low power consumption. The display can be driven passively thus making it compatible with a low cost driving system. In addition, it does not require any high temperature or complicated fabrication processes. It is most important to design the powder material to obtain the proper charging and decay properties for producing a good image quality.

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Author Biography

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