Electronic Paper Technology QR-LPD™

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A novel electronic paper technology: Quick Response-Liquid Powder Display (QR-LPD) has been developed. This panel is operated by a new material which behaves just like liquid despite powder form. This electronic paper has the advantages of outstanding image stability, easy viewing, low-power consumption and a high-response time. We have successfully developed thin and light weight flexible electronic paper using QR-LPD technology. Furthermore, we have proved there is the great potential to utilize printable technology for an electronic paper. Direct formation of line-shaped electrodes consisting of transparent conductive polymer of poly (3, 4-ethylene dioxythiophene) and poly (styrenesulfonate) (PEDOT/PSS) was successfully achieved onto a flexible polyethylene terephthalate (PET) substrate by using screen printing method.

Keywords: Liquid Powder Display, Printable, PEDOT, PSS, Screen printing

1. Introduction

There has been much interest in an electronic paper and many types have been demonstrated thus far.

We have been developing a new type electronic paper technology called QR-LPD (QuickResponse-Liquid Powder Display)1−6. Initially, we have promoted it as an electronic shelf label for use in retail stores. This electronic paper uses “Electronic liquid powder” which is a new material that we have developed. As its name suggests, it is a high-fluidity material that combines the properties of a powder and a liquid and is highly sensitive to electricity. Using this new material, QR-LPD has shown outstanding clarity just like paper along with excellent image stability, quick response, high resolution, clear threshold characteristics and low power consumption. In addition, the panel has an extremely simple structure and it can function by passive-matrix driving.

This indicates that QR-LPD is a much more suitable candidate for flexible type display implementation among ordinary paper-like displays. We have successfully developed thin and light weight flexible electronic paper with affordable substrate by a high through put roll-to-roll manufacturing system.

One of the important technical issues for the development of the flexible electronic papers is to improve durability of the materials in the flexible panels. Here, we will report the first example of a flexible display with an upper substrate composed of directly printed conductive polymer electrodes in high resolution. The line-shaped electrodes in a resolution of 88 dpi have been successfully prepared by screen printing. The improvement of the conductive polymers and printing methods has led to the achievement of the fabrication of printed panel electrodes.

2. Overview of QR-LPD

We have developed a new material that behaves just like liquid despite its powder form. Fig. 1 shows the behavior of (a) the electronic liquid powder we have developed on the right side and (b) an ordinary powder of the same size on the left side as the bottles are being shaken. In addition, the angle of repose about each powder was measured to evaluate the liquidity. The ordinary powder builds up on the plate in a flexible panels. Here, we will report the first example of a flexible display with an upper substrate composed of directly printed conductive polymer electrodes in high resolution. The line-shaped electrodes in a resolution of 88 dpi have been successfully prepared by screen printing. The improvement of the conductive polymers and printing methods has led to the achievement of the fabrication of printed panel electrodes.

![Fig. 1 The behavior of (a) the electronic liquid powder (this work) on the right side and (b) an ordinary powder on the left side.](image)
mountain–like shape, however the newly developed powder disperses evenly across the plate. From these measurements, it has been demonstrated that the developed powder has a super high liquidity.

Fig. 2 shows the cross sectional structure and the operational principle of QR-LPD. Two types of powders, including negatively charged white and positively charged black versions, are put into an area between two ITO-patterned glass plates. The rib forms a cell gap and prevents the powders from mixing. The rest of the space is filled with ordinary air. When a negative voltage is applied to the upper ITO electrode, the positively charged black powder moves to the upper electrode showing a black appearance and when a positive voltage is applied the negatively charged white powder is attracted to the upper electrode showing a white appearance. The structure of this panel, which is composed of only electronic powder, substrates and ribs, is extremely simple. Compared to LCD, this display does not require a polarizer layer, an orientation layer or a reflective layer. In addition QR-LPD is able to create a clear image without the use of TFT arrays due to the excellent threshold characteristics of the electronic powder.

The response time of this display is high and Fig. 3 shows the typical response curves of reflectance from the black state to white state and the dashed line from white to black. The response time can be roughly estimated to be about 0.2msec.

After turning off the applied voltage, QR-LPD is able to keep its image semi permanently without electrical power. Having no liquid in this panel contributes to its high response time and good performance.

3. Thin and light weight flexible QR-LPD

The portability and safety of a display are very important elements in addition to its appearance. An ideal electronic paper should be thin, lightweight, robust and flexible just like paper. As long as glass is used as a substrate, it is obviously impossible to meet such characteristics. However, there are many difficulties in adopting plastic substrates for practical use. To overcome these difficulties for practical use, it is necessary to develop a practical manufacturing process, utilizing affordable materials and a suitable panel design.

The fabrication of a TFT array on plastic is not available for production yet at present, since it requires a high temperature process. Even if a dramatic improvement could be achieved on the technology of organic TFTs and so on, it will still be difficult to refine that technology to the point where it can be readily applied into mass-production in the near future.

Maintaining an image completely is required even if a display is bent or pressed. However, most displays cannot satisfy this requirement since the gap–distance is sensitive to the image. QR-LPD can operate without TFT arrays by passive–matrix driving due to the excellent threshold characteristics. The panel production has an important advantage since it does not require a high temperature process. In addition, the displayed image on this display is not overly sensitive to external stimulus due to the ideal principle to keep the image by the attractive force between particle and substrate. This means that the image is not affected by factors such as the change of the panel gap–distance. This is important from a manufacturing standpoint since strict controlling of the gap distance is not required as compared to other display manufacturing processes such as for LCD production. Thus the manufacturing process is simplified resulting in increased yield and thus reduced cost.

A QR-LPD panel is designed to be extremely simple and does not require any components that would hinder its flexibility. The space between the upper substrate and the bottom substrate is designed to contain ordinary air. This means that QR-LPD does not require an expensive substrate that is usually coated with many protective layers to prevent the inside of the panel from coming into contact with moisture and oxygen. In case of QR-LPD it is possible to use an affordable substrate like PET, since this technology satisfies the requirements for use a plastic substrate.

Furthermore, since this panel basically doesn’t require TFT, it is fairly easy to challenge to construct an ideal process. We
have successfully developed a roll-to-roll manufacturing process with high though put. **Fig. 4** shows roll-to-rollrib
developing equipment.

**Fig. 5** shows a black & white type flexible display. The upper and lower substrates are made of transparentplastics. This display has a $260 \times 320$ array of pixels, a 89 dpi resolution, a 4.1-inch diagonal viewable image size, a thickness of 290 $\mu$m.

**Fig. 6** shows a color type flexible display with CFs. This shows 16 gray levels and 4096 colors. This display has a $260 \times 320$ array of pixels, a 28 dpi resolution, a 8.6-inch diagonal viewable image size, a thickness of 290 $\mu$m.

**Fig. 7** shows a flexible display device which has a 10.7-inch diagonal viewable image size color flexible panel, a flexible touchpanel, a flexible electrical circuit board and so on. Total thickness is only 5.7 mm.

### 4. Printable Technology for QR-LPD

Application of printable technology for an electronic paper is highly expected from the viewpoint of affordable cost andenvironment conscious.

The top electrode of the panel is required to be transparent for visibility because it affects the image quality a lot. Normally, oxides of indium such as indium–tin–oxide (ITO) are used for the transparent electrodes. However, the use of these crystalline materials to the electrodes of the flexible displays often results in cracks by the deformation of the panels. Higher cost and probable lack in resources of indium in future are also serious problems.

In contrast to the inorganic crystalline materials, organic polymers exhibiting conductivity can be considered to be quite useful for the electrode materials of the flexible displays due to their mechanical properties, lower cost, and mass productivity. Although the conductive polymers have been utilized so far for touch panel, preventing static electricity, and TFT arrays, and so on, there are few examples of that applied to top electrodes of display panel\(^7\), it would be because the transparent properties and the high resolution patterning methods have

\[\text{Fig. 8} \quad \text{Structure of PEDOT (a) and PSS (b).}\]
not yet been fully developed.

In this study, we have selected and used a polymer complex of poly (3, 4-ethylenedioxythiophene) and poly (styrenesulfonate) (PEDOT/PSS) as shown in Fig. 8. Conductive polymers such as classic poly (acetylene)s and poly (aniline) s normally absorb visible light due to their wide range-π-electron resonance in the polymer chain. On the other hand, for the polymer of thiophene having ether parts at its 3 and 4 positions (Fig. 8 (a)), the absorption band for visible light shifts toward infra-red region under doped state that gives rise to transparency. Therefore, this material can be considered to suit a top electrode of a flexible panel in particular. The dopant PSS shown in Fig. 8 (b) has a high molecular weight than PEDOT that gives this complex mechanical strength and self-standing properties. Furthermore, the ionic properties of the polymer complex results in the good solubility to water solvent, which leads to the other merits for this material in view of environmental and safety aspects.

To prepare electrodes directly by a printing method, the paste of PEDOT/PSS should desirably have high viscosity. Originally, the aqueous suspension of the PEDOT/PSS has a very low viscosity around 10 mPa·s. It is difficult to pattern electrodes directly, because the spacing areas between the electrodes are worried to be filled with the paste unwillingly. In this work, we have improved the suspension composed of PEDOT/PSS by mixing other additives which only increase the viscosity of the pastes without decreasing transparent and conductive properties of the original suspension. The viscosity of the pastes has elevated to 19,000 mPa·s successfully.

For printing methods, there are many kinds of approaches such as posi printing, screen printing, ink-jet, and so on. Here, we have used screen printing method to form electrodes on the flexible PET substrates. Screen printing has an advantage in regard to the accuracy of aligment during the assembly processes of the flexible electronic paper displays. It also has a merit for cost of apparatus.

Fig. 9 shows a photomicrograph of line-shaped electrodes prepared from the screen printing method. The formation of line-shaped electrodes through screen printing can be obviously observed although the edges of each line are a little bit vague. The line width of the electrodes is 268 μm, and the spacing is 42 μm.

The morphology of the printed electrodes was examined by using a laser microscope. Fig. 10 exhibits a cross sectional view of the printed PEDOT/PSS electrode in Fig. 9. The electrode has an arc-like shape. The height of the central part is 0.87 μm.

Transmittance spectrum of the electrode of PEDOT/PSS formed by screen printing and that of an ITO electrode as a reference were measured by micro spectroscope as shown in Fig. 11. The spot area measured on each electrode was within the circle of 100 mm diameter. The electrode of PEDOT/PSS exhibits transmittance of nearly 80% in the full range of visible region. Conductive polymer of PEDOT/PSS absorbs lights in near IR region in comparison with ITO which results in bluish appearance and decrease of the transmittance for the film substrate with the patterned electrodes.

Resistances of the line electrodes shown in Fig. 11 were
measured by using manipulator. The length of each line examined was 30 mm. The resistance of the electrode of PEDOT/PSS prepared by screen printing exhibits 57 kΩ while that of ITO electrode is 35 kΩ.

The flexible PET substrates with the line–shaped electrodes of PEDOT/PSS have been applied for the fabrication of flexible electronic papers utilizing quick response liquid–powder technology. Fig. 12 is a picture of a flexible electronic paper display having direct printed PEDOT/PSS electrodes on its upper substrate. The size of the display is 4.0 in. diagonal and it has an array of 281 × 210 pixels. The resolution is 88 dpi. It is confirmed that a checker pattern has been clearly displayed by passive matrix driving through the printed electrodes composed of the polymer materials. This electronic paper panel also shows good flexibility as shown Fig. 12.

The reflectivity of the flexible display with the printed PEDOT/PSS electrodes has been compared to that having ITO electrodes (Fig. 13). Although the black reflectivity of the panels are similar, the white reflectivity of the panel with PEDOT/PSS is lower than that having ITO electrodes. This would be due to the inferior transparent and conductive properties of the directly printed electrodes of PEDOT/PSS to those of ITO. Further development of the materials and the printing processes is now under progress.

The result described here is the first example of flexible display with electrodes composed of the transparent conductive polymer materials formed directly onto the upper substrate by a screen printing method. Although there were a lot of examples where the classical conductive pastes such as nano-scale silver inks were used for the fabrications of electric components by direct printing, transparent conductive materials have never been utilized for the patterned electrodes in high resolution to our knowledge. These results should progress the development of the materials and processing technologies of printable electronics.

5. Summary

We have successfully developed thin and light weight flexible electronic paper using QR-LPD technology. Furthermore, we have proved there is the great potential to utilize printable technology for an electronic paper.

We believe an electronic paper could be the necessity in our new life.

References


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