Photo-addressable E-Paper and Toner Display

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Abstract

Fuji Xerox has been investigating two types of electronic paper. One is Photo-addressable E-Paper using cholesteric liquid crystal (ChLC) and an organic photo conductor (OPC) for purpose of paper-like handling. The other is Toner Display using black and white charged insulative particles for paper-like appearance.

Photo-addressable E-Paper with microencapsulated ChLC stacked on the OPC can be switched quickly with light modulation by alternative current pulses. A prototype for black and white image was fabricated with coating processes on plastic substrate, which enabled the electronic paper to be thin, lightweight and flexible. The quality of the printed image was of high-resolution, a wide viewing angle, non-volatile and stable against bending or pressing. We introduced the feasibility of full color with a novel driving scheme for stacked red, green, blue ChLC layers.

Toner Display uses black and white particles with different polarities between a pair of electrodes with a certain air gap. These particles are moved to opposite directions by an applied electric field. They provide a high contrast of black and white reflective images with a wide viewing angle. The movement of particles exhibits a threshold in response to the applied electric field, thus they can form images using the passive matrix drive.

Introduction

Electronic paper is expected to be a new medium combining the advantages of paper with those of electronic displays. Electronic information is handled on electronic paper as if it were a hard copy. Electronic paper is classified into two types. One type can be printed on by a writing apparatus such as a printer. This type of electronic paper has more paper-like features (i.e., it is flexible, lightweight and inexpensive) and it can support multiple-page usage. The other type has an integrated combination of driving circuits and display media similar to a liquid crystal display. It is convenient and nonvolatile, but rigid and expensive because of its electronic circuits. The former type is Photo-addressable E-Paper,[1-6] and the latter type is Toner Display.[7,8] They are thought to be for different markets.

Photo-Addressable E-Paper

We have developed Photo-addressable E-Paper composed of a bi-stable ChLC and an OPC. Figure 1 shows one of the system images of Photo-addressable E-Paper. Our system is composed of sheets of E-Paper and a printer. The printer applies a voltage to the E-Paper, while illuminating a display image on the OPC. The E-paper can be printed quickly and repeatedly, and it has image retention. Thus, a separation of the display from the driving circuits enables a simple structure of the E-Paper without ICs and micro-fabrication. As a result, our E-Paper achieved paper features such as being thin, lightweight, unbreakable and flexible, which enable us to distribute it and to handle multiple sheets of E-Paper.

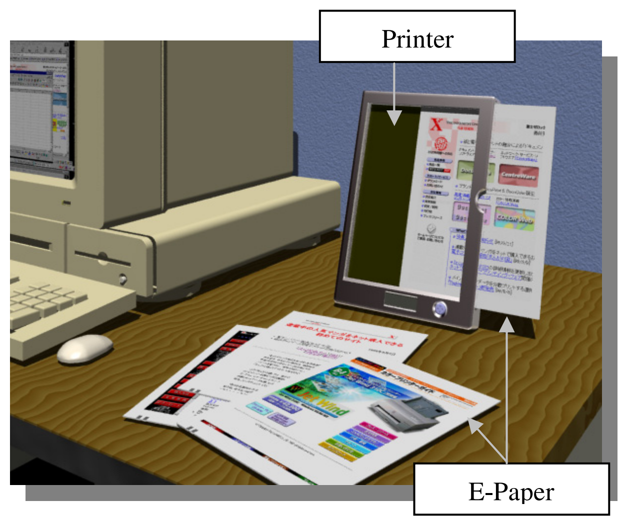

Figure 1. System image of Photo-addressable E-Paper

Structure and Driving Principle

Figure 2 shows the structure and the printing principle of Photo-addressable E-Paper. A ChLC display layer, a light absorption layer and a set of OPC layers are stacked between transparent substrates with transparent electrodes. Both of the electrodes on plastic substrates are not micro-fabricated; they are a pair of solid electrodes.

In order to apply alternating current to the ChLC, a novel OPC structure was invented, which has dual charge generation layers (CGL) stacked on both sides of a charge transfer layer (CTL) to obtain symmetrical charge transfer.

Figure 3 shows the relationship between illuminated light intensity and reflectance of the display layer. Photo excited charge generation decreases the resistance of the OPC layer, and the divided voltage of the display layer increases. When the voltage of the display layer is over a certain threshold, the reflectance is changed from the focal conic texture to the planar texture of ChLC. If electrical and optical conditions are met, a photo-addressing method is available, that is, an illuminated display image can be transferred to the print image of E-Paper.

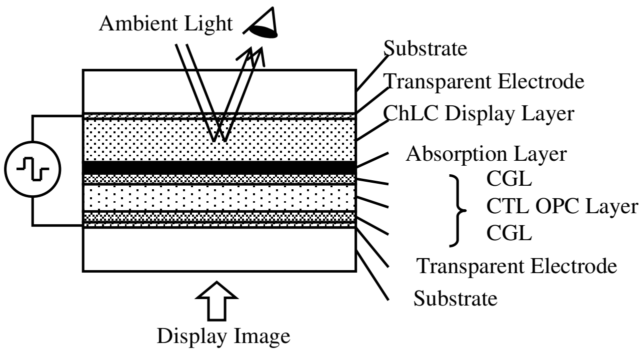

Figure 2. Structure and Printing principle of Photo-addressable E-Paper

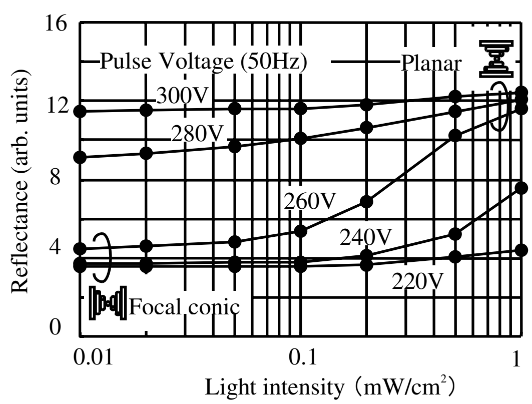

Figure 3. Relationship between light intensity and E-Paper reflectance

Prototype of B&W E-Paper

A paper-like black and white prototype was fabricated using a 125-μm-thick PET film as a substrate. A display layer was coated by an applicator with ink, which consisted of microencapsulated ChLC (E8/ CB15/ R1011 Merck) with a polyurethane polymer shell and a transparent aqueous binder polymer (PVA). Both Pink and light green ChLC capsules were mixed to achieve an achromatic appearance. The peak wavelength of the ChLC was 650nm and 550nm, respectively. The average diameter of capsules was 9μm and the thickness of the LC layer was 35μm. An OPC layer was formed with two CGLs and a CTL. A spin coated 0.2-μm-thick film, which consisted of hydroxy gallium phthalocyanine as a charge generation material and a poly-vinyl butyral binder, was used for dual CGLs. A dip coated 3-μm-thick dispersion-type CTL was used.

Table 1 lists specifications of the B&W Photo-addressable E-Paper prototype. The medium was realized to be only 0.3mm thick and flexible; the weight was only 7.7g. A display image was immediately printed in 0.2 seconds. The printed image was nonvolatile and withstood under bending or pressing due to the microencapsulated ChLC, which suppresses the flow of the liquid crystal.

Figure 4 shows a photograph of the B&W E-Paper. When a perfect diffuser reflects 100%, the reflectance of the planar state is approximately 25% measured with an integrating-sphere photometer. The contrast ratio was more than 8. The medium had a very high resolution of more than 600 dpi.

Table 1. Specifications of B &W Photo-addressable E-Paper

Size	105 X 171mm^2
Display Area	82 X 130mm^2
Thickness	0.3mm
Weight	7.7g
Driving Voltage	260V, 10Hz, 0.2sec
Reflectance	25%
Contrast ratio	8
Resolution	> 600dpi

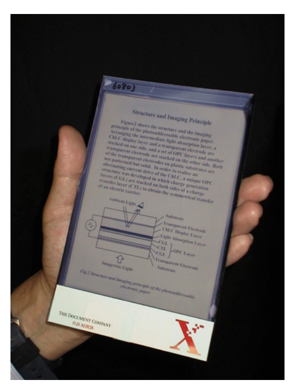

Figure 4. Photo of the B&W E-Paper

Approach to Color

The color display layer is considered to be a stacked structure of three selective reflection ChLC layers, which are red, green, and blue. This structure takes advantage of the high reflectance and no need of alignment accuracy between an electronic paper medium and an illuminating apparatus. Because the medium has no color position, such as a color filter in a LCD, it is two-dimensionally uniform. However, the problem is that a photo-addressing method can only control the voltage of all the layers together.

The stacked color layers require a new method for controlling the reflection of three layers respectively. By making use of the bistability of ChLC, a novel following driving scheme was invented. The threshold voltages of three ChLC layers are designed to be mutually shifted as shown in Figure 7 and two steps of voltage are applied, as shown in Fig. 8. For applying two appropriate steps of inter-threshold voltage pulses, we should control both of the voltages and light intensity. If Vf is applied as a reset pulse Vr, and then Vb is applied as a select pulse Vs, the applied area can be selected green. Thus, an appropriate applied voltage pair is enabled to control the reflection state of each layer independently. Therefore, any of eight colors can be created.

An experiment demonstrating color creation was conducted using the sample of color display layers. Three ChLC layers, whose voltage responses were designed as shown in Figure 7, were stacked and separated by two sheets of 4.5-μm-thick PET film. Figure 9 shows a reflective spectrum measured with an integrating-sphere photometer. Thus, the possibility of eight-color switching of stacked red, green, and blue ChLC layers with only a single pair of electrodes was confirmed by utilizing shifted threshold voltages and applying sequential voltages . The reflectance of white was 12.1%, and the contrast ratio was 5.6.

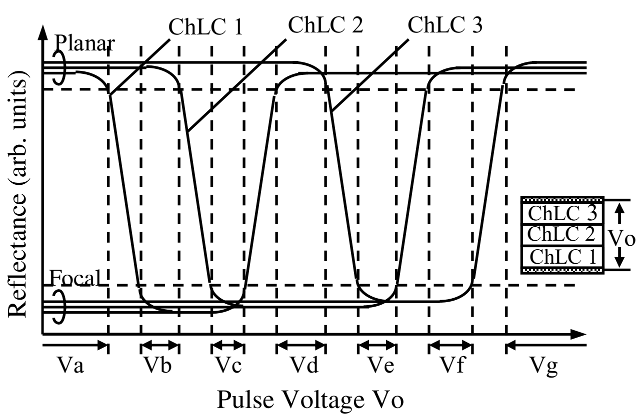

Figure 7. Threshold relationship between applied voltage and reflectance of three stacked ChLC layers

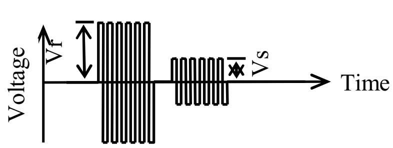

Figure 8. Waveform of the applied voltage

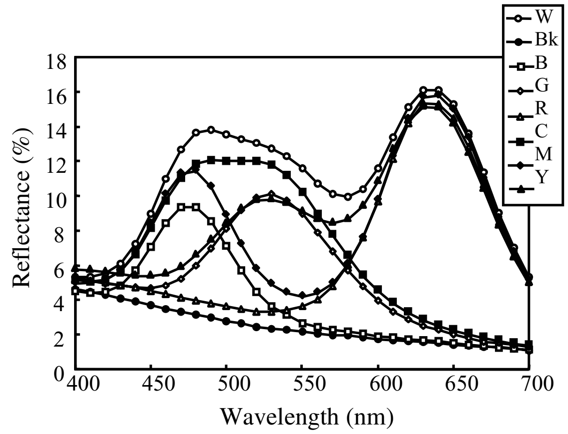

Figure 9. Reflective spectrum of the color sample

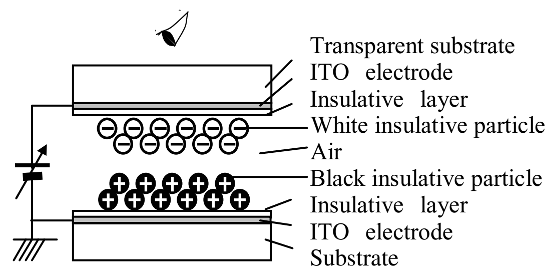

Figure 10. Structure of Toner Display using insulative particles

Toner Display Structure and Driving Principle

A device configuration of Toner Display is shown in Figure 10. The display device has two types of insulated particles, which have mutually different optical characteristics and charged characteristics. Particles are enclosed in the space filled up with gas, such as air, between a pair of substrates containing electrodes. An insulative layer covers the electrode to prevent the particles from a discharge.

The schematic diagram of the driving principle of the display device is shown in Figure 11. When a negative voltage is applied to a top plane electrode, a potential difference is generated between the substrates, while the insulative positively charged black particles move up to a top plane electrode with the application of an electric field (as shown in Figure (a)). Moreover, the insulative negatively charged white particles move down to the backplane electrode. Here, even if voltage source is disconnected, a particle is held by induced image force, van der Waals force, etc. The display appears black to an observer. Next, if a positive voltage is applied to the top plane electrode, the direction of the applied electric field between the electrodes is changed. Thus the insulative negatively charged white particles move up to the top plane electrode, and the insulative positively charged black particles move down to the backplane electrode, the display appears white from the top (as shown in Figure 11 (b)).

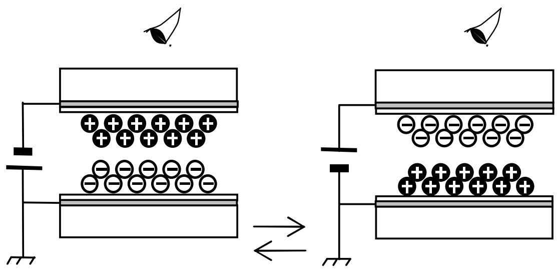

Figure 11. Driving mechanism of toner display device using insulative particles

Prototype of B&W E-Paper

Particle

White particles are spherical resin particles containing oxidized titanium pigments, whereas black particles are spherical resin particles containing carbon black pigments. Both insulative particles having a volume average size of 20μm were obtained by sorting. Moreover, fine powder was added on the surface of the particles to control triboelectric charging of the particles. The white particles were friction-charged at negative polarity, and the black particles were friction-charged at positive polarity.

Display Device

A 0.3mm-thick silicone rubber sheet with a 20mm-square hole was placed on a transparent glass substrate (50mm x 50mm) with an ITO (indium tin oxide) electrode, and the mixture of black and white particles were put into the hole. Next, another transparent glass substrate with an electrode was placed on the silicone rubber sheet, and finally, the substrates were stuck together. Each ITO electrode on the glass substrates was wired to a power supply, and a voltage of 0V ~ ±300V was applied between the substrates. Reflective density was measured by X-Rite® 404A, and reflectivity was computed from the measured reflective density.

Experimental Results and Discussion

High contrast and high reflectance are achieved using this toner display device. The magnified photograph of the surface of the top-plane is shown in Fig. 12; (a) shows the top-plane electrode subjected to a negative voltage, and (b) shows that subjected to a positive voltage. The mixture particles were separated and they adhered to the inner substrate densely. The reflective density is 1.67 and reflectivity is 2.1% when the voltage on a top-plane electrode is -300V, and 0.39 and 41%, respectively when the voltage applied on the top-plane electrode is +300V. Thus, reflective density contrast (D) is 1.28 and reflectivity contrast (R_{con}) is 20. Here, the reflective density of the top-plane substrate itself is 0.21, which is added to the above reflective density.

The prototype device is represented by a mixture of particles between the substrates, and top-plane electrode formed solid pattern segments. The display with monochrome contrast, which is shown in Fig. 13, is obtained by applying a voltage to the solid pattern segments and a counter voltage to the other segments. The display is inverted by reversing the polarity of the voltage applied.

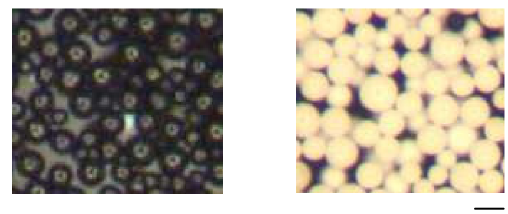

Figure 12. Magnified photograph of the top-plane plate

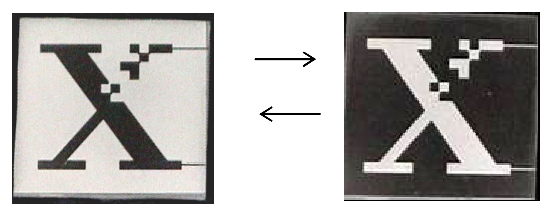

Figure 13. Sample of the solid pattern mode

A threshold in the particle movement in response to the electric field intensity is observed. If a negative voltage is applied to the top-plane where white particles adhere to the top-plane side, the positively charged black particles will move up to the top-plane-electrode side, whereas the negatively charged white particles move down to the backplane-electrode side, as shown in Figure 14 (a). Then, if a positive voltage is applied to the top-plane electrode, the negatively charged white particles adhere to the top-plane in response to the voltage applied (b). The display exhibits a threshold in response to the electric field intensity; thus a passive matrix drive is possible. Figure 15 shows the prototype passive matrix display device; the display contains a 32×32 array of pixels, each 8.4mm wide.

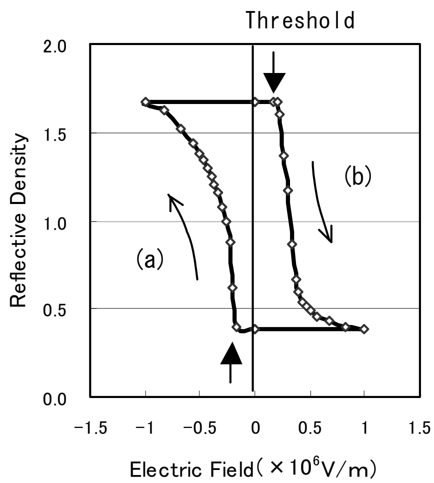

Figure 14. Reflection density curve with respect to electric field

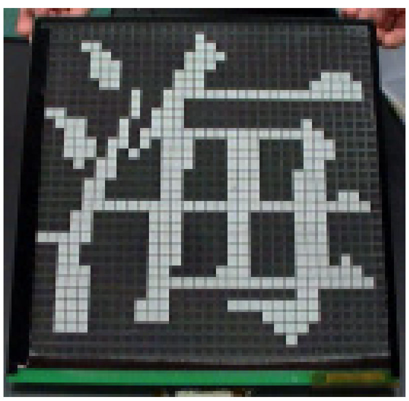

Figure 15. Image sample: the display mode is a passive matrix

Conclusion

Photo-addressable E-Paper can be printed quickly by a series of alternative current pulses with illuminated display image on the OPC. A B&W prototype was fabricated with coating processes on plastic substrate, which enabled the E-Paper to be thin, lightweight and flexible for paper-like handling. The quality of the printed image was of high-resolution, a wide viewing angle, non-volatile and stable against bending or pressing. We introduced the feasibility of full color with a novel driving scheme for stacked ChLC layers.

Toner Display has black and white particles with different polarities between a pair of electrodes with a certain air gap. A B&W prototype shows high contrast of black and white reflective image with a wide viewing angle for paper-like appearance. The movement of particles exhibits a threshold in response to the applied electric field, thus they can form images using the passive matrix drive.

We have made a technical overview of electronic paper in Fuji Xerox. Color electronic paper is our next challenge. We believe our two types of electronic paper will be promising tools for comfortable reading of electronic information.

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Biography

Mr. Arisawa received his M.E. degree in Physical Engineering from the University of Tokyo. He has been at Fuji Xerox since 1981 and been engaged in research and development of non-impact printing and electronic paper. He is presently manager of the Photo-Addressable Electronic Paper project. He is a member of the re-writable and electronic imaging committee in the Imaging Society Japan. He is also one of the Program Committee members in the 11th International Display Workshops in 2004.