Photoaddressable Electronic Paper Using Cholesteric Liquid Crystal

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Abstract

We have developed a novel electronic paper which consists of cholesteric liquid crystal (ChLC) and an organic photoconductor (OPC). The microencapsulated ChLC stacked on the dual charge generation layer (CGL) OPC can be switched between a focal-conic texture and a planar texture by light modulation under AC voltage. The prototype demonstrated a bistable and flexible monocolor image. We also demonstrated the feasibility of fullcolor with a new driving scheme for stacked red /green /blue (RGB) ChLC layers.

Introduction

Electronic paper is expected to be a new medium combining the advantages of paper with those of electronic displays. One can handle electronic information on electronic paper as if it were a hard copy. Electronic paper can be classified as two types. One has an integrated combination of driving circuits and display media similar to an electronic display. It is convenient and nonvolatile, but rigid and expensive because of its electronic circuits. The other can be detached from an imaging apparatus such as a printer. This type of electronic paper has more paperlike features, i.e., it is flexible, lightweight and inexpensive, and it can support multiple-page usage.

We have developed a novel photoaddressable electronic paper[1-4] composed of bistable ChLC and an OPC. Figure1 shows a system image of the photoaddressable electronic paper. Our system is composed of an electronic paper medium and an imaging apparatus. The medium has a nonvolatile display and it can be imaged quickly and repeatedly. The imaging apparatus applies AC voltage, simultaneously illuminating two-dimensional imagewise light. Thus, a separation of the display part and the driving part enables easy function of the electronic paper, which results in paperlike features and enables multiple-page usage.

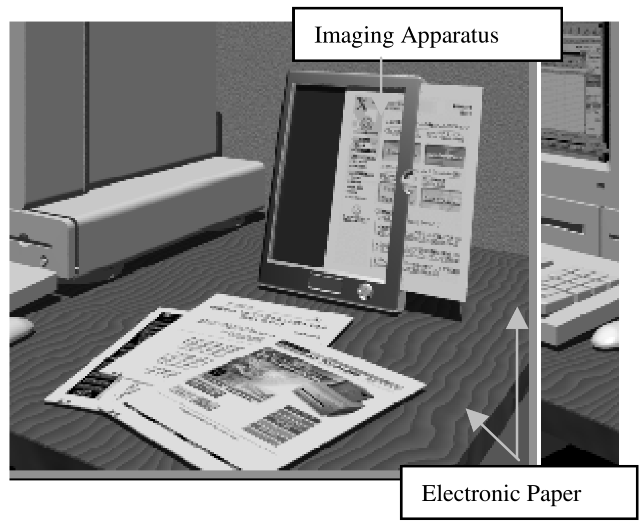

Figure 1. System image of the photoaddressable electronic paper

Structure and Imaging Principle

Figure 2 shows the structure and the imaging principle of the photoaddressable electronic paper. Arranging the intermediate light absorption layer, a ChLC display layer and a transparent electrode are stacked on one side, and a set of OPC layers and another transparent electrode are stacked on the other side. Both of the transparent electrodes on plastic substrates are not patterned; they are single electrodes. In order to realize an alternating current drive of the ChLC, a unique OPC structure was developed in which CGLs are stacked on both sides of a charge transfer layer (CTL) to obtain the symmetrical transfer of an electric carrier.

The imaging sequence consists of two steps: 1) imagewise light exposure to the OPC layer, and 2) a series of pulse voltage applications to the electrodes. For exposed parts, light-induced charge generation under electric field reduces the impedance of the OPC layer, and the divided voltage of the display layer increases. Consequently, reflectance change between the focal conic texture and the planar texture is obtained in response to the amount of exposure when appropriate pulse voltages are applied, taking into consideration the threshold voltage of ChLC. For example, the appropriate voltage in Fig. 3 is 260V. When a two-dimensional light modulation device is used, an image can be transferred immediately by a flash exposure.

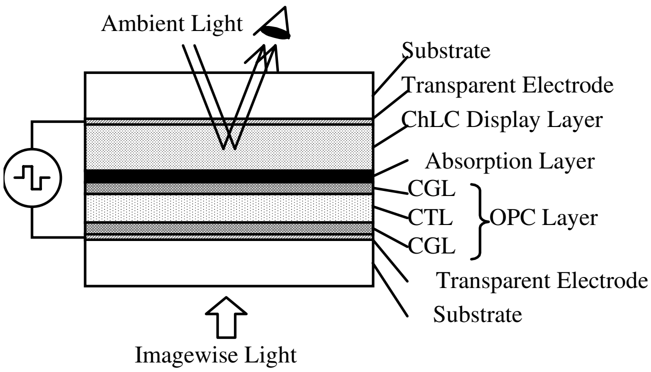

Figure 2. Structure and Imaging principle of the photoaddressable electronic paper

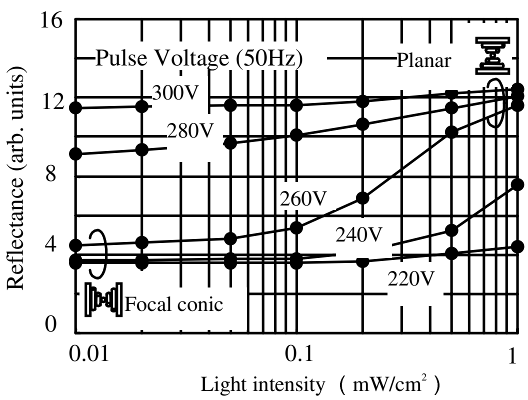

Figure 3. Relationship between light exposure intensity and electronic paper reflectance

Prototype of Monocolor Sample

A paperlike monocolor prototype sample was fabricated using a 125-μm-thick PET film as a substrate. A display layer was coated by a printing apparatus with ink, which consisted of microencapsulated ChLC (E8/ CB15/ R1011 Merck) with a polyurethane polymer shell and a transparent aqueous binder polymer. The peak wavelength of the ChLC was 550nm, the average diameter of capsules was 9μm and the thickness of the LC layer was 30μm. An OPC layer was formed with two CGLs and a CTL. Vacuum-deposited 80-nm-thick benzimidazole perylene was used for dual CGLs. A dip-coated 3-μm-thick dispersion-type CTL was used.

Table 1 lists specifications of the monocolor sample. The medium was realized to be only 0.3mm thick and flexible; the weight was only 7.7g. A display image was immediately recorded in 0.2 seconds. The obtained image was nonvolatile and persisted under bending or pressing due to the microencapsulated ChLC, which suppresses the flow of the liquid crystal.

Table.1 Specifications of the Monocolor Sample

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	4
Resolution	> 600dpi

Figure 4 shows images of the monocolor sample. AC voltage pulses were applied under light modulation with (A) a TFT LC panel and (B) a photomask. Arbitrary electronic information was imaged with a TFT LC panel. Meanwhile small six-point characters were imaged clearly with a photomask. The medium had a very high resolution of more than 600 dpi.

(A) (B)

Figure 4. Image of the monocolor sample

Figure 5 shows the reflectance spectrum of the monocolor sample, which was measured with an integrating-sphere photometer. When a perfect diffuser reflects 100%, the reflectance of the planar state is approximately 25% instead of monocolor. The contrast ratio was more than 4. Microencapsulated ChLC has a broad spectrum compared with that of conventional ChLC. As a result, color shifting or reflectance reduction was prevented by reducing the viewing angle. Encapsulation brought about not only image stability but also a paperlike appearance such as a wide viewing angle.

Imaging Apparatus

Figure6 shows an imaging apparatus with a TFT LCD, which imaged the samples in Fig. 4 (A). This system is called a subviewer system, and consists of a notebook PC, a TFT LCD with an LED backlight, a power supply, and a sheet of electronic paper. When a person is working on a PC and wants to print what he sees, he can obtain the image on electronic paper immediately after clicking the mouse. Although the applied voltage is higher than 200V during the imaging, a compact power supply with a dry battery can drive the medium because it utilizes the electric-field effect of liquid crystal.

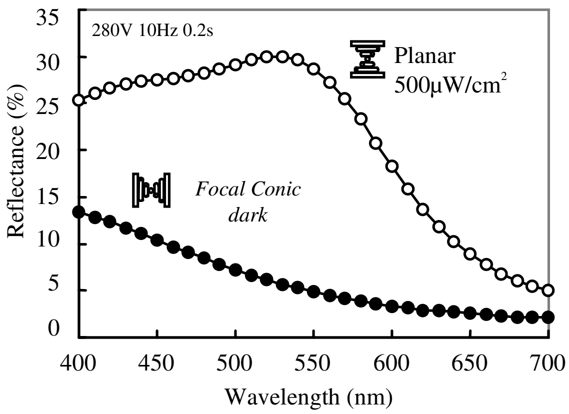

Figure 5. Reflectance spectrum of the monocolor sample.

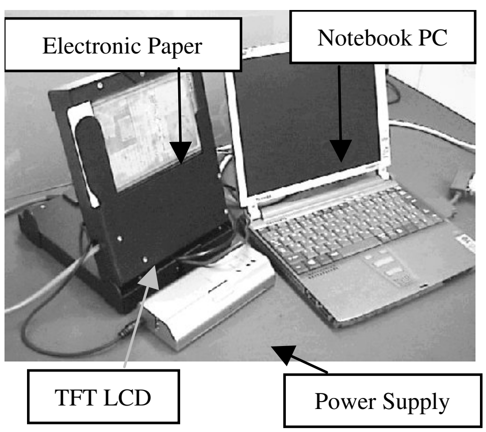

Figure 6. Imaging apparatus with TFT LCD.

The imaging apparatus of photoaddressable electronic paper only requires an image illuminating device and a power supply. Therefore, various displays are candidates for the system, which can expand its applications. For example, an information stand using a projector enables an information pick-up system. In this study, several kinds of experimental models have been fabricated for various assumed applications of electronic paper.

Approach to Color

The color display layer is considered to be a stacked structure of RGB selective reflection ChLC layers. This structure takes advantage of the high reflectance and the lack of alignment requirement between an electronic paper medium and an imaging apparatus. Because the medium has no color position, such as a color filter in LCD, it is two-dimensionally uniform. However, the photoaddressing method can only control the voltage of all the layers together.

The stacked color medium requires a new method for controlling the reflection of three individual layers. By making use of the bistability of ChLC, the following driving scheme was invented. The threshold voltages of three ChLC layers are designed to be mutually phase shifted as shown in Fig. 7 and two steps of voltage are applied, as shown in Fig. 8. When applying two appropriate steps of interthreshold voltage pulses, we should control both 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 pixel 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.

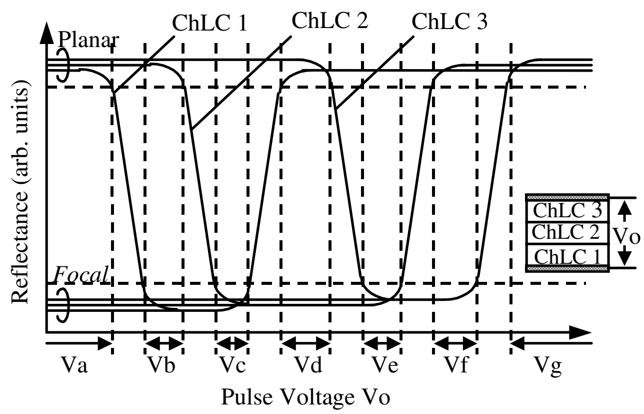

Figure 7. Threshold relationship between applied voltage and reflectance of three stacked ChLC layers.

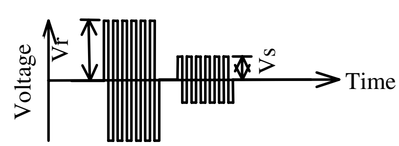

Figure 8. Waveform of the applied voltage

An experiment demonstrating color creation was conducted using the sample of color display layers shown in Fig. 9. RGB ChLC layers, whose voltage responses were designed as shown in Fig. 7, were stacked and separated by 4.5-μm-thick PET films. Figure10 shows a reflective spectrum measured with an integrating-sphere photometer. Thus, the possibility of eight-color switching of stacked RGB 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.

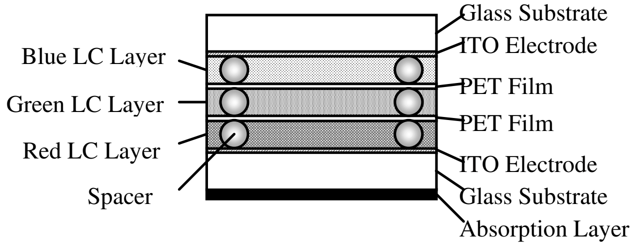

Figure 9. Structure of the eight-color sample

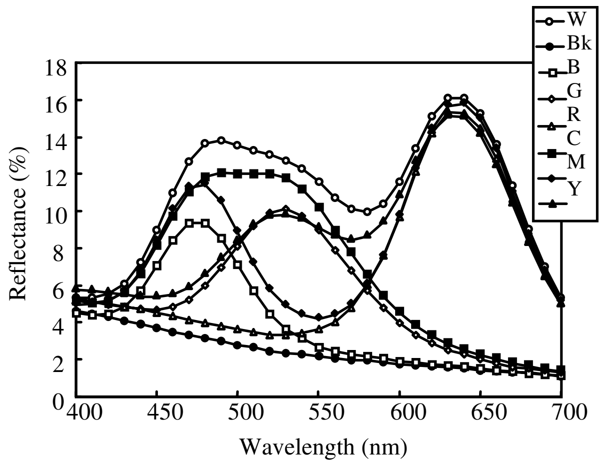

Figure 10. Reflective spectrum of the color sample

Summary

We have provided a technical overview of photoaddressable electronic paper, which combines bistable microencapsulated ChLC with an OPC. A prototype monocolor sample was successfully fabricated. This electronic paper has several unique merits, including high-speed imaging with a two-dimensional light modulation device, a thin and flexible medium shape, a detachable nonvolatile display, image stability against bending or pressing, a wide viewing angle, high resolution, and so forth. We also demonstrated the feasibility of fullcolor with a new driving scheme for stacked RGB ChLC layers.

We believe that photoaddressable electronic paper is a promising tool for reading electronic information.

References

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