Digital Paper with Guest-Host type Liquid Crystal Medium

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Digital Paper was recently proposed as a new medium that offers the advantages of both softcopy and hardcopy. This study examines the possibility of realizing Digital Paper by using an ion projection head to drive a liquid crystal medium. A guest-host type liquid crystal sheet medium is prepared. An ion projection head with charge dot density of 300 dpi is used for surface charging. It is confirmed that white images could be repeatedly formed on a black background by ion projection followed by image erasure (by heating) to the black background. It is demonstrated that this sheet medium has ideal characteristics; it reproduces the viewing angle and flexibility of paper. This method is thus promising as a candidate for realizing Digital Paper.

Journal of Imaging Science and Technology 47: 304-308 (2003)

Introduction

Visual Display Terminals such as CRTs, LC (Liquid Crystal) Displays, and Plasma Displays are used to access very popular services and often used in daily life. These softcopy devices have several advantages in terms of digital information handling and rewritability, but they are handicapped in terms of awkward physical form and poor support when reading large volumes of material. Hardcopy is still recommended if we want to read a lot or want to carry the information around. The concept of Digital Paper[1] was recently proposed as an ideal medium that combines the advantages of softcopy and hardcopy. Various methods have been proposed as candidate technologies for Digital Paper.[2,3] This study examines the possibility of using an ion projection head to establish surface electric charges on a liquid crystal medium as one way of realizing Digital Paper.[4–6] Figure 1 shows our target and our approach to the LC medium: divorcing the LC medium from driver. Our idea is to realize a paper-like liquid crystal medium by separating liquid crystal sheet from the writing unit. This represents a totally different approach to the liquid crystal display from the conventional concept of a liquid crystal screen with integrated driving circuit.

Liquid Crystal Sheet

We prepared a guest-host type liquid crystal medium that has guest dichroic dye in Smectic A LC droplets held in a polymer binder.[7] Figure 2 shows the principle of surface charge driving a guest-host type polymer dispersed liquid crystal (PDLC). The materials of the guest-host type PDLC used in this study are listed in Table I.

The rewritable medium consists of a PDLC film that has LC droplets dispersed in a polymer binder as shown in Fig. 2. The alignment of host LC molecules and guest dichroic dye in a droplet is controlled by the electric field created by the local surface charge of the sheet. Image contrast is determined by the alignment of the guest dichroic dye. Controlling electric field across the medium controls the light transmission of the medium by changing the orientation of the liquid crystal molecules; the light absorption characteristics of the dichroic dye varies with its molecular direction, which mirrors that of the liquid crystal molecules. The substrate of the medium sheet is a PET film (188 μm thick) with evaporated ITO electrodes. The 6 μm thick guest-host type liquid crystal layer is formed on the base PET film. The protecting layer is a 2 μm thick layer of UV curable resin. We prepared, in total, 4 media: two types of LC materials (A and B) and two ratios of LC to polymer binder (40/60 and 50/50 by volume). Each test sheet was 200 mm × 300 mm.

Experimental Method

We confirmed that the LC medium could be driven using the apparatus illustrated in Fig. 3. The test sheet on the stage receives a controlled ion flow from the ion projection head[8,9] set above the stage. The distance between the ion projection head and the test sheet was adjusted to around 1 mm. The ion projection head comprises corona discharge ion source with many apertures through which the ion flow passes. The apertures on the ion projection head were arranged with a density of 300 per inch: this head was originally designed for a printer with 300 dpi. The ion projection head contains a driving circuit that provides a driving voltage for each aperture in order to control ion projection.[10] The stage speeds, which regulate the ion density projected onto the test sheet on the stage, were 1.0 and 2.5 mm/sec. Negative corona ions were projected from the head to form surface electric charge patterns on the sheet. The surface electric potential of the medium was measured

Original manuscript received December 20, 2001

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Table I. Materials of the Guest-Host Type PDLC Used in This Study.

Contents	Material		Details
Host liquid crystal	Smectic A type liquid crystal	(A) (B)	(Mixture of cyanobiphenyl LC, B) cyanotriphenyl LC, and phenylbenzoate LC No.S-6 of Merck Ltd.
Guest dichroic dyes	Azo dye (Mixture of yellow,	Yellow	4-[4-(4-Butylphenylaze)naphythylaso]-1-ethoxybenzene
(Added 2.0 wt% to the host liquid crystal)	blue, and bluish purple: mixture rate = 22:25:40)	Blue	1-Hepthl-6-[4-[4-[4-(4-penthlophenoxycarbonyl)phenylazo]-1-naphthlazo]-1-naphthylazo]-2,2,4,7-tetramethyl-1,2,3,4-tetrahydroquinoline
		Bluish Purple	4-{[4-[[4-[(4-Buthlphenyl)azo]phenyl]azo-1-naphthalenyl]azo}N, N'-diethl benzoamine
Polymer binder	Acrylic resin		Acrylic resin of molecular weight of 300,000

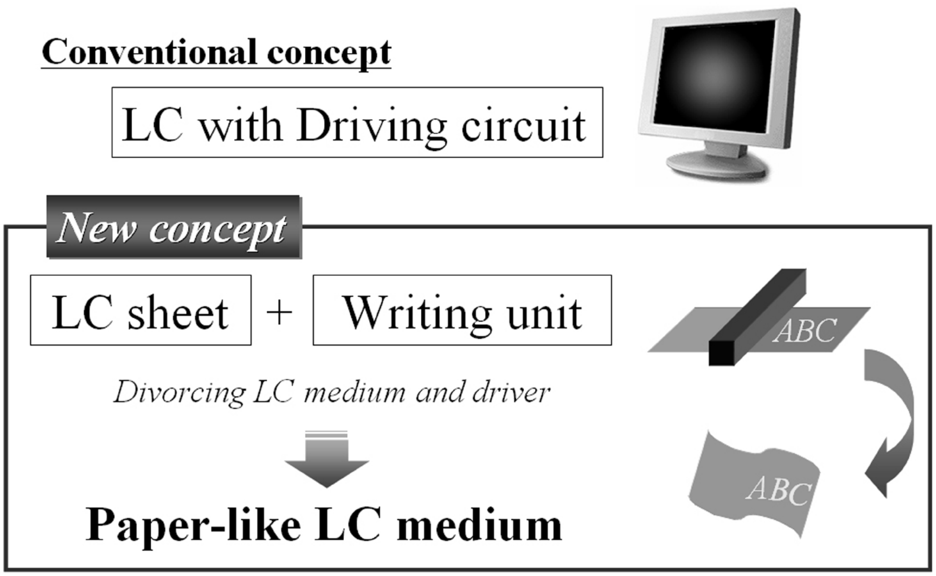

Figure 1. Target and new concept of paper-like LC medium.

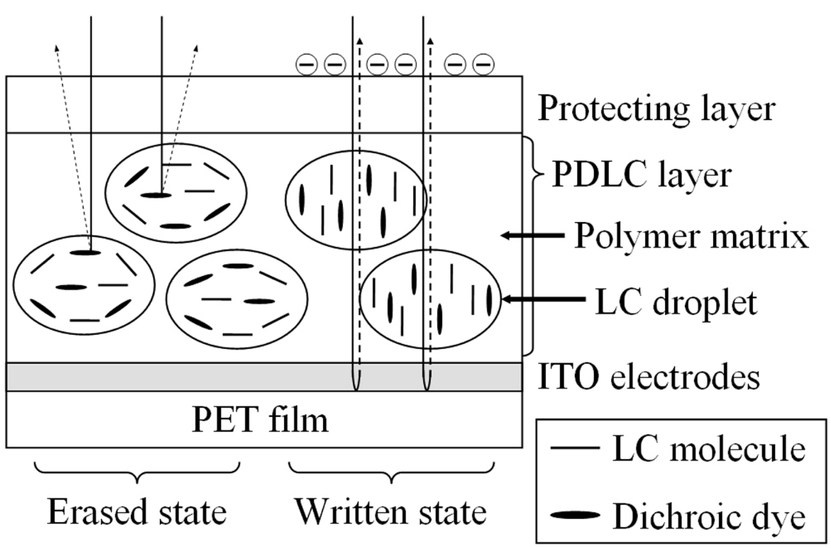

Figure 2. Structure and imaging principle of the guest-host type polymer dispersed liquid crystal.

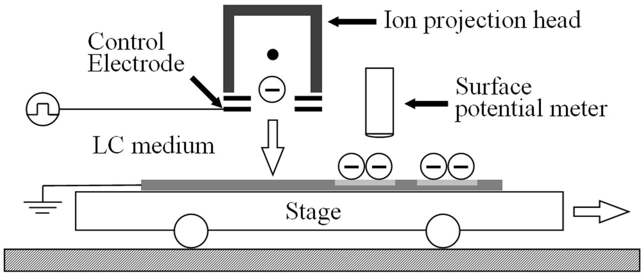

Figure 3. Imaging process.

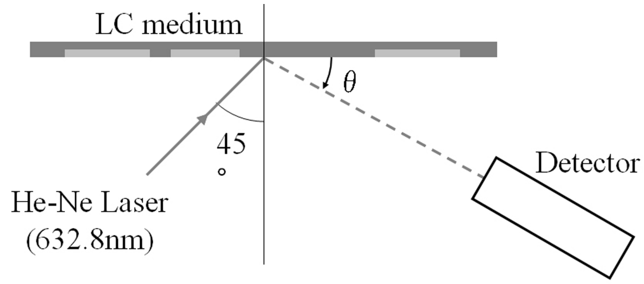

Figure 5. Measurement of reflection characteristic: cross section view (θ: 0~90°).

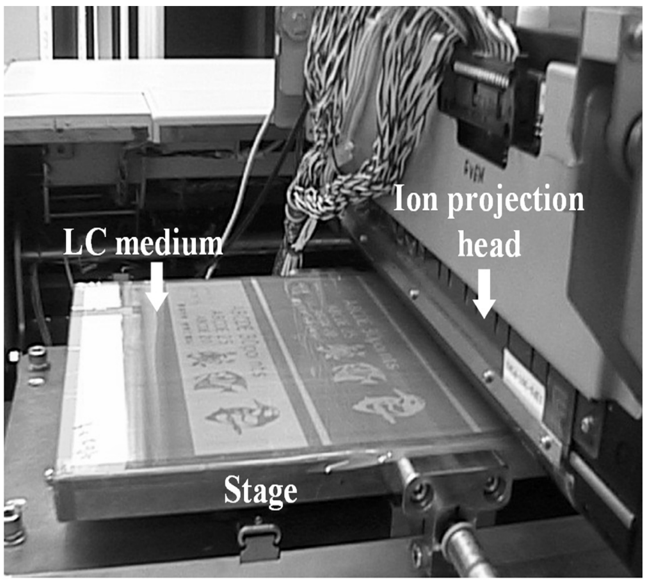

Figure 4. Experimental apparatus for image formation.

Figure 6. Typical image formed on liquid crystal medium by ion projection (LC type B, Composition ratio-50/50).

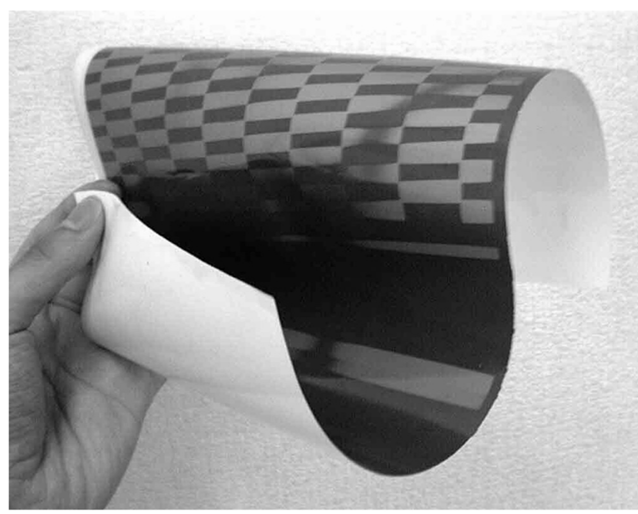

Figure 7. Overview of guest-host type liquid crystal sheet medium (LC type B, Composition ratio-50/50).

just after the imaging process by using a surface potential meter in order to confirm the surface electric potential needed to form images on the sheet. We measured the reflection optical densities of image and non-image areas using an optical densitometer and calculated the contrast ratios.

The reflection characteristics of the images formed on the medium (see Fig. 5) were measured at angles ranging from 0° to 90° relative to the medium's front surface using light from a 45° angled He-Ne laser (632.8 nm). The reflection characteristics of Plain Paper copier (PPC) paper were also measured in the same way for reference.

Erasure experiments were carried out using water baths. Hot water baths of temperature 20 to 60°C with steps of 5° were prepared. The test medium was immersed in the hot water with a period of 5 sec at each bath; optical densities of image area and background were measured just after pulling the medium up from each bath.

Experimental Results

A typical image formed on the liquid crystal medium by ion projection, white characters on a black background, is shown in Fig. 6. The overview of the medium, as shown in Fig. 7, demonstrates its flexibility; it can be curled up like paper.

Figure 8 shows a typical measured relationship between the optical density of the medium and surface potential (LC type B). The optical density of the sheet is almost linear with surface potential from 160 V to 320 V.

The optical densities and contrast ratios measured for the 4 test media are shown in Table II. The optical den-

Table II. Measured Results: Image Density and Contrast Ratio.

Medium	LC material:	A		B	
	Composition ratio (Volume ratio of LC/polymer)	40/60	50/50	40/60	50/50
Surface Potential (-V)	Start	210	250	160	170
	End	350	350	310	320
Final Optical density (O.D.)	(A) Min	0.49	0.59	0.47	0.61
	(B) Max	0.83	1.05	0.80	1.09
Contrast ratio	Log scale (B/A)	1.69	1.78	1.70	1.79
	Linear scale $10^{(B-A)}$	2.19	2.88	2.14	3.02

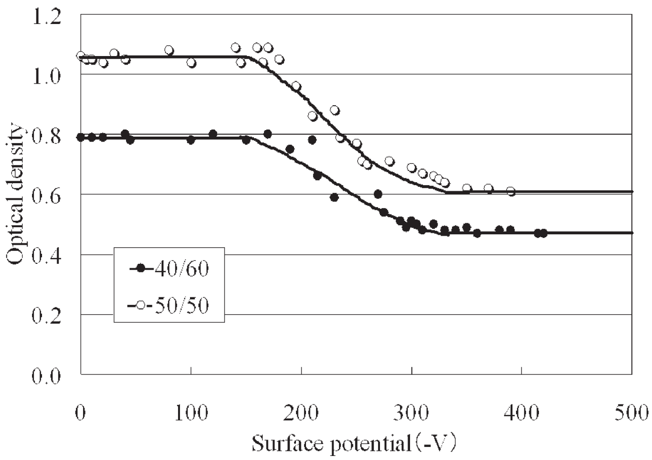

Figure 8. Measured relationship between surface potential and optical density (LC type B).

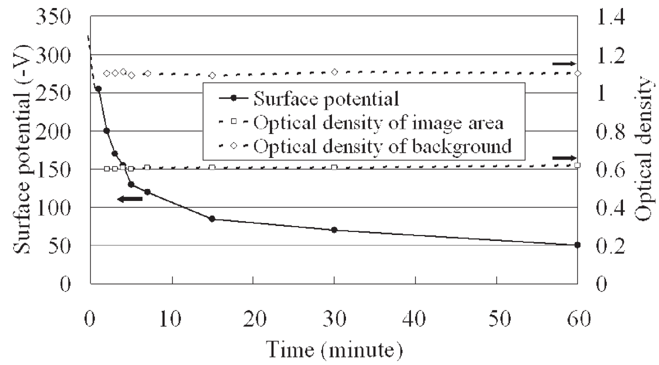

Figure 9. Decay of surface potential and constancy of optical density (LC type B, Composition ratio-50/50).

sity of each medium saturates at surface potentials from 310 V to 350 V. The measured optical densities increase as the ratio of liquid crystal to polymer binder increases. We infer that this is because the dichroic dye quantity increases with the liquid crystal quantity.

The surface electric potential starts to decline just after ion projection. Figure 9 shows the measured surface electric potentials on an LC medium, which starts decreasing just after image formation. Optical density of the medium was also measured at the same time. The decrease in surface potential is rapid; the surface potential decreased by 50% after 3 min. Optical density, however, remained constant, despite the drastic change in surface potential, in both image areas and background. The image formed on this medium showed no visual change even though the surface electric potential gradually decreased. It has been confirmed that such images show no change even 1 year after their formation, by which time the surface electric potential had decreased to zero.

Figure 10 shows the measured reflection characteristics of the image formed on the medium using the apparatus shown in Figure 5. Measured values were normalized by the reflection intensity of PPC paper when θ equaled 45°. Reflection ratios between image areas and background calculated from Fig. 10 are shown in Fig. 11 (medium: LC type B, composition ratio 50/50). The relative reflection ratio ranges from 2.0 to 3.0 over the practical viewing angle range of 20 to 90°, except for

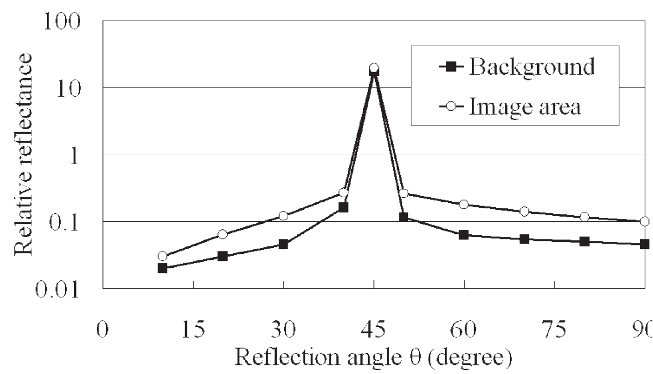

Figure 10. Reflection characteristics normalized by the reflection intensity value of plain paper when θ = 45° (LC type B, Composition ratio-50/50).

the mirror surface reflection condition at 45°. These reflection characteristics are similar to those of coated paper and so indicate that we can expect to realize an ideal viewing appearance.

The erasure characteristics obtained on heating are shown in Fig. 12 (medium: LC type B, composition ratio 50/50). It is shown that the entire display area returned to its black state at about 60ºC. We found that the image formation cycle, ion projection followed by thermal

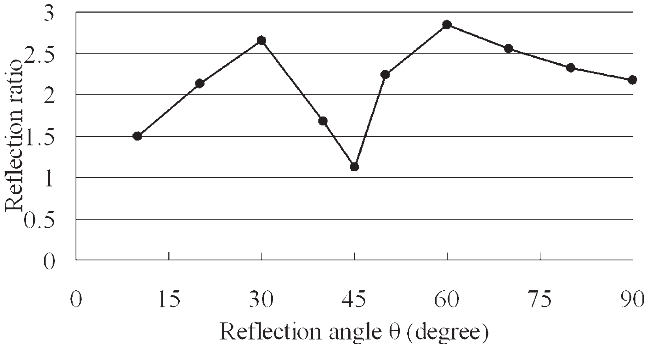

Figure 11. Viewing angle dependence of reflection ratio between the image area and the background (LC type B, Composition ratio-50/50).

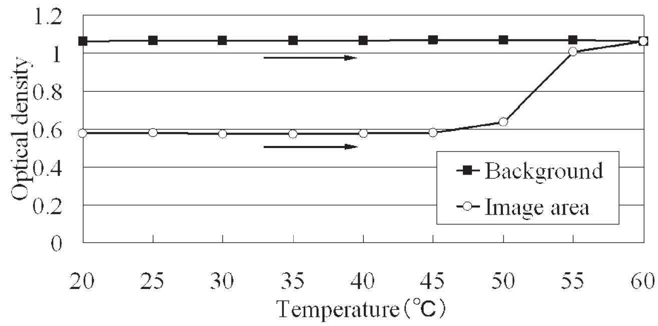

Figure 12. Erasure by heating (LC type B, Composition ratio-50/50).

erasure, could be repeated. This confirms the rewritability of this medium.

Summary

This study examined image formation on liquid crystal media by the ion projection driving method. The main results are as follows.

1. Image formation can be realized on a guest-host type liquid crystal sheet medium using the ion projection head.
2. The surface electric potential necessary for saturated image formation lies in the range 310 V to 350 V for the media used in this experiment. It was confirmed that there was no degradation in formed images even after the surface potential decreased to zero.
3. Ideal display characteristics can be achieved that are almost independent of viewing angle.

These results indicate that the sheet medium and imaging process demonstrated in this study form a promising approach to Digital Paper. Further study is needed on enhancing the contrast ratio, writing speed, resolution, and erasure.

Acknowledgment. The authors would like to express their thanks to Mr. Shinichi Hikosaka, Mr. Teruo Sakamaki, Mr. Satoshi Ishikawa, Ms. Keiko Sekine, Mr. Atushi Baba, Mr. Wataru Saito, and Mr. Takahiro Kasahara of Dai Nippon Printing Co. Ltd. We are indebted to them for carrying out this study: the sheet samples of guest-host liquid crystal sheet used in this study were supplied from them, and many useful discussions with them supported this study.

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