

# Flexible and Transparent Liquid Crystal Display with Azobenzene Optical Switch

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## ABSTRACT

An optically switchable transparent liquid crystal display consists of a polymer network liquid crystal (PNLC) containing azobenzene and a light source. The PNLC switches between transparent and screen states through photoisomerization of azobenzene. The flexibility and transparency of the PNLC were achieved by combining monomers of monofunctional reactive mesogens and bifunctional methacrylates.

## 1 Introduction

Transparent displays have attracted significant attention in recent years. They can be applied to store signage windows and automotive windows.

Organic light-emitting diode (OLED) displays [1] are a self-emitting type of transparent display. OLED displays can be large and offer advantages in terms of image quality, such as a large viewing angle, superior color gamut, and high resolution. However, OLED transmittance is low due to the several thin-film transistors (TFTs) and capacitors in each pixel.

As a projection system, there is a flexible transparent display using polymer dispersed liquid crystal (PDLC) and a projector [2]. PDLC films are marketed for the dimming application besides the display. PDLC is composed of a liquid crystal and a reactive monomer, and micro-sized liquid crystal domains are formed in the polymer matrix by phase separation during photopolymerization. The transparent and light scattering screen states are electrically controlled. As a mechanical property, the monomer concentration is high, so it is flexible and does not break even if it is bent or pressurized. Amorphous acrylate monomers, which are easily mixed with liquid crystals, are often used as reactive monomers. However, since the optical anisotropy of liquid crystal and the isotropic monomer are mixed, light scattering due to the refractive index difference occurs except in the orientation direction. In addition, since an active-matrix circuit for pixel selection is not formed in the transparent electrode of PDLC, it is not possible to screen and display any desired area.

Especially, when a large area transparent display is

applied to the windshield of a car, it is required to be highly transparent even when viewed from an oblique angle, to be flexible and to be mounted on a curved surface, and to be able to be displayed in any desired area.

In our previous study [3], [4], we reported a projection-type optically switchable transparent LC display. It consists of an optically switchable polymer network liquid crystal (PNLC) film using azobenzene and a projector for image projection. The film area irradiated with UV light is changed from a transparent state to a light scattering screen state by azobenzene photoisomerization. Subsequently, blue light is irradiated to return from the screen state to the transparent state.

PNLC is made of a mixture of liquid crystal and reactive mesogen as a monomer. The composition ratio of the monomer is lower than that of PDLC, and the polymer is formed in a network. The refractive index difference between a liquid crystal and a reactive mesogen can be reduced, and high transparency is expected even from an oblique view. [5]

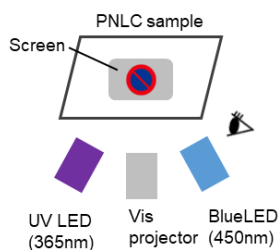
In addition, a bifunctional reactive mesogen can often be mixed with the liquid crystal by only about 10 wt%, and the polymer matrix is brittle. By using a monofunctional reactive mesogen instead of a bifunctional one, it is easy to mix with a liquid crystal to increase the concentration and to obtain flexibility and transparency [6].

In this report, a mixed monomer of monofunctional reactive mesogen and cross-linker was used for the optically switchable PNLC we proposed. By this monomer ratio optimization, a flexible, transparent and high-reflection liquid crystal display has been achieved.

## 2 Principle of optically switchable transparent LCD

Figure 1 shows the system layout of optically switchable transparent LCD. It is composed with optically switchable PNLC, photochromic film, a visible light projector, a UV light LED, and a blue light LED. In the initial transparent state, PNLC are transparent. When a UV light is irradiated to the display, PNLC in irradiated

area converts from the transparent state to the light-scattering screen state. Then, visible light projector projects images on the screen area. Subsequently, irradiation with blue light returns the PNLC to their initial transparent state.



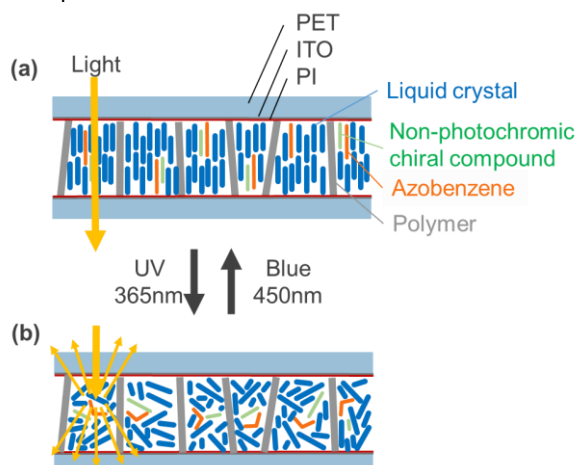
**Fig. 1 System layout of optically switchable transparent LCD**

Figure 2 shows a schematic diagram of optically switchable PNLC. Polyethylene Terephthalate (PET) films are coated with ITO electrode and a vertical alignment polyimide (PI) film. Chiral azobenzene and non-photochromic chiral compound are doped into the PNLC.

In the initial transparent state, Helical twisting power (HTP) of trans-chiral azobenzene and non-photochromic chiral compound are equal, so liquid crystals are in compensated nematic phase, and shows high transparency. [8,9]

Upon UV irradiation, the chiral azobenzene transforms from the trans state to cis state by photoisomerization, thus disrupting the balance of the chirality and generating a twisting power in the LC. Consequently, the orientation of the LC is disordered, and it becomes a light-scattering screen, as shown in Fig. 2(b).

When blue light is irradiated to the screen, the chiral azobenzene in PNLC return to their initial trans state, and the PNLC changes from the light scattering screen state to the transparent state.



**Fig. 2 Schematic diagram of an optically switchable transparent PNLC in the transparent state (a) and screen state (b).**

### 3 Experiment

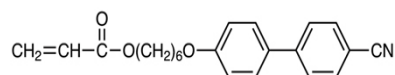
Table 1 lists the composition of LC mixture, and Figure 3 shows the materials we used in this study.

We used a positive nematic LC, two monomers of a monofunctional reactive mesogen and a cross-linker, chiral azobenzene compound, non-photochromic chiral compound and photo initiators. The positive LC was Sb-826010 ( $\Delta n=0.26$ ) from Shanben Co., Ltd., and the main part of the LC possessed cyano biphenyl (CB) group. The monofunctional reactive mesogen, 4-[(6-Acryloyloxy) hexyloxy]-4'-cyanobiphenyl (CB6) and the cross-linker, 1,6-hexanediol dimethacrylate (HDDMA) were purchased from Tokyo Chemical Industry, Japan. Chiral azobenzene and non-photochromic chiral compound were synthesized and mixed. Photo initiator was Iragcure819 (Ciba Specialty Chemicals Inc.).

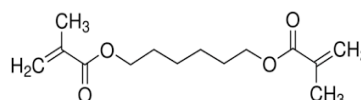
Optical properties are sensitive to the cross-linker concentration. In this experiment, as shown in Table 1, the total mixed monomer concentration was fixed to 25 wt% at which mechanical strength and flexibility was obtained, and the cross-linker concentration was varied from 0.6 to 4.5 wt% to prepare samples.

**Table.1 Liquid crystal mixture (wt%),  
CB6 + HDDMA = 25wt%**

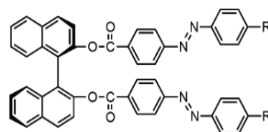
LC	CB6	HDDMA	Azobenzene	Chiral	Iragcure819
67	20.5~24.4	0.6~4.5	4.65	3.35	0.3



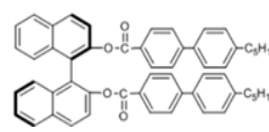
4-[(6-Acryloyloxy)hexyloxy]-4'-cyanobiphenyl (CB6)



1,6-hexanediol dimethacrylate (HDDMA)



Chiral azobenzene  
( $R=C_8H_{17}$ )



Non-photochromic  
chiral compound

**Fig.3 Monomers and chiral materials in LC mixture. Monofunctional reactive mesogen (CB6), bifunctional methacrylate monomer (HDDMA) as a cross-linker, chiral azobenzene and non-photochromic chiral compound. LC and photo initiator are not shown in this figure.**

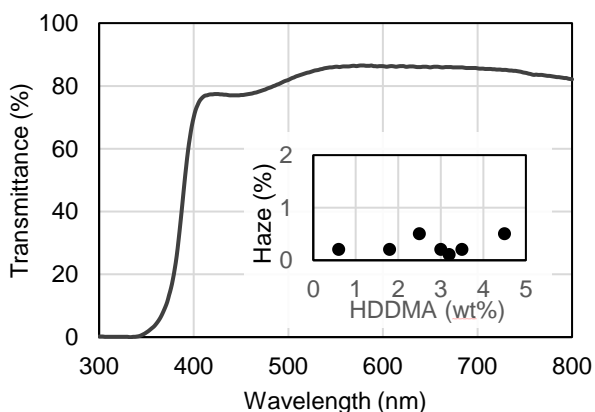
We fabricated the optically switchable PNLC as the following procedure. LC mixture was injected into the empty 10 $\mu$ m-gap PET film cells via capillarity on a hot plate at 100 °C, which is equal to the liquid crystal clearing point.

LC mixture in a cell were polymerized by 420nm light under voltage application (50 V- 50 Hz) at room temperature for 10 minutes. The blue light intensity was set to 7 mW/cm<sup>2</sup>.

The optical properties evaluation of fabricated PNLC and photochromic film were carried out by measuring a transmittance spectrum, haze values before and after UV irradiation. transmittance spectrum was measured by using color difference meter (CM3600 KONICA MINOLTA, INC). Each Haze value was measured using a haze meter (HM-65 W, Murakami Color Research Laboratory).

#### 4 Results and Discussion

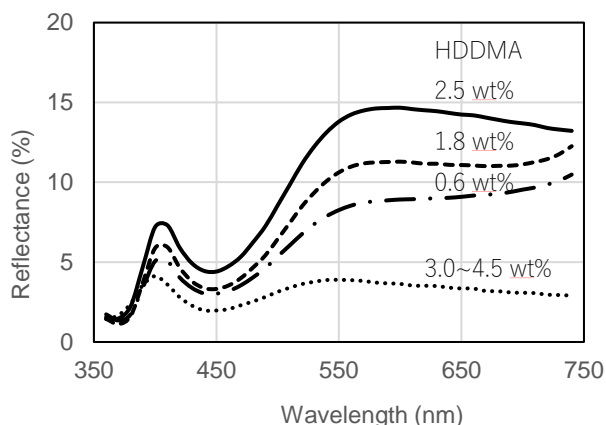
The transmission spectrum in the transparent state before UV irradiation is shown in Fig. 4. Inset is the Haze of each HDDMA concentration difference sample. Similar transmission spectra and as low haze as glass have been obtained in all samples.



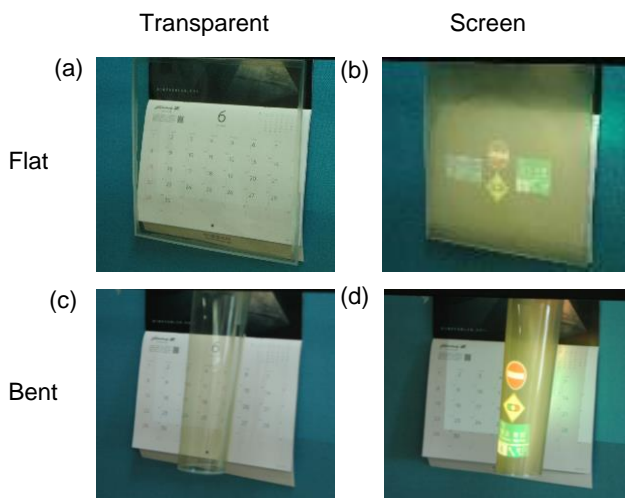
**Fig. 4** Transmittance in the transparent state with CB6 22.5wt% and HDDMA 2.5wt%. The inset shows each Haze in the transparent state as a function of the weight % of HDDMA with the range from 0.6 to 4.5 wt%. All samples have as low haze as glass.

The diffuse reflectance in the screen state is shown in Fig. 5. The higher the reflectivity, the better the screen characteristics. The reflectance was highest when the concentration of HDDMA was 2.5 wt%. In the region of 0.6 ~ 2.5 wt% of HDDMA, the reflection increased as the HDDMA concentration increased. This is because cross-linking points increased and the domain size decreased, which increased the surface area of the polymer network and made it easier to reflect light. Above 3 wt%, the reflectivity was less than 5%. This is because the domain size of the liquid crystal becomes so small and the

alignment force received from the polymer network becomes larger, so that the orientation of liquid crystal hardly changes.



**Fig. 5** Diffused reflectance in the screen state as a function of the weight % of HDDMA with the range from 0.6 to 4.5 wt%. The solid line at HDDMA concentration 2.5 wt%, the dashed line at 1.8 wt%, the dot-dashed line at 0.6 wt% and the dotted line at 3.0, 3.2, 3.5 and 4.5 wt%.



**Fig. 6** Photographs of an optically switchable transparent liquid crystal display of 300 mm x 300 mm in each state. (a)Transparent state and (b) screen state at flat shape. (c)transparent and (d) screen state at bent shape with a curvature radius of around 50mm. Displayed images in (b) and (d) were projected from the front projector after UV irradiation.

Photographs of the PNLC film fabricated using the highest reflectance obtained compositions of 22.5 wt% CB6 and 2.5 wt% HDDMA are shown in Fig. 6. The film size was 300 mm x 300 mm in size and has a flat shape and a bent cylindrical shape with a curvature radius of around 50mm. The PNLC film was suspended, and a calendar was placed about 30 cm away behind the PNLC

film. As shown in the transparent state (a) and (c), high transparency was maintained even when it was bent. It indicates that the polymer network was not broken. Also, in the screen state (b) and (d) after UV irradiation, the projected images on the screen were photographed.

## 5 Conclusions

A flexible and highly transparent optically switchable PNLC film was fabricated. Since the screen area can be controlled by UV, any area of the film can be displayed. In this study, in the resin composition of LC mixture, a monofunctional reactive mesogen, CB6, was used as the main monomer and HDDMA was used as the cross-linker. We found the optimum concentration of HDDMA and obtained a PNLC film with high reflectivity in addition to high transparency and flexibility.

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