

Optically Switchable Transparent Liquid Crystal Display

Yoshimi Ohta¹, Shunta Nabetani¹, Maki Shimada¹, Tomoya Ohara¹, Ryota Maehashi¹, Fuminori Satou¹, Tsuyoshi Fukaminato², Seiji Kurihara²

ohta-yoshimi@mail.nissan.co.jp

¹Reserch Division, Nissan Motor Co., Ltd, 1 Natsushima, Yokosuka, Kanagawa 237-8523, Japan

²Department of Applied Chemistry and Biochemistry, Faculty of Engineering, Kumamoto University
Kurokami 2-39-1, Kumamoto 860-8555, Japan

Keywords: PNLC, transparent display, azobenzene, chiral

ABSTRACT

We demonstrated a new transparent display consisting of an optically switchable polymer network liquid crystal and light sources. Optical switching between transparent and screen states was achieved through trans-cis photoisomerization of azobenzene. Furthermore, we improved screen reflectance by increasing the helical twisting power difference between the trans and cis states.

1 Introduction

Recently, transparent displays have been actively developed for applications in signage windows of stores and automotive windows. Transparent displays are required to meet demands such as large sizes, good flexibility, high transparency, cost-effectiveness, and high contrast.

Organic light-emitting diode (OLED) displays [1] are a 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.

Transparent liquid crystal displays (LCDs) are another type of transparent display. Polymer-dispersed liquid crystal (PDLC) displays with TFTs [2, 3] can achieve a high transmittance of > 80% in the transparent state, on account of the high aperture ratio of each pixel. When flexible displays with TFTs, such as OLED displays and LCDs, are mounted on a curved surface, such as automotive windows, they are required to be flexible. Transparent polyimide (PI) films are typically used to fabricate TFTs on the substrate surfaces. To date, the demand for transparent PI films is limited only to high-end optoelectronic products, and they are not economical [4].

However, transparent PDLC and polymer-network liquid crystal (PNLC) displays using affordable polyethylene terephthalate (PET) films coated with indium tin oxide (ITO) are commercially available. A transparent display using the combination of a projector with PDLCs or PNLCs was proposed [5, 6]. However, the area to be controlled from transparent to screen state by applying voltage was limited, depending on the ITO coating.

Therefore, when mounted in the entire area of a car windshield, there was an issue of blocking the driver's view in the screen state.

Optical switching of liquid crystals (LCs) doped with chiral azobenzene compounds were proposed as an alternative to electrical switching [7, 8]. It was considered to possess high transparency, flexibility, and screen area control. A compensated and transparent nematic phase LC was formed by mixing a chiral azobenzene with a non-photochromic chiral compound having opposite chirality in the host nematic LC by balancing the helical twisting powers (HTPs) of both chiral compounds. The HTP of the chiral azobenzene compounds was decreased using ultraviolet (UV) irradiation to induce their trans-cis photoisomerization and consequently transform the compensated nematic LC into a cholesteric phase. Resultantly, the optically switching LC film changed from its transparent state to light scattering screen state. The transmittance was restored using visible light (Vis) irradiation. As the difference in HTP (Δ HTP) between the trans and cis states of the chiral azobenzene increased, the specular transmittance changed significantly. However, reflectance has not been investigated.

In this paper, we describe the improvement of the optical performance of optically switchable reverse-mode PNLCs by increasing the Δ HTP of azobenzene and present a front-projection transparent LCD.

2 Principle of optical switching in transparent LCD

2.1 System set-up

Fig. 1 depicts the system layout of the optically switchable transparent LCD. It is composed of an optically switchable reverse-mode PNLC, a Vis projector, a UV LED, and a blue LED. Typically, a PNLC is transparent; upon irradiation with UV light, its irradiated area converts from the transparent state to the screen state. The Vis projector stops the UV irradiation and projects images on the screen area in front of the viewer. Subsequently, blue light irradiation reverts the PNLC to its initial transparent state.

2.2 Structure of optically switchable reverse-mode PNLC

The optically switchable reverse-mode PNLC is a composite of an LC, polymer network, chiral azobenzene, and non-photochromic chiral compounds. The polymer network consists of reactive mesogen (RM) monomers. It is phase-separated from the LC and has a strong aligning effect on the LC. When the HTP of chiral azobenzene in the trans state without UV irradiation is equal to that of the non-photochromic chiral compound having opposite chirality, the LC is in a compensated and transparent nematic phase. The PNLC composite was sandwiched between two glass substrates covered with ITO and a vertically aligned PI layer. Before the application of UV light, the LC and polymer network are aligned vertically, resulting in the transparent state, as shown in Fig. 2(a).

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).

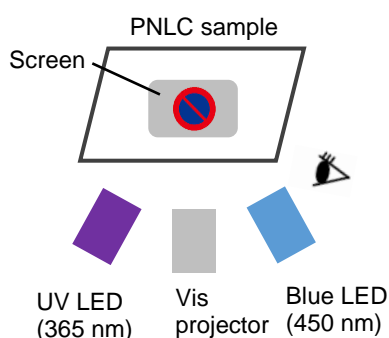


Fig. 1 System layout of optically switchable transparent LCD

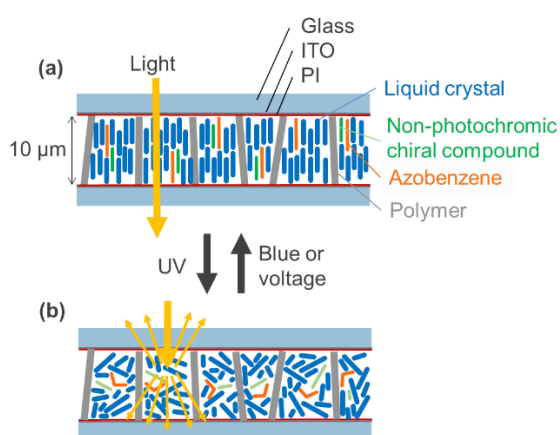
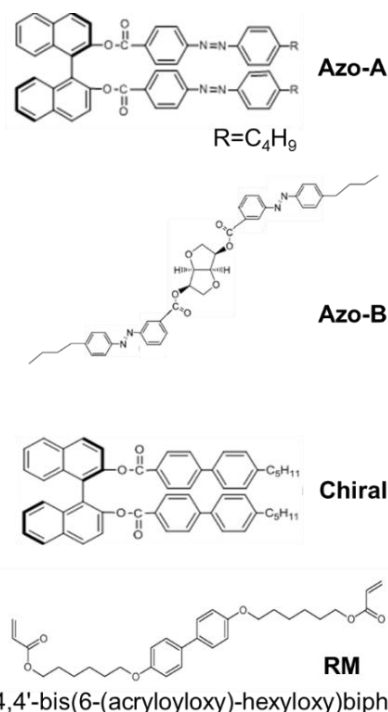


Fig. 2 Schematic diagram of optically switchable reverse-mode PNLC in (a) transparent state and (b) screen state

3 Experimental

Fig. 3 presents the materials used in this experiment. Chiral azobenzene (Azo-A and Azo-B) and a non-photochromic chiral compound (Chiral) were synthesized, and their HTPs are presented in Table 1. The Δ HTP of Azo-A with axial chirality of binaphthyl moiety[9] is stronger than that of Azo-B with point chirality. We prepared two LC mixtures using Azo-A and Azo-B to investigate the effects of their Δ HTP. Table 2 lists the composition of each material. In this study, we used a positive nematic LC, Sb-826010 (Shanben. Co., Ltd), which has birefringence of $\Delta n = 0.26$. RM, 4,4'-bis(6-(acryloyloxy)-hexyloxy)biphenyl (Tokyo Chemical Industry Co., Ltd.), and photo-initiator, Iragcure819 (Ciba Specialty Chemicals Inc.). Compensated and transparent samples were prepared by mixing the chiral azobenzene and Chiral, according to the measured HTP values listed in Table 1.



4,4'-bis(6-(acryloyloxy)-hexyloxy)biphenyl

Sb-826010: Host positive nematic LC
Iragcure819: Photo initiator

Fig. 3 Material structures

Table 1 HTP of chiral materials

	HTP (μm)		Δ HTP (μm)
	trans	cis	
Azo-A	76	37	29
Azo-B	20	3	17
Chiral	60		-

Table 2 Material composition (wt.%)

No	Azobenzene	Chiral	LC	RM	Photo initiator
1	Azo-A: 5.1	2.9	83.75	7.5	0.75
2	Azo-B: 6.2	1.8	83.75	7.5	0.75

Empty glass cells (EHC. Co., Ltd) with a cell gap of 10 μm were prepared by assembling two ITO glass substrates treated with vertically aligned PI layers. Each LC mixture was injected into the empty glass cells using the capillary force on a hot plate at 100°C, which is equal to the LC clearing point. The cells were cured by exposure to blue light from an LED ($\lambda_{\text{max}} = 450 \text{ nm}$), under 50 V–50 Hz at room temperature, to align the LC orientation. The power of the blue light was 7 mW/cm^2 . After 10 min of curing, the optically switchable reverse-mode PNLC was prepared in the transparent state without the application of voltage.

To investigate the optical properties of the PNLC, its total transmittance spectra in the transparent state and total reflectance spectra in the screen state were measured using a spectrometer with an integrating sphere (U-4000, Hitachi, Ltd). Each haze was measured using a haze meter (HM-65 W, Murakami Color Research Laboratory).

4 Results and discussion

Fig. 4(a) demonstrates the total transmittance of the PNLC samples in the transparent state. Transmittance spectra were as high as approximately 80% over a wide visible range. In the region less than 500 nm, the transmittance decreased due to the absorption of the azobenzene itself. Fig. 4(b) depicts the total reflectance of the PNLC samples in the screen state after sufficient UV irradiation at 20 mW/cm^2 for 60 s at room temperature. The PNLC samples were sufficiently screened using this UV energy until the optical properties stopped fluctuating. The reflectance of No.1 sample with Azo-A was higher than that of No. 2 sample with Azo-B. The optical properties in terms of haze values are summarized in Table 3. From Table 2, it is evident that the ΔHTP of azobenzene influenced the reflectance and haze of the PNLC in the screen state. As ΔHTP increased, the orientation of the LC was disturbed more significantly, resulting in greater reflectance and haze in the screen state.

Fig. 5 depicts the dependence of luminance on the viewing angle. In the screen state of sample No.1 after UV irradiation, a white image was projected using the Vis projector (MW612, BenQ Corporation) under the illuminance of 3350 lx, and we measured the luminance excluding the background light using a luminance meter (LS-110, Minolta Co., Ltd) for different viewing angles. The light scattering effect indicated that images could be seen at a viewing angle of 60°.

The photographs in Fig. 6 present sample No. 1 in each

state. The sample was 10 × 10 cm in size. In the transparent state, it was as transparent as the glass. Following UV irradiation, a screen appeared in the irradiated area. After turning off the UV LED, we could see the images projected from the front projector. When the projection was stopped and blue light irradiation was applied, the sample reverted to the transparent state.

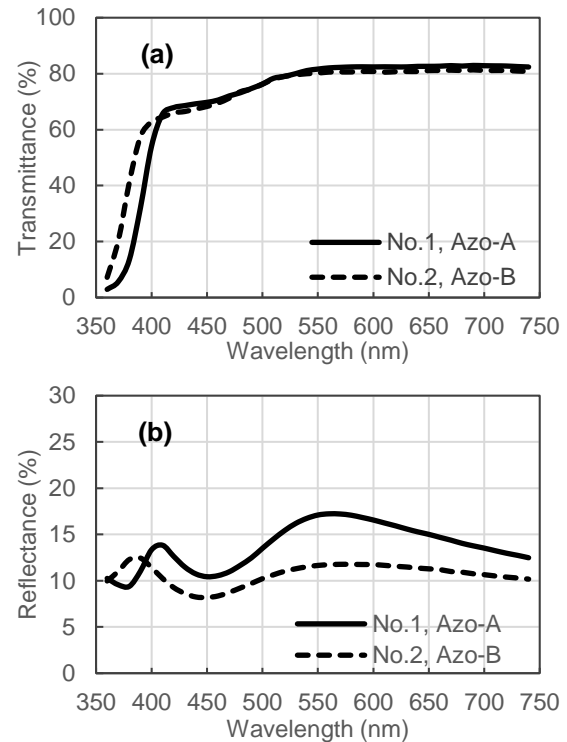


Fig. 4 Optical properties of PNLC samples. (a) Total transmittance spectra in the transparent state before UV irradiation, and (b) total reflectance spectra in the screen state after UV irradiation.

Table 3 Optical properties

	Transparent state	Screen state
	Transmittance @550 nm/Haze	Reflectance @550 nm/Haze
No.1	81.6% / 2.3%	17.1% / 94.9%
No.2	80.2% / 2.3%	11.7% / 39.3%

5 Conclusions

We demonstrated a new transparent display consisting of an optically switchable reverse-mode PNLC (of size 10 cm × 10 cm), a Vis projector, a UV LED, and a blue LED. Optical switching between the transparent state and the screen state of the PNLC was achieved through the reversible trans-cis

photoisomerization of chiral azobenzene molecules under UV and blue light irradiation. A low-haze transparent state and a higher reflecting screen state of the PNLC were achieved at a high Δ HTP of chiral azobenzene. We confirmed that the projected images on the screen could be seen at a viewing angle of 60° due to the light scattering by the screen. We expect that this PNLC can be made flexible and large in size by utilizing PET films instead of glass substrates. This display can be used not only for signage but also for curved car windows.

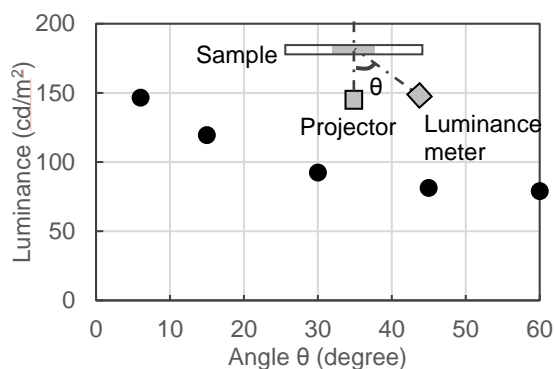


Fig. 5 Viewing angle property in the screen state of sample No. 1 with Azo-A under the illuminance of 3350 lx.

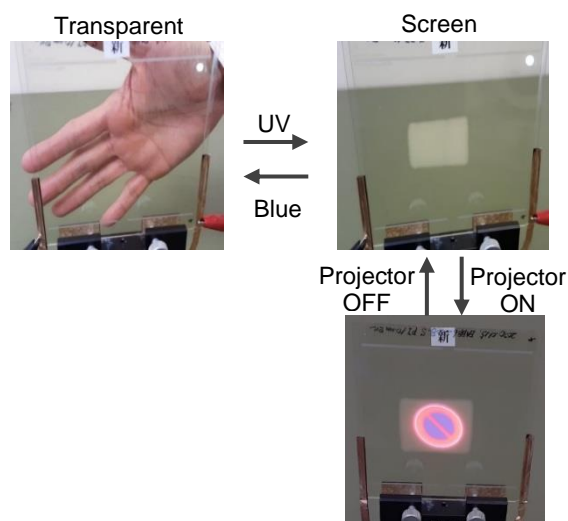


Fig. 6. Photographs of optically switchable transparent liquid crystal display of 10 cm x 10 cm sample No. 1. Image is projected from the front projector after UV irradiation.

Acknowledgement

This research was partly supported by the Adaptable and Seamless Technology Transfer Program through Target-driven R&D (A-STEP) from the Japan Science and Technology Agency (JST).

References

- [1] C. Park, M. Seong, M. A. Kim, D. Kim, H. Jung, M. Cho, S. H. Lee, H. Lee, S. Min, J. Kim, M. Kim, J. H. Park, S. Kwon, B. Kim, S. J. Kim, W. Park, J. Y. Yang, S. Yoon and I. Kang "54 - 1: Distinguished Paper: World 1st Large Size 77 - inch Transparent Flexible OLED Display." SID. Vol. 49, No. 1, pp. 710-713, (2018).
- [2] K. Okuyama, Y. Omori, M. Miyao, K. Kitamura, M. Zako, Y. Maruoka, K. Akutsu, H. Sugiyama, Y. Oue, T. Nakamura, K. Ichihara, H. Irie, S Ito, K HIRAMA, N Asano, T Imai, D Takano and S. Ishida, "12.3-in Highly Transparent LCD by Scattering Mode with Direct Edge Light and Field-Sequential Color-Driving Method" SID 2021 DIGEST, pp. 519-522 (2021).
- [3] M. Honda, K. Murata, K. Nakamura, T. Hasegawa, Y. Haseba, K. Hanaoka, S. Shimada, "Transparent Display with High-Contrast-Ratio Reverse-Mode PDLC," SID 2021 DIGEST, pp. 535-538 (2021).
- [4] H. Ni, J. Liu, Z. Wang, S. Yang, "A review on colorless and optically transparent polyimide films: Chemistry, process and engineering applications," Journal of Industrial and Engineering Chemistry, 28, pp16–27, (2015).
- [5] T. Higuchi, T. Yoshikawa, K. Hashikawa, M. Akagi, T. Yoshizawa, K. Iwawaki, Y. Ito, H. Kogoma, N. Saegusa, "See-Through Projection System" Proc. IDW '15, pp. 820-821 (2015).
- [6] S. Ho, N. Oh, and S. Kwon, "Electro-optical properties of vertically aligned polymer network liquid crystals for normally transparent light shutters." Molecular Crystals and Liquid Crystals 644.1, pp. 130-136 (2017).
- [7] S. Kurihara, S. Nomiya, T. Nonaka, "Photochemical switching between a compensated nematic phase and a twisted nematic phase by photoisomerization of chiral azobenzene molecules," Proc. SPIE Vol. 4107, pp. 69-76 (2000).
- [8] M. Z. Alam, T. Yoshioka, T. Ogata, T. Nonaka, and S. Kurihara, "Influence of Helical Twisting Power on the Photoswitching Behavior of Chiral Azobenzene Compounds: Applications to High-Performance Switching Devices," Chem. Eur. J. 13, pp. 2641-2647 (2007).
- [9] X. Chen, L. Wang, Y. Chen, C. Li, G. Hou, X. Liu, X. Zhang, W. He and H. Yang, "Broadband reflection of polymer-stabilized chiral nematic liquid crystals induced by a chiral azobenzene compound," Chem. Commun., 50, pp. 691 (2014).