

COMPENSATION EFFECT OF POLYIMIDE THIN FILMS ON NORMALLY WHITE TWISTED NEMATIC LIQUID CRYSTAL DISPLAYS*

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ABSTRACT

The disadvantages of Normally White Twisted Nematic Liquid Crystal Display (NW-TN-LCD) were discussed. The reason that the negative birefringent polyimide thin films were used to compensate NW-TN-LCD to decrease off-axis leakage, improve contrast ratios and enlarge viewing angles was explained in this paper. A certain polyimide thin film was taken as an example to show compensation effect on NW-TN-LCD.

INTRODUCTION

Twisted nematic liquid crystal display (TN-LCDs) were widely used in toptick, pocket computers, watches^[1,2], because of their lower power consumption, wide viewing angles as compared with other kinds of LCDs. But the off-axis light leakage exposes their disadvantages. Off-axial wave propagation in TN-LCD infers that there is phase difference (δ) between ordinary (o) and extraordinary (e) waves because of the birefringence (Δn) of liquid crystal medium, when they pass LC cell^[3]. The phase difference, which turns the incident planar polarized light into ellipsoid polarized light, is the reason that off-axis light leakage takes place. In fact, the birefringence of the medium ($\Delta n(\theta)$), determining the phase difference, is proportional to the incident angle^[4] (for detail, see the equations below) so that the displaying quality is relevant to the viewing angle.

As far as Normally White Twisted Nematic Liquid Crystal Display (NW-TN-LCD), whose working principle has particularly described in Ref. [2], is concerned, the outline is schematically illustrated in Fig. 1.

$$\frac{1}{n_e^2(\theta)} = \frac{\cos^2 \theta}{n_o^2} + \frac{\sin^2 \theta}{n_e^2} \quad (1)$$

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Received January 17, 1996

$$\Delta n(\theta) = n_e(\theta) - n_o \quad (2)$$

$$\delta = \frac{2\pi \Delta n(\theta) d}{\lambda} \quad (3)$$

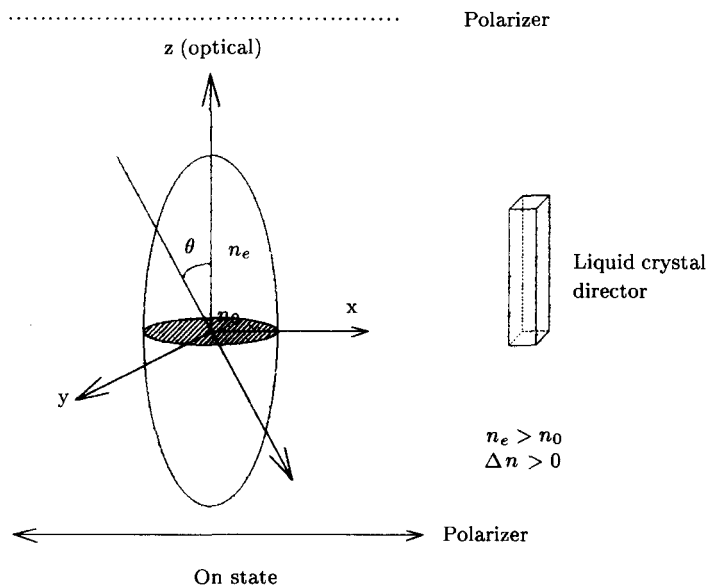


Fig. 1 Scheme of 'On state' of NW-TN-LCD

It is necessary that compensators should be utilized to make the total phase difference of the media of LC cell and the compensator near to zero (see Eq. 4) when the display is working, so that the contrast ratios and viewing angles are improved. In Eq. 4, 1 and 2 denote liquid crystal cell and compensators, respectively. Δn , which is defined as the difference between the indices of e and o wave in the medium, is the birefringence. d is the thickness of the medium. $\Delta n d$ is called the retardation value.

$$\Delta n_1 d_1 + \Delta n_2 d_2 \rightarrow 0 \quad (4)$$

The birefringence of liquid crystal in TN-LCD is positive. In order to realize Eq. 4, the birefringence of compensators must be negative. Some methods are discussed below for preparing negative birefringent compensators.

Inorganic multilayer films^[5] have been utilized to compensate TN-LCD because of their negative birefringence. But its preparation is time-consuming and costly.

Polymer films having been drawn two dimensionally can also compensate TN-LCD to improve its contrast ratios and viewing angles. But the disadvantages of this method lie in the nonuniformity of extension at all directions, and consequently, the birefringence obtained is not unique in the films.

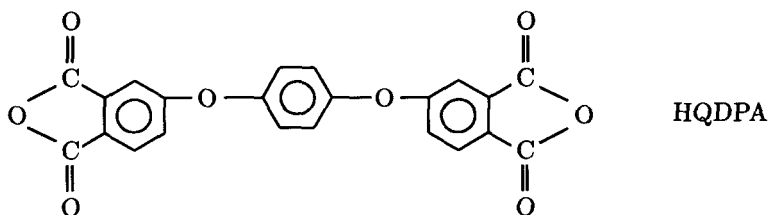
Ong^[6] has calculated and simulated the compensation for TN-LCD with negative birefringent films, whose characteristic is that the molecules orient along the plane perpendicular to the optical axis. Fortunately the results of the studies^[7,8] on polyimide thin films showed that polyimide molecules orient along the film plane, which in turn is perpendicular to the optical axis. The indices along in-plane and out-of-plane directions are not the same. The negative polyimide thin films may be the choice of compensators for TN-LCDs. But the polyimides studied previously with insolubility in the ordinary organic solvents and straw-berry color are not qualified for the compensators. Recently the oil-soluble polyimides have been developed. Thin films can be prepared by solution casting and spin-coating techniques. They show transparency in visible region. Thus the oil-soluble polyimides have attracted much attention in the optical application^[9,10].

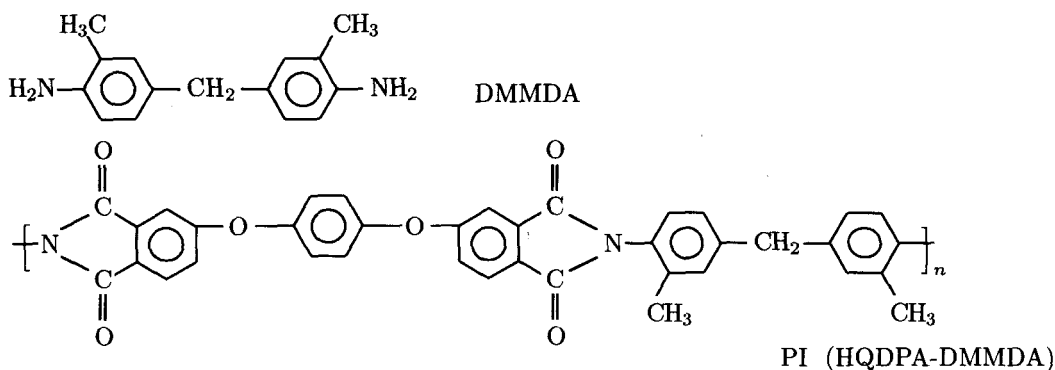
This polyimide thin films prepared in our laboratory show potentiality for the compensation effect on TN-LCDs. Of course the compensation films should have the characteristics as follows: first, compensators must be transparent in the range of 400 nm to 800 nm; second, they possess proper mechanical properties; and the last, the ordinary index of the film is close to that of the substrate so that there is as less an interface for light refraction and scattering.

EXPERIMENTAL

Synthesis

Equimolar of dianhydride and diamine monomers, whose chemical structures are shown below, were stirred in the medium of N, N-dimethyl acetamide (DMAc) in a reaction container at room temperature for about 24 hours until a slight yellow solution regarded as polyamic acid solution was obtained. Then the imidization reaction was carried out by adding triethylamine and acetic anhydride and kept for 48 hours. Ethanol (95%) was added to the solution with stirring so that polyimide (PI) can be precipitated. The polymer was washed for 3 times, white polyimide powders were obtained.





Film preparation

The thin films were prepared by solution casting in different solvents, i.e. N,N-dimethyl formamide (DMF), DMAc and γ -butyrolactone, with a solid content of 12% (w/w). They were treated first at 60°C for 12 hours and then evacuated at 160°C in a vacuum oven for at least 8 hours so that the solvent can be removed.

Determination of the indices

n_{TE} and n_{TM} of the films were determined by means of Prism-Coupler. For polyimide thin films, n_{TE} , $n_{//}$, and n_o refer to in-plane refractive index; while n_{TM} , $n_{\perp}$ and n_e , refer to out-of-plane refractive index^[7]. The index ellipsoid of the film is depicted in Fig. 2.

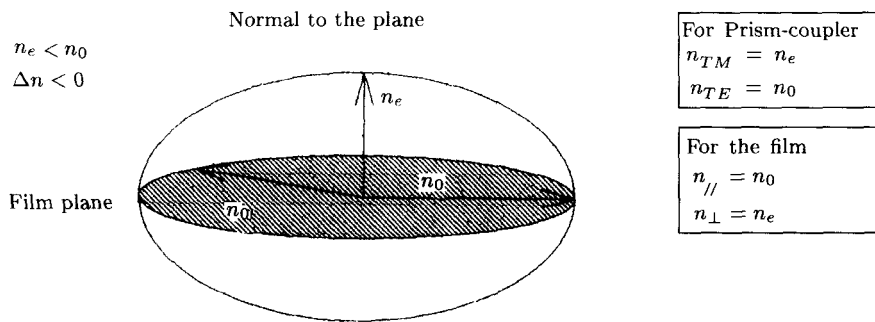


Fig. 2 Outline of the index ellipsoid of polyimide thin film

Iso-contrast maps

A kind of NW-TN-LCD, whose physical properties are listed in Table 1, was chosen for this study. At different voltages, the display was applied.

By comparing the transmission at a certain voltage in the range of 0 V to 5 V and that at 0 V, we can get contrast ratios. Furthermore, iso-contrast maps of the display without and with compensation of polyimide thin film can be outlined (as shown in the following).

Table 1 Physical properties of the liquid crystal in the NW-TN-LCD

n_e	n_o	Δn	Δnd (nm)	$d(\mu m)$	$\epsilon_{//}$	$\epsilon_{\perp}$
1.5500	1.4621	0.0879	439.5	5	8.3	3.2

Notes: Δnd is the retardation value, d the thickness of the LCD cell,
 $\epsilon_{//}$ and $\epsilon_{\perp}$ are relative permittivity parallel and perpendicular to
molecular axis

RESULTS AND DISCUSSION

Polyimide thin films prepared in our laboratory shows preference in qualification for the compensator for TN-LCD. The transmission UV/VIS spectrum (as illustrated in Fig. 3) indicates that the film is at least 90% transmission in the range of 400 nm to 800 nm. The indices of in-plane and out-of-plane for this polyimide film prepared by solution casting in different solvents, are listed in Table 2. The negative birefringence is found to be -0.03 or so.

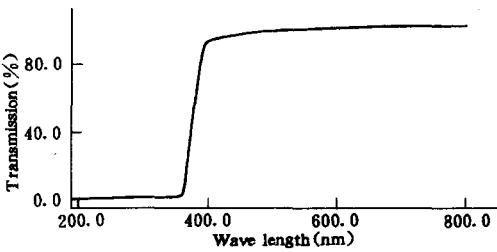


Fig. 3 Transmission UV-Visible spectrum of thin film of PI (HQDPA-DMMDA)

Table 2 The indices and birefringence of the film prepared by solution casting from different solvents

Solvent	DMAc	DMF	γ -Butyrolactone
n_o	1.6421	1.6426	1.6408
n_e	1.6130	1.6158	1.6131
Δn	-0.0291	-0.0268	-0.0277

The compensation effect of polyimide thin film on a kind of NW-TN-LCD (normally white TN-LCD), was illustrated below.

The iso-contrast map of the display is illustrated in Fig. 4. The iso-contrast map of the display with a polyimide thin film of $5\mu m$ thickness placed between a polarizer and LC cell is presented in Fig. 5. By the way, it should be noted that the film used was prepared from its solution of DMAc. It is obviously noticed that in the azimuths of 135° and 345° , the iso-contrast improves, the viewing angle extends. Superficially speaking, the compensation is not unique for all directions. However, this is due to the asymmetry of TN-LCD of its own^[11].

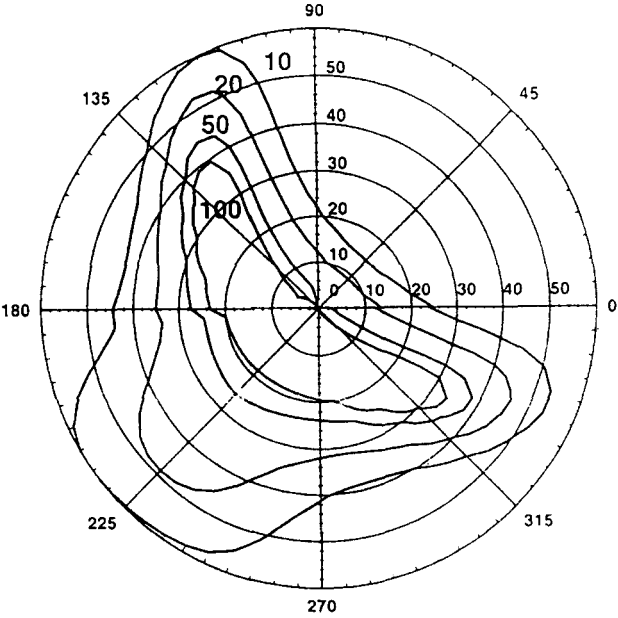


Fig. 4 Iso-contrast map of NW-TN-LCD without compensation

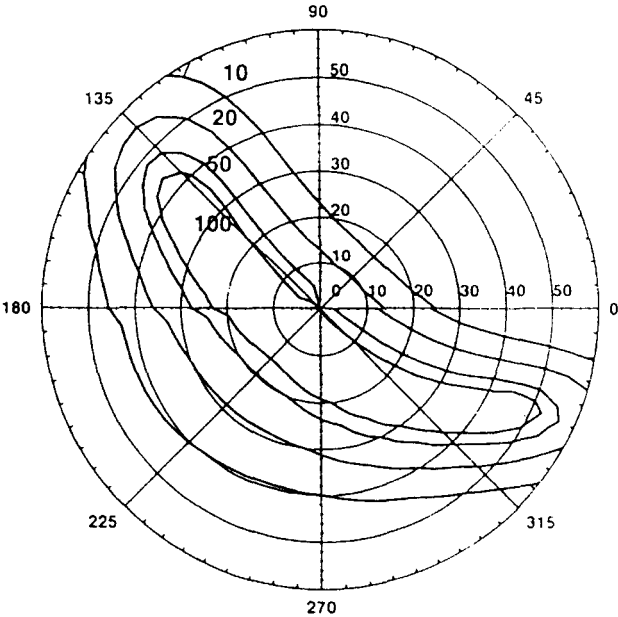


Fig. 5 Iso-contrast map of NW-TN-LCD with compensation of polyimide thin film

CONCLUSION

Because of the negative birefringence of polyimide thin films, they can be used as compensating films for normally white twisted nematic liquid crystal displays to

enlarge the viewing angles. Theoretically speaking, the retardation value (Δnd) of compensation film must be equal to that of LC cell. As a result, phase difference between o and e waves can be compensated completely in the two media. But it is not likely to make it a reality.

Acknowledgement The authors thank Prof. Stephen Z.D. Cheng and Dr. Fuming Li in the University of Akron for their benevolence to provide necessary equipment to determine the birefringence of the film and iso-contrast of NW-TN-LCD.

Keywords:

Polyimide thin films; Retardation; Compensation; Negative birefringence; Normally white twisted nematic liquid crystal display

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