P-85: Reflective Liquid-Crystal Cell-Gap Measurement Using Input-Polarization-Angle Dependence

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Abstract

A simple technique of measuring a reflective TN liquid crystal (LC) cell gap using a laser is described. It utilizes a very unique property of strong input-polarization-angle dependence of the reflective LCs, which is not observed in the conventional transmissive LCs. This technique eliminates the surface-reflection problem which can be encountered by most other techniques using a monochromatic light source. Quantitative experimental results obtained have confirmed the validity of this scheme.

1. Introduction

Reflective LCDs with single polariser have attracted a lot of interests in recent years due to their advantages of low power consumption, light weight and compact structure. In these devices, cell gap is a very important parameter for controlling their performances such as brightness, color and response time. Recently, there have been a few techniques proposed for measuring a reflective TN LC cell [1-6]. Quite a few of these techniques use a spectrometer and a white-light source to deduce the cell gap by measuring the zero-reflectance wavelengths [1-3]. These techniques are informative as data at different wavelengths can be extracted simultaneously. However, these techniques require the use of a spectrometer. There are several techniques proposed which can allow the use of a monochromatic light (e.g. a laser or a white-light source with an interference filter) [2, 4-6]. Many of these techniques involve direct analysis of the reflected light polarization change caused by the LC layer. This is done either by rotating the analyzer [4-6] or an optical compensator [4]. Although some of these techniques, such as the compensator or Stokes parameters, are highly accurate for the transmissive TN mode [7, 8], they may become not so accurate for the reflective mode. One of the major differences between transmissive and reflective measurements is that very often the reflective mode encounters the presence of surface reflection, $R_s$, as shown in figure 1. This $R_s$ may seem small ($\sim 4\%$) but in most reflective LCD products, this ‘wanted’ reflected light, $R_w$, from the reflector is also very weak (can be $\ll 20\%$) after traveling through the bulk layers of color filter, ITO, polyimide and LC twice. Hence $R_w$ can become comparable to $R_s$. This $R_s$ can interfere with $R_w$ and alters the resultant reflected light polarization. Thus analyzing this resultant light directly can lead to very inaccurate results for the cell gap. Although in ref [5] a technique was described in an attempt to maximize the $R_w$ and $R_s$ ratio, this is however only possible for devices with very high $R_w$.

In this paper, we describe a very simple technique which was proposed [9] for measuring a filled reflective TN LC cell. It utilizes a very unique property of the reflective LC cells, which is not observed in the conventional transmissive TN cells. This technique allows the use of a laser and at the same time can eliminate the surface-reflection problem described above. The surface-reflection component, which has the same polarization as the input, is removed by the analyzer as it is ‘permanently’ crossed to the input polarizer throughout the measurement process as illustrated in figure 1. Only the LC cell is rotated during the process. This technique doesn’t require the use of a compensator or a spectrometer. A technique similar to this was also proposed by Tang et al [2] independently using the polarization state concept. Quantitative experimental results have been obtained and will be presented in this paper to support this proposed scheme.

* This work was carried out when the author was with Unipac Optoelectronics (now AU Optronics), Taiwan.
2. Principles

Unlike the conventional transmissive TN LC cells, reflectance of a reflective TN cell between crossed polarizers around its optimum operation condition (maximum reflection) often exhibits a strong dependence on input-polarization-angle $\beta$, where $\beta$ corresponds to the angle between the input LC director and the input polarizer transmission axis as shown in figure 2. In general, $\beta$ is adjusted to a non-zero degree to achieve a maximum or a minimum reflection. We may denote these angles as $\beta_{\text{max}}$ and $\beta_{\text{min}}$. It can be shown that $\beta_{\text{max}}$ and $\beta_{\text{min}}$ angles have a strong dependence on the cell gap of the reflective LC cells.

The normalized reflectance $R_\perp$ of a reflective TN LC cell between crossed polarizers can be derived using 2x2 Jones matrix method and is given as follows[10]:

$$R_\perp = \left(\frac{\sin X}{X}\right)^2 \left(\sin 2\beta \cos X - \frac{\phi}{X} \cos 2\beta \sin X\right)^2$$

(1)

where $\Gamma = \frac{2\pi d \Delta n}{\lambda}$ and $X = \sqrt{\phi^2 + (\Gamma/2)^2}$, $d =$ cell gap thickness, $\Delta n =$ birefringence of LC, $\phi =$ LC twist angle, $\lambda =$ wavelength of the incident light and $\beta =$ angle between input polarization and the front LC director.

By differentiating $R_\perp$ with respect to $\beta$ we obtain solutions Eqs. (2) & (3) which correspond to $\beta_{\text{max}}$ and $\beta_{\text{min}}$.

$$\frac{dR_\perp}{d\beta} = 0 \quad \Rightarrow \quad \beta_{\text{max}} = \frac{\arctan(-\frac{X}{\phi \tan X})}{2}$$

(2)

$$\beta_{\text{min}} = \frac{\arctan(\frac{X}{\phi \tan X})}{2}$$

(3)

As can be seen from Eqs. 2 & 3, both $\beta_{\text{max}}$ and $\beta_{\text{min}}$ are a function of $\phi$, $d$, $\Delta n$, and $\lambda$. Hence, $\beta_{\text{max}}$ and $\beta_{\text{min}}$ become solely a function of cell gap $d$ when the other parameters are constant. As an example, figure 3 shows $R_\perp$ vs. $\beta$ of a reflective TN cell with 80°
twist angle for different cell gap \( d \) between 3\( \mu \)m to 6\( \mu \)m. The \( \Delta n \) of LC is 0.064 and \( \lambda \) of incident light is 632.8nm. This reflective LC mode belongs to the MTN mode [10].

As can be seen clearly in figure 3, \( R_L \) vs. \( \beta \) plot shifts to the right as the cell gap \( d \) increases and the values of \( \beta_{\text{max}} \) and \( \beta_{\text{min}} \) increase accordingly. Moreover, the maximum reflectance also varies at the same time. Figure 4 shows plots of \( \beta_{\text{max}} \) and \( \beta_{\text{min}} \) vs. \( d \) of the above reflective TN cell with \( d = 0 \) to 20\( \mu \)m. It can be seen that there is a one to one correspondence between \( \beta_{\text{max}} \) (or \( \beta_{\text{min}} \)) and \( d \) for \( d \) below about 14\( \mu \)m. Hence, cell gap \( d \) can be determined by measuring \( \beta_{\text{max}} \) (or \( \beta_{\text{min}} \) which is \( \pm 45^\circ \) of \( \beta_{\text{max}} \)) if other parameters are known beforehand.

![Figure 5](image)

*Figure 5. Normalized Transmittance \( T_L \) of a 80\(^\circ\) twist transmissive TN LC cell vs. \( \beta \) with cell gap \( d = 3 \) to 6\( \mu \)m.*

As a comparison, transmission of a transmissive TN cell (80\(^\circ\) twist) between crossed polarizers is quite insensitive to the \( \beta \) angle around the optimum operation region (\( \approx 6\mu \)m, First-minimum condition with maximum transmission) as shown in figure 5. Moreover, the values of \( \beta_{\text{max}} \) and \( \beta_{\text{min}} \) remain constant as the cell gap varies. Therefore, our proposed technique is very unique for the reflective TN cells and is not suitable for the transmissive TN cells. (Note: in the above example, twist angle of 80\(^\circ\) was chosen as a fair comparison to the reflective case, the same conclusions can be drawn for the conventional 90\(^\circ\) twist TN cells or any other twist angles.)

### 3. Experiment

Experiment was carried out to verify the validity of this scheme. Fabricated test cells with spacers between 3.5\( \mu \)m to 5\( \mu \)m and twist angles of 80\(^\circ\) and 90\(^\circ\) were used. The samples were transmissive LC cells so that the cell gap of the devices could be verified by a commercial cell-gap system [11]. An Al mirror was attached behind the samples in order to make them reflective.

<table>
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<tr>
<th>LC Sample</th>
<th>Twist angle/degree</th>
<th>Spacer/( \mu )m</th>
<th>Measured ( \beta_{\text{max}} ) angle/degree</th>
<th>Reflective cell gap measurement/( \mu )m</th>
<th>Transmissive cell gap measurement/( \mu )m</th>
<th>Deviation/( \mu )m</th>
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A very simple experimental set-up was required for measuring the reflective cell gap using this proposed method as shown in figure 6. A He-Ne laser was used as the light source and the detector was a silicon photodiode. The LC cell was mounted on a rotation stage so that the \( \beta \) angle could be varied. The polarizer and analyzer at the input and output of the beam-splitter were crossed (Note the polarizer and analyzer are not necessary if polarizing beam-splitter is used. In this case the light throughout can be improved, which is useful when the reflected light is very weak.). The \( \beta_{\text{max}} \) or \( \beta_{\text{min}} \) angles were obtained by rotating the LC sample until a minimum or a maximum on the detector was recorded. After measuring the \( \beta_{\text{max}} \) or \( \beta_{\text{min}} \) angle, the cell gap could then be determined by finding the corresponding \( d \) using the plots in figure 4 or through equations (2) or (3). A different set of plots is considered.
required for a different twist angle. Table 1 compares the experimental results obtained for the reflective measurements using this proposed scheme and the transmissive measurements (without the attached mirror) using the commercial system. As can be seen from Table 1, the reflective cell gap measurements (5th column) obtained using this proposed technique are in very good agreement with the corresponding transmissive cell gap measurements (6th column). The average deviation between the two types of measurements was found to be about 0.1μm. These results demonstrate that this method of determining the reflective LC cell gap is indeed valid and with an acceptable accuracy.

4. Conclusions

A very simple and convenient technique of measuring the cell gap of a filled reflective TN LC cell is described. It utilizes a unique property of the strong input-polarization-angle dependence of the reflective TN LCs. The key advantages of this technique are i) it can eliminate the surface-reflection problem by the use of ‘permanent’ crossed polarizers and hence leads to more accurate and consistent measurement and ii) it is very simple and convenient as it requires only basic laboratory instruments and optical components. Quantitative experimental results have been obtained to confirm the validity of this scheme.

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6. References