Abstract

We propose a method for measuring the cell gap of reflective liquid crystal cells. We can determine the thickness of a nematic liquid crystal cell by measuring the total intensity ratio of the reflected light at two arbitrary wavelength regions. This method, which is easy to use, can provide precise results for low cell gaps as well as high cell gaps.

1. Introduction

Liquid crystal displays (LCD) are used widely in display markets because of their excellent electro-optic properties and low cost. Recently, interest on reflective LCDs in mobile devices is increasing gradually because of their low power consumption and lightweight. Since reflective LCDs usually have low cell gap and low cell gap margin, it is very important to keep the cell gap optimized and to measure it accurately and quickly.

Several types of measurement method have been studied in order to measure the cell gap for transmissive LCDs. For empty cell, we can easily determine the cell gap by using the spectral interferometric method known as the peak to peak method [1], phase compensation method [2-3], rotating wave plate method [4], and single wavelength intensity ratio method [5]. However, it is not easy to find simple measurement methods available for reflective LCDs because we can’t measure the cell gap by the conventional methods used for transmissive cells. Lee and Tang have been presented cell gap measurement method for single polarized reflective liquid crystal cells based on spectroscopic[6-7]. However, these methods are not suitable to low cell gap for which there is no wavelength with null reflectance. Up to now, LC cells with low cell gap has not been widely used in commercial production because of the difficulty in mass production. However, it is expected to use widely in near future because of its merits, such as low driving voltage and fast response time.

In this work we propose the total intensity ratio method (TIRM) for the cell gap measurement of reflective LCDs. This method has been applied already to transmissive LCDs [8]. This method is a novel method of determining the cell thickness using the integrated intensity ratio of the reflected light in two arbitrary wavelength regions. The proposed method, which is easy to use, can provide precise results for low cell gaps as well as high cell gaps.

2. Theory

For reflective twisted nematic (TN) cell, the optical reflectance can be expressed by the jones matrix using parameters such as \( \phi \), \( d \), \( \Delta n \), \( \alpha \), and \( \gamma \). Here, \( \phi \) is the twist angle, \( d \) is the thickness of a LC cell and \( \Delta n \) is the wavelength-dependent birefringence of the LC material, \( \alpha \) and \( \gamma \) are the angles of the polarizer and the analyzer with the direction of the input director as the reference. For the optical setup shown in Fig.1, the reflectance \( R \) is given by

\[
R = \left( \cos \gamma, \sin \gamma \right) \cdot \tilde{M}(\phi) \cdot M(\phi) \cdot \left( \begin{array}{c}
\frac{\alpha}{\sin \alpha} \\
\frac{\sin \alpha}{\cos \alpha}
\end{array} \right)
\]

where \( M \) is the jones matrix of a twisted nematic LC layer:

\[
M = \left[ \begin{array}{cc}
\frac{\cos X - i \frac{\Gamma \sin X}{2} X}{\sin X} & \frac{\phi \sin X}{\cos X + i \frac{\Gamma \sin X}{2} X} \\
\frac{-\phi \sin X}{\sin X} & \frac{\phi \sin X}{\cos X + i \frac{\Gamma \sin X}{2} X}
\end{array} \right]
\]

with

\[
X^2 = \phi^2 + \left( \frac{\Gamma}{2} \right)^2 \quad \Gamma = \frac{2 \pi}{\lambda} \Delta nd
\]

where

\[
\Delta n = \frac{n_e}{\sqrt{1 + \left( \frac{n_e}{n_o} \right)^2 - 1}} \sin^2 \theta
\]

Here \( \theta \) is the pretilt angle and \( n_e \) and \( n_o \) are the extraordinary and ordinary refractive indices of the LC material. Then, Eq.(1) can be rewritten as
We find that the total intensity of the reflected light in each wavelength region changes with the cell gap. The total intensity of the reflected light in the wavelength region of 400-800nm is given by

\[ I_{\text{total}} = \int_{400\text{nm}}^{800\text{nm}} Rd\lambda \]

We can determine the cell gap once the total intensity of the reflected light is obtained experimentally. However, the absolute values of the measured total intensity in an arbitrary wavelength region may differ from calculated values because of the absorption by the liquid crystal layer, glass, indium tin oxide (ITO), the polarizer, and the analyzer. Namely

\[ \int_{\lambda_1}^{\lambda_2} R_{\text{exp}} d\lambda \neq \int_{\lambda_1}^{\lambda_2} R_{\text{cal}} d\lambda. \]

On the other hand, we found that the total intensity ratios are nearly the same, since the wavelength dependence of the absorption rate of the liquid crystal layer, glass, indium tin oxide (ITO), the polarizer, and the analyzer can be ignored.

3. Experimental Results

Our measurement was performed for LC cells [LC: ZLI-2359, spacer: 2.45 µm, no-twist; LC: ZLI-1557, spacer 6 µm, 20° twist] with the experimental setup shown in fig.1. Information in the dispersion of the LC material (ZLI-2359, ZLI-1557) is available from the manufacturers (MERCK). A halogen lamp is used as the light source. A spectrometer (MCPD-3000 Otsuka Electronics) in which the wavelength of the light is scanned automatically is used in our experiment. Absorption rate of cell and polarizer at each wavelength in the visible wavelength range (400-800nm) is nearly constant, which demonstrates the validity of this method.

For cell 1, we setup at \( \alpha = \gamma = 45^\circ, \phi = 0^\circ \) (this is typical ECB mode). As an experimental result for cell 1, the total intensity ratio of the reflected light for two wavelength regions (500-600 nm and 550-650 nm) was found to be 0.404:

\[ \int_{500\text{nm}}^{600\text{nm}} R_{\text{exp}} d\lambda \int_{550\text{nm}}^{650\text{nm}} R_{\text{exp}} d\lambda = 0.404. \]

This value corresponds to a cell gap value of 2.3 µm.

We can measure the cell gaps, which has arbitrary twist angle. For cell 2, we setup at \( \alpha = \gamma = 45^\circ, \phi = 20^\circ \). As an experimental result, the total intensity ratio of the reflected light for two wavelength regions (500-650 nm and 600-700 nm) was found to be 0.435:
In this case, we found that two cell gap values exist. In order to solve this problem, we have to calculate the total intensity ratio in other wavelength regions (550-650 nm and 600-650 nm). Then, the total intensity ratio of the reflected light for two wavelength regions (550-650 nm and 600-650 nm) was found to be 0.859:

\[
\int_{650\text{nm}}^{500\text{nm}} R_{\exp} d\lambda \int_{500\text{nm}}^{700\text{nm}} R_{\exp} d\lambda = \int_{700\text{nm}}^{600\text{nm}} R_{\cal} d\lambda \int_{550\text{nm}}^{650\text{nm}} R_{\cal} d\lambda = 0.859.
\]

This value corresponds to a cell gap value of 6.04 µm.

In this method, an important cause of the measurement error is the inaccuracy of the pretilt angle for small cell gaps and the twist angle. The total error including these would be ±0.03 µm.

These two cell gaps determined by the proposed method were compared with those measured by interferometric method for an empty cell as summarized in Table 1.

**Table 1. Comparison of measured cell gap data**

<table>
<thead>
<tr>
<th>spacer</th>
<th>Twist angle</th>
<th>Interferometric method (an empty cell)</th>
<th>Proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.45 µm</td>
<td>0°</td>
<td>2.25 µm</td>
<td>2.3 µm</td>
</tr>
<tr>
<td>6.0 µm</td>
<td>20°</td>
<td>5.97 µm</td>
<td>6.06 µm</td>
</tr>
</tbody>
</table>

**Fig. 2.** Total reflectance ratio for two wavelength regions in a LC cell. [LC: ZLI-2359, spacer: 2.45 µm, \(\alpha=\gamma=45^\circ\), \(\phi=0^\circ\)].

**Fig. 3.** Total reflectance ratio for two wavelength regions in a LC cell [LC: ZLI-1557, spacer: 6.0 µm, \(\alpha=\gamma=45^\circ\), \(\phi=20^\circ\). (a) 500-650 nm and 600-700 nm, (b) 600-650 nm and 550-650 nm.

}\[500-650\text{nm}/550-650\text{nm}\] \[600-650\text{nm}/550-650\text{nm}\]
4. Conclusion

We proposed that the cell gap of a reflective LC cell can be measured by comparing experimental values with calculated values of the total intensity ratio of the reflected light for two arbitrary wavelength regions. Because this method is simple and accurate, it could be used widely during the manufacturing process of LCDs.

5. Acknowledgements

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6. References