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Application guided wave method in testing for a vertical aligned liquid crystal cell

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ABSTRACT

After many experiments of vertical alignment liquid crystal cell have been carried out, a series of reflectivity–internal angle curves at several driving voltages was obtained. Then the liquid crystal multi-layer optical theory and the elastic continuum theory were applied to make the theoretical curves. By adjusting the parameters of both liquid crystal material and the cell according to experimental conditions, the theoretical curves calculated were in good agreement with experimental curves. Thus the director profile in this cell is achieved. This experimental method described in this article is shown possible to measure a number of important parameters of liquid crystal material and the cell.

1. Introduction

Although reflection anisotropy spectroscopy (RAS) has been developed and widely used [1], the guided wave method will provide sufficient information much more easily while testing a liquid crystal (LC) cell [2]. Optical waveguide is a medium with geometric structure which can keep the light propagating near the surface or inside and then guide the direction of light [3]. Optical waveguide is a research focus in the field of optical communication [4,5] and optical sensing [6,7]. Many research works have been done about the guided wave method being applied to the study of LC devices by Fuzi [8–10]. Although the LC cell is not designed as an optical waveguide, it is just a very good guided wave structure [10]. Along with the director deformation of LC layer the light propagation characteristics (e.g. intensity, phase, polarization and wavelength) will change, so the optical waveguide with LC layer can be used to sense the information of the LC layer. The optical properties may be changed greatly as the director makes subtle change in the LC cell, which can be also used to explore some parameters of both LC material and LC cell such as anchoring energy of substrate [11], permittivity [12,13], director profile [8,14–16], and surface and flexoelectric polarization [17]. So we can apply the optical guided wave technology to demonstrate the director distribution of LC layer in details.

Vertical aligned (VA) LC devices can provide considerable high contrast and fast response [18,19]. Using the guided wave method, not only the director distribution of LC layer in VA cell can be obtained, but also its precision can reach detecting the changes of director by 0.05°. And a number of important parameters of LC material and the cell can be measured through this experimental method described in this paper. Therefore, it is very significant for parameter test of LC material and the cell to research the application of guided wave in VA cell.

2. Experimental principle

The planar waveguide geometry mainly consists of three parts as shown in Fig. 1. The three materials in the waveguide geometry have been labeled as the cladding layer, of index n_c, the guiding layer, of index n_g and the substrate layer of index n_s. For the ensuing discussion we further suppose $n_s > n_c$, unless explicitly stated otherwise, so $n_g > n_s > n_c$.

There are three types of waveguide modes as shown in Fig. 2. One is full guided mode, as shown in Fig. 2(a), the light is primarily contained inside the guiding layer by total internal reflection at both the top and bottom boundaries. The second type is half-leaky guided mode, as shown in Fig. 2(b), only the cladding interface acts as a totally reflecting surface, part of the radiation energy of the mode escapes into the substrate layer. The final type is fully leaky guided mode, as shown in Fig. 2(c), the radiation energy of the mode will leak into both the substrate and cladding half spaces across both interfaces.

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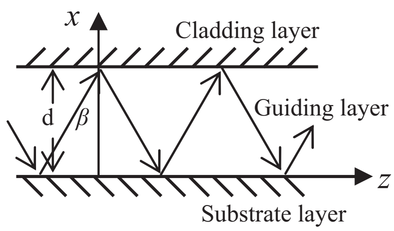

Fig. 1. Planar waveguide geometry.

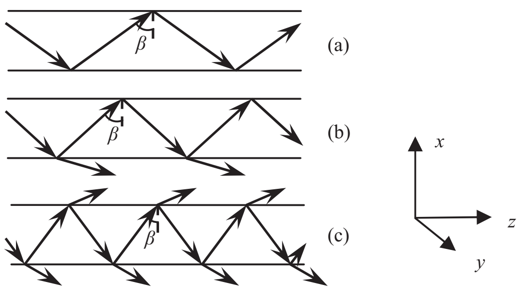

Fig. 2. Three guided modes in a planar waveguide: (a) full guided mode; (b) half-leaky guided mode; (c) fully leaky guided mode.

Both the momentum along the *z*-axis and the optical field distribution along *x*-axis in the three waveguide modes depend on the thickness and the refractive index of the guiding layer, moreover the guided modes with different order have more sensitivity to the different parts of the guiding layer. Here we take LC layer as guiding layer, and the LC waveguide structure was constructed. In general the waveguide eigen mode is no longer a pure TE (s-polarized plane wave) or TM (p-polarized plane wave) because of the optical anisotropy of LC. Let a linearly polarized optical beam incident to the LC waveguide structure, the reflected and transmitted radiation will include the polarization-conversion signals R_{sp}, R_{ps}, T_{sp} and T_{ps} as well as the polarization-conserving signals R_{pp}, R_{ss}, T_{pp} and T_{ss}. If one monitors accurately the angle dependent reflectivity (and/or transmissivity) over a wide range of angles and then fits these data to predictions from a multilayer optical model of the geometry [14]. In particular, using angle dependent polarization conversion reflectivity and/or transmissivity, the sensitivity to the director twist/tilt is greatly enhanced and fitting of this sort of data may yield, in exquisite detail, the director profile through the cell. Furthermore, some parameters of the LC layer and the cell can also be determined by curve fitting.

3. Experimental setup and procedure

There are three optical waveguide mode geometries corresponding to three guided modes by means of the prism-coupling

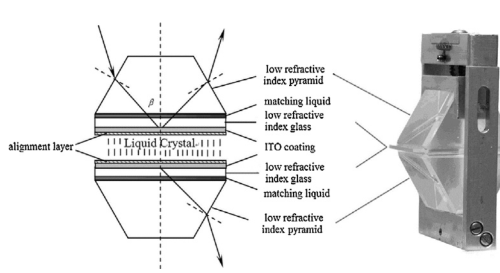

Fig. 3. Structure of fully leaky LC waveguide.

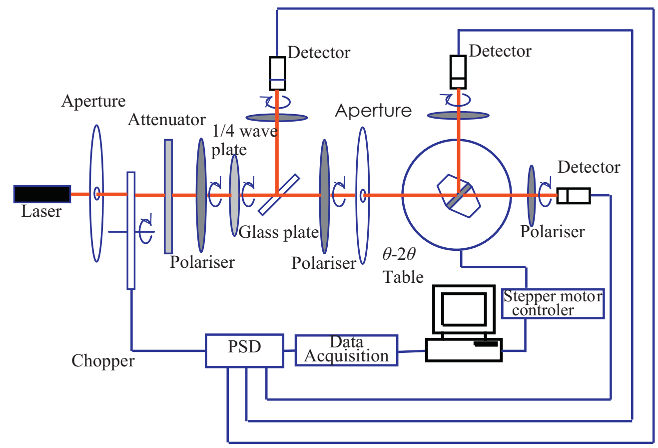

Fig. 4. Experimental setup of optical guided wave.

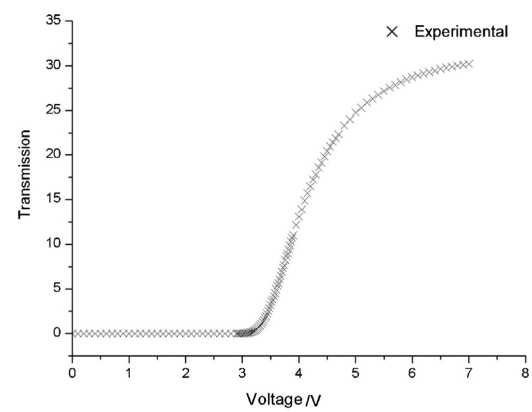

Fig. 5. Voltage–transmission curve of VA cell.

technique. Here the fully leaky LC waveguide type was used, as shown in Fig. 3. It mainly includes two low refractive index pyramids ($n = 1.52$), matching liquid ($n = 1.52$), two low refractive index glass substrates ($n = 1.52$), ITO coating, rubbed polymer aligned layer and LC layer. When the incident angle β is smaller than the angle for total reflection between the pyramid and the liquid crystal layer, the incident light beam enters the liquid crystal layer and the fully leaky guided mode is formed. Thus the angle dependent reflectivity can be recorded through rotating the fully leaky geometry.

The whole experimental setup is shown in Fig. 4. The experimental procedure is as follows. Firstly a level collimated laser beam should be obtained by adjusting the He–Ne laser to pass through the same aperture twice in different position along the straight line rail and incident on the prism on the rotary table. Secondly a circularly polarized light is obtained by adjusting the rotation angle of the polarizer and the 1/4 wave plate. Thirdly the fully leaky LC waveguide

Table 1
Parameters of the negative LC and the VA cell.

Negative LC		VA cell	
$\varepsilon_{\parallel}, \varepsilon_{\perp}$	3.27, 5.06	Cell thickness	4.30 μm
$\Delta\varepsilon$	−1.79	ITO thickness	41.5 nm
k_{11}	26.3 PN	PI thickness	84.5 nm
k_{22}	–	Testing temperature	26 °C
k_{33}	17.0 PN	V_{th}	$3.09V_{rms}$
γ_1	154.5 mPa s	V_{10}, V_{90}	3.606 V, 5.613 V
n_e, n_o	1.5748, 1.4848	T_{on}, T_{off} (6V)	19.5 ms, 8.5 ms
$\Delta n = n_e - n_o$	0.09	Rubbing direction	0°/180°