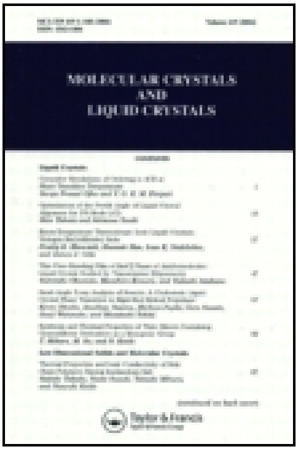

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A Technique for Director Profiling Utilising Convergent Beam Excitation of Fully-Leaky Guided Modes

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A Technique for Director Profiling Utilising Convergent Beam Excitation of Fully-Leaky Guided Modes

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The recently developed Fully-Leaky Guided Mode (FLGM) technique has paved the way for using optical waveguiding to study standard commercial cells. Previous FLGM experiments have utilised a plane-polarised collimated beam to excite optical modes. Here we describe the use of an alternative convergent beam procedure. The Convergent Beam Guided Mode (CBGM) technique has in addition the potential to be used to explore switching dynamics and single pixels. The work presented here is a demonstration of the CBGM technique via a study of the static director profile of a pi-cell (parallel rubbed) filled with the nematic liquid crystal material E7.

Keywords: optics; liquid crystal; guided-mode; fully-leaky; convergent beam

INTRODUCTION

The success of guided mode techniques in determining the director profile of a thin liquid crystal layer can be attributed to the fact that each optical mode has a different field intensity profile across the liquid crystal layer. Individual modes are therefore sensitive to the director in different spatial regions through the cell and consequently details in the director profile can be accurately resolved.

Three different experimental cell geometries have been developed over the past decade for coupling light into waveguide modes that are resonant within the liquid crystal layer[1-6]. The cell geometry largely dictates the type of guiding that optical modes experience. The recently developed fully-leaky guided mode technique (FLGM) has received interest since unlike previous waveguide techniques, this new technique can be used to study commercially fabricated cells[7, 8].

The cell and prism arrangment for coupling to fully-leaky guided modes is shown schematically in figure 1.

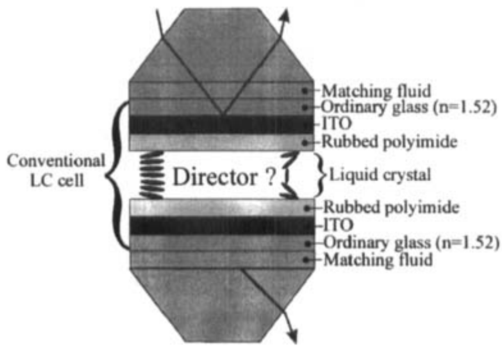

FIGURE 1. Prism coupling to fully-leaky modes can be used to determine the director profile in conventional cells.

Coupling prisms are optically matched onto the cell by use of a suitable non-volatile silicone based oil that also enables the cell to be easily rotated to any azimuth angle. This is an important feature since numerical modeling has revealed that at certain azimuth angles the optical response is considerably more sensitive to the twist/tilt profile of the director[8].

The input prism enhances the in-plane momentum of the incident radiation and at certain incident angles, the light couples to fully-leaky guided modes. Since the effective index of the liquid crystal is invariably higher than the glass plates, the resulting angular dependent reflectivity and transmissivity features tend to be rather broad. However, by monitoring the input and output polarisation state of both the reflected and transmitted probe beam, eight data sets in total are available for study. Director profiles are obtained by fitting model data produced from multi-layer optics theory to all eight data sets[9]. A schematic of the standard experimental geometry is shown in figure 2.

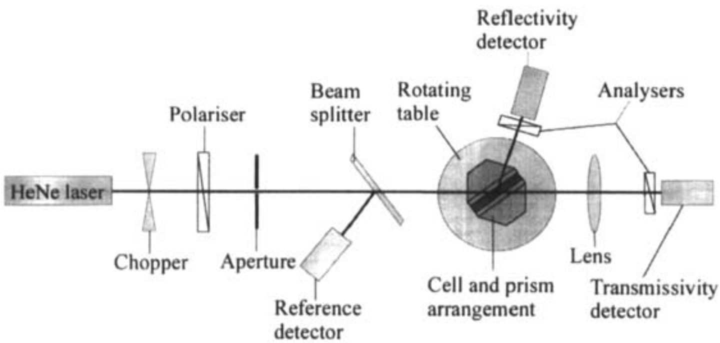

FIGURE 2. Schematic representation of a conventional experimental set up used to excite fully-leaky modes in a liquid crystal layer with a collimated beam.

The prism and cell arrangement are rotated through an angle θ and the reflected signal is recorded by a detector that rotates through an angle 2θ. The transmitted beam is focussed into a second stationary detector, thus enabling two data sets to be recorded simultaneously.

An alternative approach to this angle-scan collimated beam experiment is to use a convergent beam. This alternative approach may have several advantages. The Convergent Beam Guided Mode (CBGM) technique uses a highly focused beam spot that simultaneously excites many guided modes and produces reflectivity and transmissivity data over a wide angle range[10, 11]. Such reflectivity and transmissivity data can be captured considerably faster (ms) than is possible with the conventional collimated beam technique which requires several minutes for a single scan. The CBGM technique therefore has the potential for exploration of switching dynamics. This technique also removes the need to physically rotate the LC cell and consequently the focused beam remains completely stationary on the liquid crystal layer. Combining this experimental virtue with a focal spot diameter of less than 100μm allows the study of single pixels.

EXPERIMENTAL

The ray diagram in figure 2 shows a hemisphere-coupled convergent beam incident upon a LC layer arranged in the fully-leaky guided mode geometry. The polarization states s (TE) and p (TM) are also indicated.

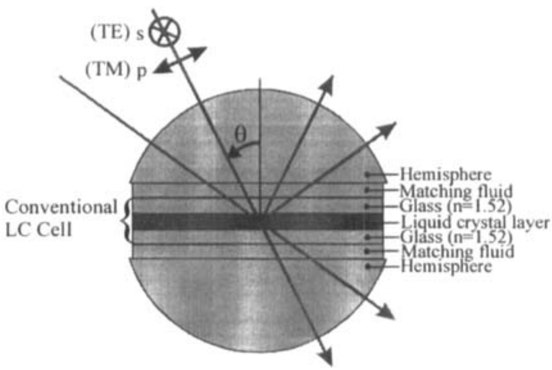

FIGURE 3. The use of hemispheres to couple a convergent beam into and out of fully-leaky guided modes.

Clearly, the converging rays of either s or p polarisation are incident upon the LC layer over a range of angles and thus the rays have a range of in-plane momentum values. It is apparent that it is now possible to simultaneously excite many guided modes within the LC layer without requiring the cell/hemisphere arrangement to be physically rotated.

The use of hemispheres for coupling a convergent light source into guided modes has two advantages over the use of coupling prisms. Firstly, the resulting beam spot incident on the LC layer is smaller using a hemisphere and consequently, pixelated regions around 100μm in diameter may be studied. Secondly, for the same aperture of expanded beam, the hemispheres allow more guided modes to be excited. As a first approximation, the internal angle range of rays incident on the LC layer in a hemisphere coupled system will be higher than the prism coupled system by a factor n_p, where n_p is the refractive index of the coupling prism. Recording data over the largest possible internal angle range is desirable since exciting more guided modes provides more features to fit to and consequently, the risk of finding a degenerate solution is reduced. The advantages of using hemispheres over coupling prisms are attributed to the fact that all converging rays are normal to the air/hemisphere interface and therefore none of the rays are refracted.

A schematic of the convergent beam experimental arrangement is shown in figure 4.

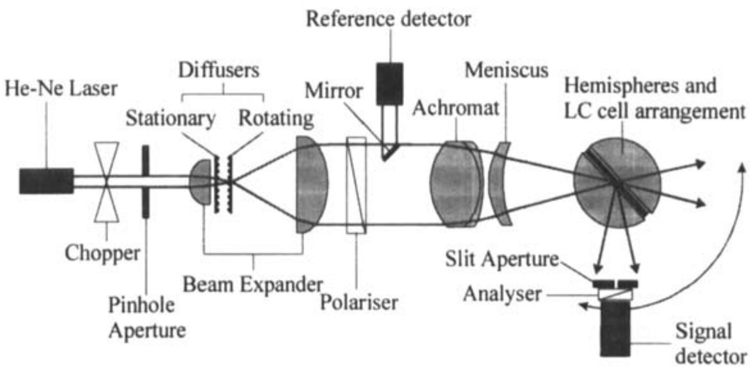

FIGURE 4. Schematic representation of the novel experimental set up used to excite fully-leaky modes in a liquid crystal layer with a convergent beam.

The He-Ne laser (wavelength 632.8nm) is expanded, polarised and focussed down though the input hemisphere onto the liquid crystal layer. The diffuser arrangement situated in the beam expander serves two purposes. Firstly, it breaks up the spatial and temporal coherence of the laser and secondly it provides an intensity profile across the expanded beam such that approximately the same intensity is available to excite each guided mode. A slit aperture, oriented parallel to the y axis, is mounted on the signal detector. The product of the signal detector width ($\approx$0.2mm) and its distance from the convergent beam focus ($\approx$15cm) determines the angular resolution of the system ($\approx$0.08°).

RESULTS AND DISCUSSION

The sample used in this study was a homogeneously aligned nematic (E7) layer. The parallel rubbed polyimide layers deposited upon ITO coated glass induced a typical splayed director configuration. Angular dependent reflectivities and transmissivities are normalised using a scan of the beam profile reflected from beyond the critical edge of a hemisphere/air interface. Typical experimental results (circles) compared with theoretical predictions (full line) are shown in figure 5(a) for T_{pp} and T_{ps} and in figure 5(b) for R_{ss} and R_{sp} (the first subscript refers to the input beam polarisation and the second subscript refers to the output).

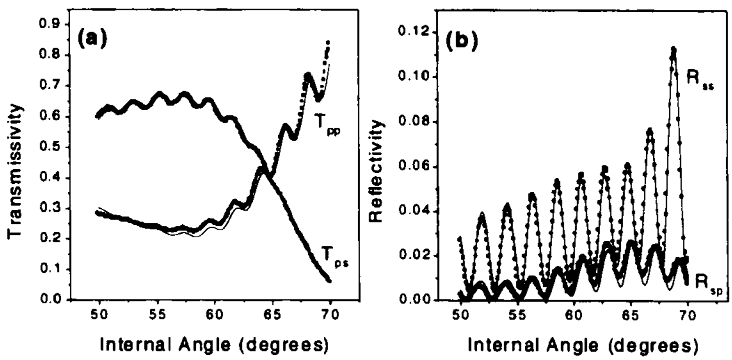

FIGURE 5. Experimental data (circles) and fitted theory (solid line) for a parallel rubbed E7 filled cell: (a) T_{pp} and T_{ps}, (b) R_{ss} and R_{sp}.

The optimum theoretical fits were obtained by careful and progressive adjustment of all the optical parameters followed by the use of a steepest-decent routine to minimise the sum of squares between experiment and theory. A linear twist/tilt profile was assumed for the liquid crystal director[12]. The azimuth angle of the cell was around 45°, thus providing a relatively large polarisation conversion component for study in transmission and reflection. The deduced director profile had a 5° pre-tilt at both polyimide layers and a 3° twist through the cell.

CONCLUSIONS

A convergent beam technique has been successfully implemented to excite fully-leaky guided modes in a liquid crystal layer in order to characterise the optical tensor profile. This work has effectively demonstrated equivalence between the new CBGM technique and the conventional angle-scan collimated beam experiment. However, the full potential of convergent beam fully-leaky guided mode studies has yet to be explored. By dispensing with the rotating detector and capturing angular dependent reflectivity and transmissivity in milliseconds with a CCD array, CBGM technique may be used for studying liquid crystal dynamics in conventional, pixelated cells.

ACKNOWLEDGEMENTS

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