Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

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Version of record first published: 24 Sep 2006

To cite this article: Ju-Hyun Lee, Chang-Jae Yu & Sin-Doo Lee (1998): A Novel Technique for Optical Imaging of Liquid Crystal Alignment Layers, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 321:1, 317-322

To link to this article: http://dx.doi.org/10.1080/10587259808025098

Mol. Cryst. Liq. Cryst., Vol. 321, pp. 317–322
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A Novel Technique for Optical Imaging of Liquid Crystal Alignment Layers

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We have employed a phase modulation method using a photoelastic modulator to determine the uniformity and quality of the alignment layer of liquid crystals (LCs). It is demonstrated that a two-dimensional map of the phase retardation, associated with irregular rubbing and/or chemical contaminants, provides invaluable information about an early detection of defects involved for aligning the LC molecules on a substrate.

Keywords: phase modulation, alignment layer, rubbing

INTRODUCTION

The liquid crystal display (LCD) technology relies heavily on preferred molecular alignment in the bulk, which is predominantly governed by surface treatment[1]. Preparation of a uniform, defect-free LC layer in a large area, sandwiched between two treated glass substrates, is a prerequisite for the construction of the high performance LCDs. Among several methods of molecular alignment, the use of rubbed polymer layers[2] is of particular interest because of its simplicity and applicability over large areas for mass production. However, the rubbing process modifies the morphology of the polymer in a contact way and potentially involves surface defects in the alignment. Therefore, an early detection of defects, such as physical scratches, dust particles, and chemical contaminants introduced into the

LCD fabrication, is extremely important. A reliable and viable tool of such detection has not been developed so far.

In this work, a phase modulation method using a photoelastic modulator is employed to detect the inhomogeneity, the irregularity, and chemical contaminants in the polymer layer for aligning the LC molecules. A two-dimensional map of the phase retardation clearly distinguishes between the well-prepared, rubbed region and the unrubbed one or the area with chemical contaminants such as acetone.

EXPERIMENTAL

The substrates used in this study were transparent indium-tin-oxide deposited glasses of 0.75 mm thick which were coated with polyimides. The thickness of the polyimide layer on the substrate was about 300 Å. Two different samples were prepared, one of which had both the rubbed and unrubbed regions and the other was purposely contaminated with a small droplet of acetone. Measurements of the optical retardation were carried out by a scanning system of phase modulation detection[3]. The scanning system was equipped with a motorized rotary stage as well as a translational one.

The sample in conjunction with a photoelastic modulator (PEM) was placed between crossed polarizers, and the optic axis of the sample make an angle of 45° with respect to one of the polarizers. A He-Ne with the wavelength λ of 632.8 nm was used as a monochromatic light source. The ac component of the transmitted light intensity through the sample was detected with a lock-in amplifier. The measurements were performed at room temperature.

RESULTS AND DISCUSSION

We first describe the principle of the phase modulation technique for mea-

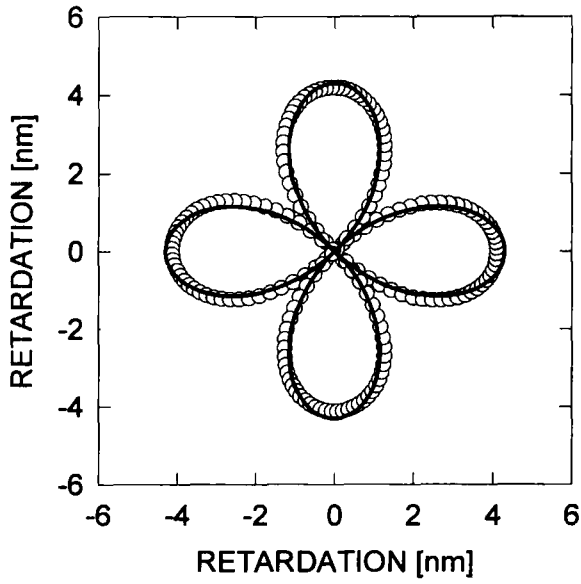

Figure 1: The phase retardation measured as a function of the angle θ for rotation.

suring the optical retardation. Suppose that the time-dependent phase shift $A(t)$ by PEM at the frequency ω is $A_o \cos(\omega t)$, the phase retardation of the sample is B, and the angle between the optic axis of PEM and that of the sample is θ. The transmitted light intensity I through the sample under crossed polarizers is then given by

$$\begin{aligned} I &= I_{dc} + 8J_1(A_o)\sin B \cos 2\theta \cos \omega t \\ &+ 4J_2(A_o)[(1-\cos 4\theta) + \cos B(1+\cos 4\theta)]\cos 2\omega t, \end{aligned} \quad (1)$$

where J_1 and J_2 denotes the first and the second orders of the Bessel function, respectively. Here, I_{dc} denotes the dc component of the transmitted intensity.

Assuming that R_1 and R_2 are the first and the second harmonic

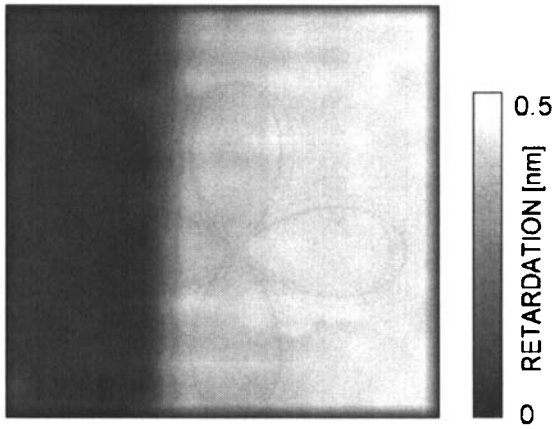

Figure 2: A two-dimensional map of the phase retardation through the sample with the unrubbed (left) and rubbed (right) regions.

terms, the phase retardation can be written as

$$B(\theta) = \tan^{-1}\{2 \sin B_o \cos 2\theta / [(1 - \cos 4\theta) + \cos B_o (1 + \cos 4\theta)]\}. \quad (2)$$

For the case that $\theta = 0$, the maximum retardation B_o is obtained by $\tan^{-1}[J_2(A_o)R_1/J_1(A_o)R_2]$. Accordingly, the birefringence retardation $\Delta nd = \lambda B_o/2\pi$ with d the sample thickness.

Fig. 1 shows the phase retardation a uniform, homogeneous sample as a function of the rotation angle θ between the optic axis of PEM and that of the sample. The solid line is the least-square fit of the data to Eq. (2). As expected, the phase retardation has the maximum at four different positions such that $\theta = 0°$, $90°$, $180°$, and $270°$. This tell us that our phase modulation technique is sensitive enough to detect surface modification of the alignment layer by rubbing.

The difference in the phase retardation between the rubbed and unrubbed regions is shown in Fig. 2. Clearly, the two regions can be distinguished because of the induced birefringence by rubbing. The total area we scanned for the phase modulation detection was 1 cm^2. Note that any irregular or inhomogeneous rubbing can be represented by the gray scale

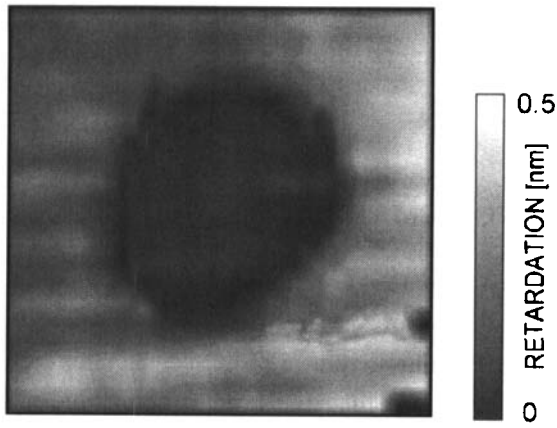

Figure 3: A two-dimensional map of the phase retardation through the sample contaminated chemically by acetone.

in the two-dimensional map as seen in Fig. 2. Moreover, the map can be further enhanced by digital signal processing.

We now turn to examine the chemical contaminants in the alignment layer involved in the LCD fabrication. A small droplet of acetone was purposely dispersed on the surface of the alignment layer. The area contaminated with acetone was nearly invisible since the glass substrate with the alignment layer of about 300 $\mathring{A}$ is quite transparent in the visible range of the wavelength. However, the change in the resultant retardation was large enough to detect using our phase modulation technique as shown in Fig. 3.

As shown in Figs. 2 and 3, the degree of the inhomogeneity of the alignment layer produced by irregular rubbing or chemical contamination is characterized by the gray level. This means that the criterion for rejection or acceptance of the quality of the alignment layer can be adjusted by the contrast in the two-dimensional map. In principle, the phase retardation measurement can be utilized for monitoring the uniformity of the rubbing process and detecting the chemical contaminants. However, the

optical inhomogeneity of the glass substrate itself often limits the sensitivity of such measurement since the phase retardation of the alignment layer of rubbed polymer is very small.

CONCLUDING REMARKS

We have demonstrated that a scanning system of phase modulation is a simple and useful tool for an early detection of surface inhomogeneities involved in the molecular alignment of LCs. Such inhomogeneities include the dust particles, the irregularity during rubbing, and possible chemical contaminants.

Acknowledgements

This work was supported in part by Samsung Electronics, Ltd and Korea Science and Engineering Foundation through AMCRC at Korea University.

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