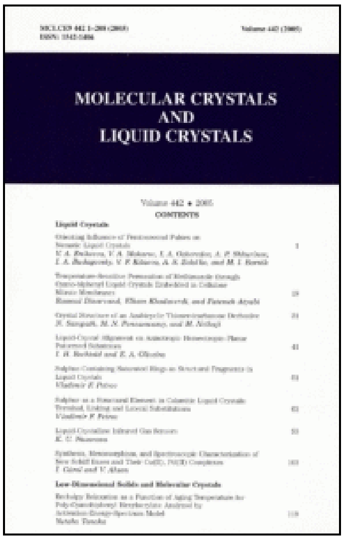

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Continuous Pretilt Angle Controlled No-Bias-Bend Pi Cell via Blended Polyimide Liquid Crystal System

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Continuous Pretilt Angle Controlled No-Bias-Bend Pi Cell via Blended Polyimide Liquid Crystal System

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The controllable pre-tilt angle of liquid crystals was investigated using a blend of horizontal and vertical polyimide prepared using a rubbing method. Various pretilt angles ranging from 0° to 90° were achieved as a function of the vertical polyimide content. We observed uniform liquid crystal alignment on the rubbing-treated blended polyimide layer. A no-bias-bend (NBB) pi cell with an intermediate pretilt angle of 47.8° was manufactured. This cell had no initial bias voltage and a low threshold voltage, which indicates that it has low power consumption. In addition, the response time of the NBB pi cell was rapid.

Keywords Pretilt angle; response time; rubbing method; voltage-transmittance characteristics

Introduction

Most liquid crystal display modes, including the twisted nematic (TN) mode [1], the in-plane switching (IPS) mode [2], the fringe field switching (FFS) mode [3], and the vertically aligned (VA) mode [4], are based on either a horizontal or vertical alignment. However, for some applications, such as the no-bias-bend (NBB) pi cell or bistable bend-splay display, an intermediate pretilt angle is essential [5]. NBB pi cells have been a focus of interest because of their fast response time; however, it is challenging to provide the reliable control of the intermediate pretilt angle of liquid crystals required for the fabrication of NBB pi cells.

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Using various alignment methods, it is relatively easy to induce pretilt angles of liquid crystals (LCs) in the range of 0–10° and 85–90°, but intermediate pretilt angles of 10–85° are very difficult to obtain. The SiO_2 evaporation method is the best available method for generating intermediate pretilt angles [6]. The topological surface structures of SiO_2 made using various deposition conditions can generate intermediate tilting orientations of the LC molecules. Numerous alternative methods have been proposed to provide alignment at intermediate pretilt angles, including the use of rubbed polyimide (PI) with trifluoromethyl moieties [7], a dual alignment layer with PI and poly-dimethylsiloxane (PDMS) [8], and amorphous fluorinated carbon thin film via an ion-beam (IB) [9].

However, these methods have several technical limitations. The SiO_2 evaporation method is not adequate for large panel displays, and it cannot be mass-produced due to the uniformity of the deposited layer and the vacuum process. The limitations of the other methods include non-uniform deposition, stability issues, lack of fidelity, and high manufacturing costs.

Recently, Kwok *et al.* presented a novel method to address these limitations. They adjusted the pretilt angles by mixing horizontal and vertical PIs via rubbing and an ultra-violet (UV) light method [10,11]. Various pretilt angles were created by varying the vertical PI content. This method has several advantages over existing methods. However, the NBB pi cell made using this method was not documented. Therefore, we experimented in order to control continuous pretilt angles and to fabricate an NBB pi cell in order to characterize its electro-optic (EO) characteristics.

In this paper, we report that the pretilt angle of LCs can be controlled when the blended PI alignment layer is treated using the rubbing method. Uniform alignment of the LCs was observed in all samples. In addition, we measured the EO characteristics of an NBB pi cell with an intermediate pretilt angle of 47.8°. The NBB pi cell had no initial voltage with which to maintain a bend state, and it exhibited a fast response time of 7.281 ms.

Experimental

In this experiment, we used blended PIs (JSR Co. Ltd) of different concentrations for the horizontal and vertical alignment layers. Indium-tin-oxide (ITO)-coated glass (Samsung Corning, 1737) substrates were cleaned in a bath using acetone, isopropyl alcohol, and deionized water. These blended PIs were deposited uniformly onto ITO-coated glass at 3000 rpm for 1 min using a spin-coating machine. These coated PIs were pre-baked at 80°C for 10 min and cured at 230°C for 1 h. The PI film was approximately 50 nm thick, which is sufficient to prevent a leakage current when an electric field is applied and to maintain the voltage retention ratio for thin film transistor (TFT) devices. After applying the rubbing treatment to obtain a uniform LC configuration, various pretilt angles were obtained by varying the concentration of the vertical PI. The rubbing strength has been discussed in previous papers [12]. Anti-parallel cells filled with negative LC (MJ98468, Merck) were fabricated in order to measure the LC alignment of the pretilt angles and to take photomicrographs of the LCs. The anti-parallel cell gap was set to 60 μm. The pretilt angles of the anti-parallel cells were measured using the crystal-rotation method (TBA 107, Autronic) at room temperature, and the LC alignment characteristics were observed using a photomicroscope (BXP51, Olympus).

An NBB pi cell with a cell gap of 4.25 μm was fabricated to examine its EO characteristics. The voltage-transmittance (V–T) and response time characteristics of the NBB cell were obtained using the LCMS-200 system (an EO evaluation system manufactured by Sesim Photonics Technology).

Results and Discussion

The side chains of PI materials play an important role in the vertically aligning functional groups. The pretilt angle of the LCs is determined by the length, amount, and type of PI side chain [13]. If the LC molecules are sterically hindered by the side chains of the PI materials, then the LC molecules will align vertically, depending on the force of the steric hindrance. Therefore, we hypothesized that we could achieve various pretilt angles by varying the concentration of vertical PIs according to the difference in the side chain mounts.

Figure 1 shows the pretilt angles of the LC on a blended PI layer as a function of the concentration of the vertical PI. The pretilt angles generated were strongly dependent on the concentration of vertical PI; the pretilt angles increased rapidly as the vertical PI content increased from 0 wt% to 20 wt%, but the angles then tended to gradually saturate near 80° even as the vertical PI content continued to increase. These tendencies were caused by variations in the side chain mounts of blended PI materials, depending on the vertical PI content, as discussed previously.

Figure 2 shows the plots of the transmittance and incident angle obtained from the pretilt angle measurements of the anti-parallel cells as functions of the vertical PI concentration are shown in Figure 2. Each anti-parallel cell had a 0–20 wt% vertical PI content. The measured pretilt angles increased as these anti-parallel cells contained more vertical PI content. The plots and error data values indicate that the pretilt angle measurements were highly reliable. From these results, we found

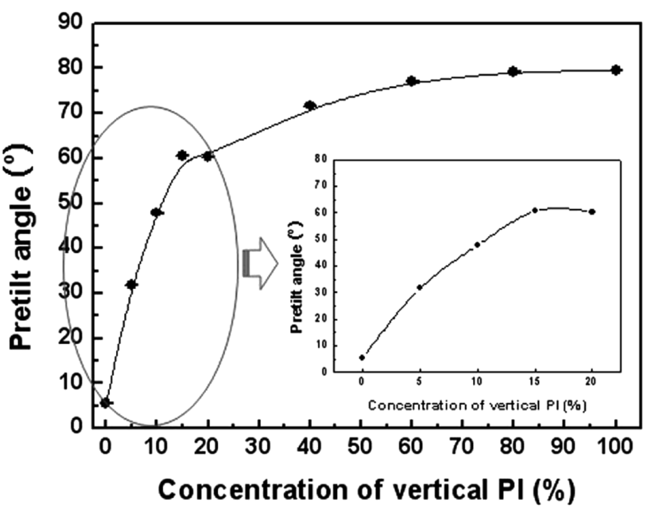
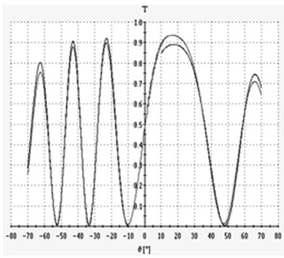
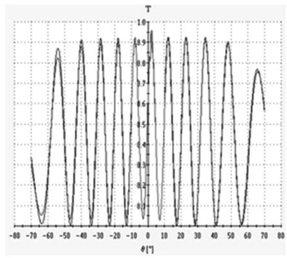


Figure 1. Measured pretilt angles of LCs on the rubbing-treated blended PI as a function of the concentration of vertical PI. The inset shows pretilt angles in the range of 0–20%.



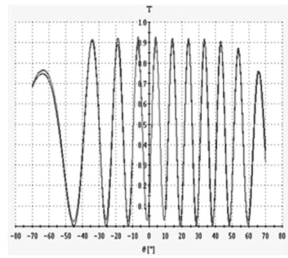
Pretilt angle	Error
5.59 °	0.0017

(a)



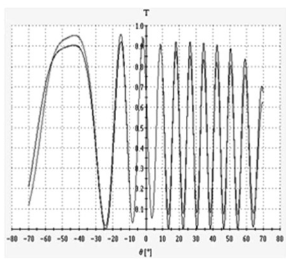
Pretilt angle	Error
31.75 °	0.0024

(b)



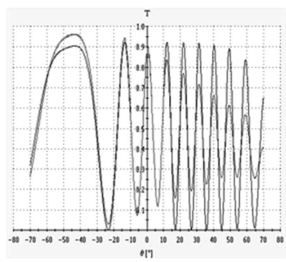
Pretilt angle	Error
47.88 °	0.0037

(c)



Pretilt angle	Error
60.59 °	0.0044

(d)



Pretilt angle	Error
60.29 °	0.0148

(e)

Figure 2. The plots of transmittance and incident angle obtained from pretilt angle measurements of the anti-parallel cells as a function of the concentration of vertical PI: (a) 0%, (b) 5%, (c) 10%, (d) 15%, and (e) 20%.

that the blended PI layer created using the rubbing treatment could be applied to a variable mode including an NBB pi cell with an intermediate pretilt angle.

It is vital to achieve uniform alignment of the LCs on blended PIs for alignment technologies such as rubbing, UV, and the ion-beam method to be successful. Otherwise, random LC molecules will induce tilt reverses, which can create defects such as disclination. Among the various alignment technologies, the rubbing method is used widely due to the fact that it is simple, convenient, low cost, and can be used for mass production. Figure 3 shows photomicrograph images of the anti-parallel cells with rubbing-treated blended PI layers and 0–20 wt% vertical PI content (in crossed Nicols). A uniform LC alignment texture was observed in all samples with the rubbing-treated blended PI layer.

The anchoring energy is an important parameter for an NBB pi cell because it affects not only the LC alignment but also the EO characteristics such as the threshold voltage and the response time. Figure 4 shows the polar anchoring energy of LCs on the rubbing treated blended PI as a function of vertical PI concentration. The polar anchoring energy was measured using the voltage-capacitance method, which is different from the high voltage method used by Seo *et al.* [14–16]. The measured anchoring energy was in the range of $3\text{–}10 \times 10^{-3}\,\mathrm{J/m^2}$, which is similar to previous data for regular rubbed PI [14]. The results show the polar anchoring energy did not

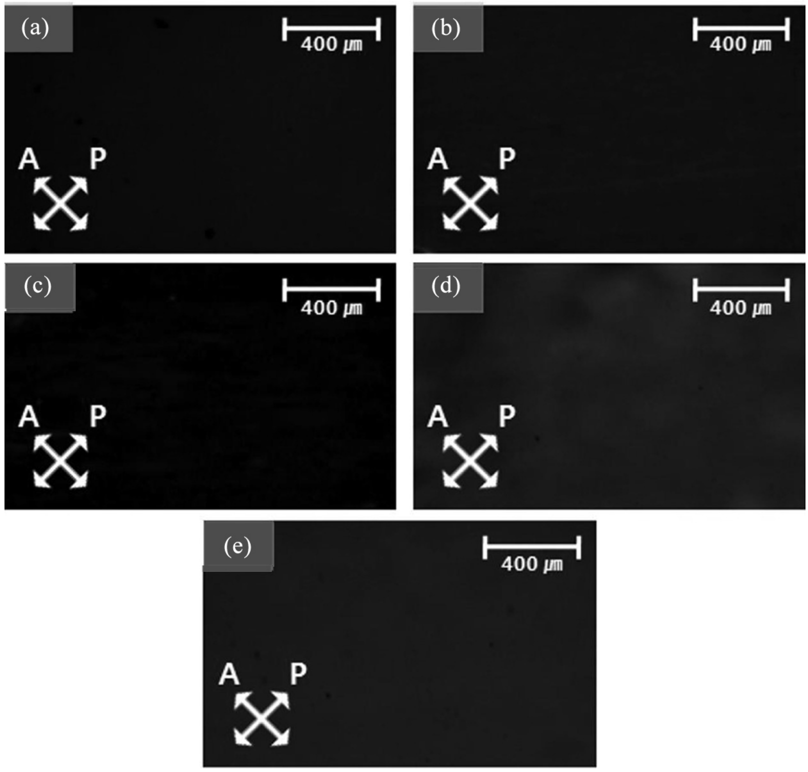


Figure 3. Photomicrographs of LC cells aligned on rubbing-treated blended PI layers with different concentrations of vertical PI: (a) 0%, (b) 5%, (c) 10%, (d) 15%, and (e) 20% (A: analyzer, P: polarizer).

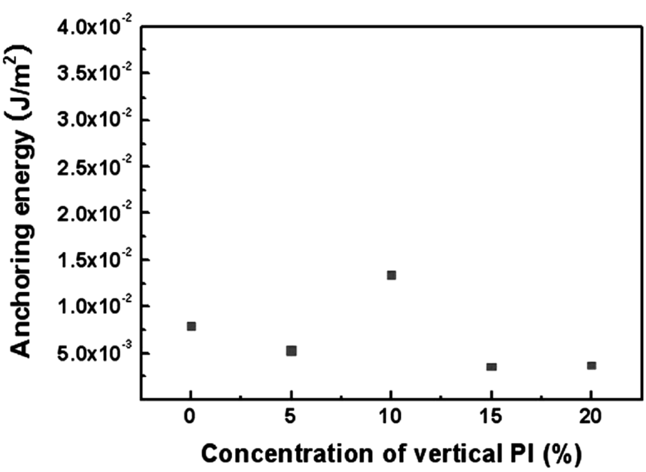


Figure 4. The polar anchoring energy of LCs on the rubbing treated blended PI as a function of concentration of the vertical PI.

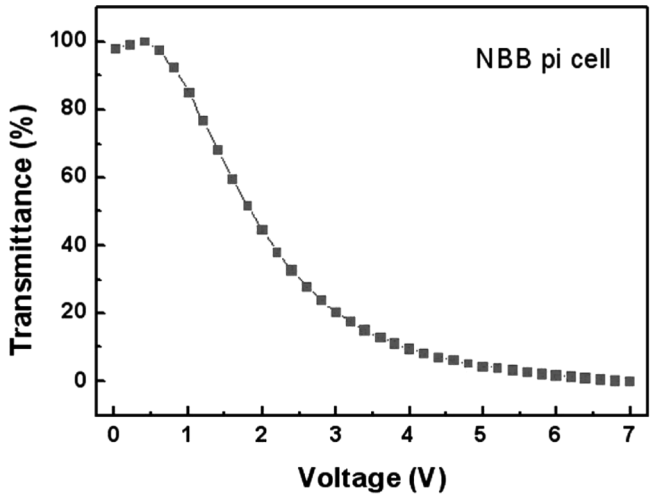


Figure 5. V–T curves of the NBB pi-cell with an intermediate pretilt angle of 47.8°.

seem to change with the increased pretilt angle as a function of the vertical PI concentration, which means that the polar anchoring energy is independent of the concentration of the vertical PI.

To examine the EO characteristics of an NBB pi cell, we fabricated one with an intermediate pretilt angle of 47.8°. The V–T curve of the NBB pi cell with a rubbing-treated blended PI layer is shown in Figure 5. The plot clearly shows that no initial voltage is required to sustain a bend state. This indicates that the bend state is energetically more stable than the splay state when the pretilt angle is about 47.8°. The threshold voltage of the NBB pi cell was 0.559 V at a transmittance of 90%. This indicates that this cell can be used to created devices with low power consumption.

The major advantage of an NBB pi cell is its fast response time. The total response time of the NBB pi cell was measured as 7.281 ms. The rise time and fall time were 1.963 ms and 5.318 ms, respectively.

Conclusions

In conclusion, we investigated the controllable pretilt angles of LCs aligned on a substrate that was treated using the rubbing method. The rubbing treatment of the blended PI and varying the concentration of the vertical PI made it possible to achieve various pretilt angles ranging from 0° to 90°. We observed uniform LC alignment in all samples, regardless of the concentration of vertical PI. We successfully fabricated an NBB pi cell with an intermediate pretilt angle; this cell operated effectively with no initial bias voltage, and is characterized by low power consumption.

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