Liquid Crystal Device with Nanopatterned Indium–Zinc-Oxide Layer

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Nanoscale grating patterns with indium–zinc-oxide (IZO) layer have been successfully fabricated by ultraviolet (UV) nanoimprinting technique and sputter deposition process. Nanoscale groove prepared here can play important roles as alignment layers as well as conducting electrodes. Performance for LC alignment was tested by evaluating order parameter. A preliminary version of twist nematic (TN) LC cell with the nanopattern coated IZO was also fabricated and evaluated.

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1. Introduction

Uniform and defect-free alignment of liquid crystal (LC) molecules is one of the critical factors that influence the electro-optical performance of LC devices.[1)] In general, the rubbing process has been employed to align the LC molecules. The rubbing process realigns the polymer chains of polymer surfaces, resulting in preferential alignment of LC molecules along the direction of the polymer chains. However, the rubbing method creates several problems, such as the creation of contaminating particles.[2)] Alternatively, a variety of methods for generating surface topography have been proposed because LCs can be aligned by topographically micro- or nanopatterned surfaces.[3–7)]

For example, Behdani *et al.* showed that laser-ablated nanoscale gratings on an indium–tin-oxide (ITO) surface can align LC molecules.[6)] More recently, Lin *et al.* reported that nanopatterned ITO film grown on polymer substrates is also capable of aligning LC molecules.[7)] In Lin's work, the ITO film, prepared by thermal nanoimprinting lithography (NIL), can play important role as not only an electrodes but also an alignment layers. They proposed that the nanopatterned ITO film grown on polymer substrates was promising for flexible plastic LC devices. However, conventional ITO films grown on polymeric layers have several problems, such as high sheet resistance, low transition temperature from the amorphous phase to the crystalline phase, and rapid degradation resulting from bending stress.[8)] Therefore, in order to fabricate more stable and reliable devices, it may be necessary to replace ITO layers with another transparent conducting oxide (TCO) layer that exhibits lower resistance, higher nucleation energy of crystallization, and superior flexibility.[8)]

In this study, we fabricated nanoscale groove patterns coated indium–zinc-oxide (IZO) employing the ultraviolet (UV) NIL technique and sputter deposition process for novel LC devices. It has been reported that the IZO film has lower resistivity and higher nucleation energy of crystallization than that of ITO film.[9)] This nanoscale groove coated IZO can play important roles in alignment layers as well as conducting electrodes for novel LC devices. Performance of LC alignment was tested by evaluating the order parameter.

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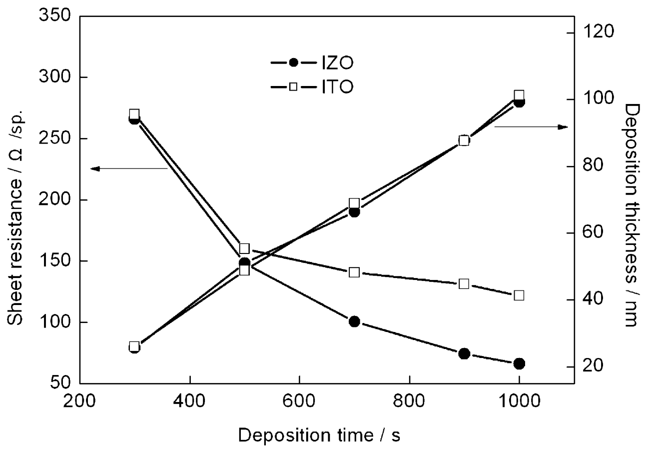

Fig. 1. The sheet resistance and film thickness of IZO and ITO film prepared as a function of deposition time at room temperature.

We also fabricated preliminary version of twisted nematic (TN) LC cells using our nanopattern layer, and confirmed the stability and reliability of the fabricated cells by measuring their electro-optical performance.

2. IZO and ITO

2.1 Sheet resistance

Figure 1 shows the sheet resistance and film thickness of IZO and ITO film prepared as a function of deposition time at room temperature. This data were simply evaluated using flat substrates without nanopatterns, since the preliminary data for comparing the electric performance of IZO with that of ITO was required according to the deposition time. Increasing the deposition time led to an increase in film thickness and a significant reduction in the sheet resistance for both IZO and ITO film; there was a rapid decrease in sheet resistance for deposition times longer than 300 s. In the case of IZO films with deposition times longer than 700 s, sheet resistance was observed to be less than 100 Ω/sq. which was lower than the sheet resistance value for ITO film. After deposition for 1000 s, the sheet resistance and film thickness of IZO film were 66 Ω/sq. and 100 nm, respectively. Although the deposition thickness of ITO and IZO was linearly increased with same trend, the high resistivity of the ITO films prepared here was due to the absence of *in-situ* substrate heating or a post annealing process.

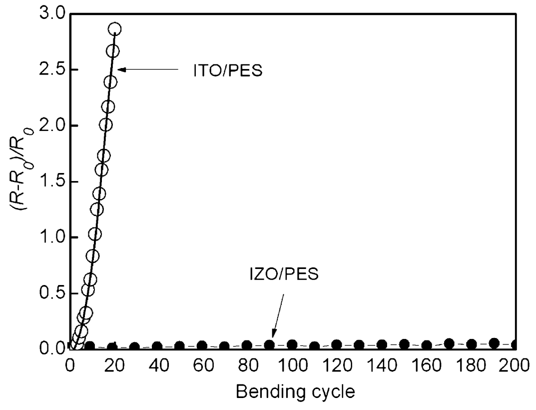

Fig. 2. Normalized resistance change after repeated bending stress as a function of the number of cycles for IZO/PES and ITO/PES.

2.2 Flexibility

The IZO and ITO film respectively prepared on a poly-(ethylene sulfonate) (PES) substrate were examined against repetitive mechanical bending stress. In this experiment, the test of the mechanical stability was performed with the homemade equipment described in previous literature,[10] where the geometrical curvature was defined as radius on a round stage. The prepared samples were exposed to repetitive mechanical bending stress (bending deformation of radius varied from ∞ to 21 mm). During the bending test, the resistance of the IZO/PES and ITO/PES sample was checked by a multimeter. The change in resistance was expressed as $(R - R_0)/R_0$, where R_0 is the initial resistance and R is the measured resistance after repetitive bending stress. Figure 2 shows changes in the resistance of both IZO/PES and ITO/PES with increasing bending cycles. The $(R - R_0)/R_0$ value of ITO/PES sample increased remarkably at initial bending cycles due to the generation and propagation of cracks.[8] On the other hand, the IZO/PES sample exhibited a constant $(R - R_0)/R_0$ value (less than 0.05) even after 200 times bending deformation, which indicates the IZO film has superior flexibility over ITO film against repetitive mechanical bending stress.

3. Procedure for Fabricating Multifunctional Layer

The UV-NIL procedure for fabricating topographically nanopatterned alignment layer coated IZO thin films is shown in Fig. 3. First, the patterned master (period of 218 nm and depth of 98 nm) was converted to a soft poly(dimethylsiloxane) (PDMS) mold, which was fabricated by casting the PDMS precursor against the patterned master ready-made. During two-step curing, (1) at 120 °C for 5 min and (2) at 60 °C for 30 min, the PDMS rubber (replica) became rigid and was easily separated from the patterned master to a freestanding film. UV curable polymeric material (Norland NOA 81) was drop cast on a glass substrate and the prepared replica was pressed against it for 2 min at room temperature under UV irradiation (365–436 nm, 15 mW/cm^2). Then, the patterned structure was replicated onto NOA 81 on a substrate. On the patterned layer, IZO as an electrode was sputter deposited at room temperature using an in-line magnetron sputter deposition system equipped with DC power suppliers. The coated thickness was controlled by means of deposition time.

4. Results and Discussion

4.1 Surface profile

The nanoscale groove of the NOA 81 film after NIL was measured by an atomic force microscope (AFM), shown in Fig. 4(a). The imprinted patterning on the polymer surface was observed to have a period of 200 nm and a depth of 90 nm. The observed period of the imprinted polymer film was in good agreement with that of the master. After the deposition of the IZO film (deposition time: 1000 s) on the nanoscale groove surface of the imprinted polymer layer, the groove structures were still maintained according to the topographical structures of base surfaces, as shown in Fig. 4(b). Although depth of the patterns was decreased up to approximately 60 nm as the deposition time increases up to 1000 s, the obtained dimension of nanoscale groove was still good enough for aligning LC molecules.

4.2 Sheet resistance for IZO film on the groove surface

The sheet resistance in the case of the deposited IZO film on the groove surface was also evaluated. The observed value of sheet resistance for IZO film (deposition time: 1000 s) on the groove surface was 69 Ω/sq. Thus, the detected value of IZO film on the groove surface was the same level as that of IZO film on the flat surface. Although, the IZO was not uniformly deposited due to the undulated surface against flat one, the observed value of sheet resistance was same level. The sheet resistance for the deposited ITO film on the groove surface was also same level as that of ITO film on the flat one. The details for the ITO film will be described in separated literature.[11]

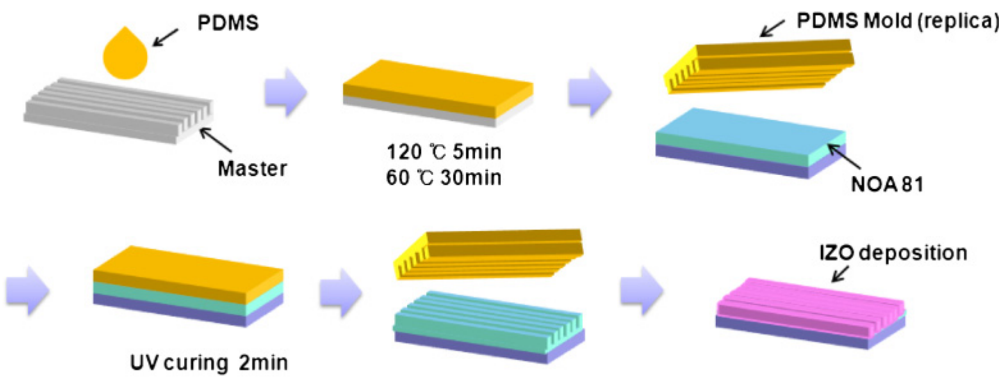

Fig. 3. (Color online) The UV-NIL procedure for fabricating topographically nanopatterned alignment layer coated IZO thin films.

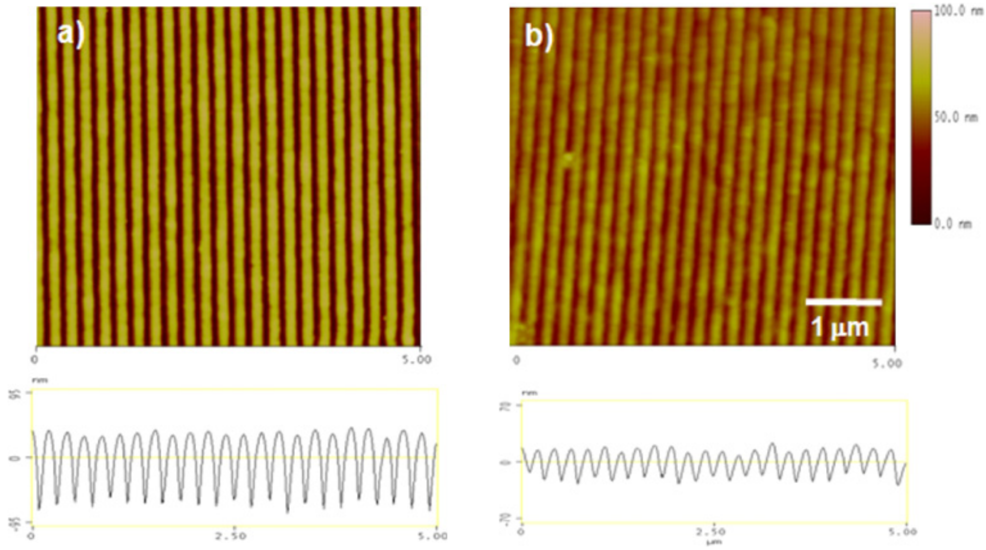

Fig. 4. (Color online) AFM image of (a) the NOA 81 film after NIL and (b) the NOA 81 film coated IZO.

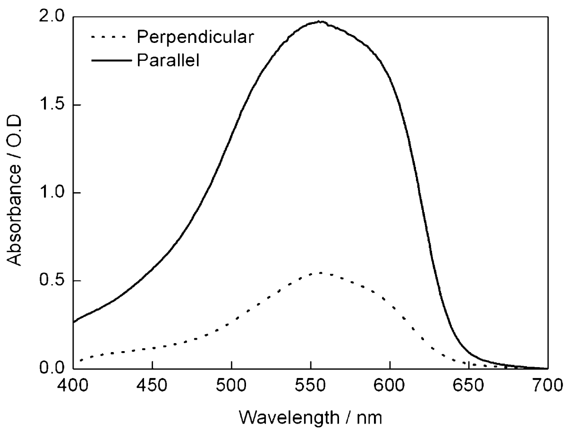

Fig. 5. Absorbance spectra of the planar nematic LC cell doped with 0.7% methylene violet dye.

4.3 LC alignment

To evaluate the LC alignment strength of the imprinted layers coated with IZO, we used dye-doped guest–host LC,[12] that is, commercially available nematic LC (E7) doped with 0.7% methylene violet dye. The imprinted layers coated with IZO were assembled with 6-µm spacers, and dye-doped guest–host LCs were injected into the isotropic phase to prevent the effects of flow alignment. We observed the dichroic transmittance of the cell with the guest–host LC and calculated the order parameter of the dye. Polarized absorption spectra of the 0.7% dye-doped LC cell are shown in Fig. 5. We calculated the dichroic ratio at $\lambda_{\max}$, $N = D_{\parallel}/D_{\perp} = 3.63$, where $D_{\parallel}$ and $D_{\perp}$ are the optical densities of the cell with light polarization parallel and normal to the nanoscale groove direction of the imprinted layers coated IZO, respectively. The order parameter S is related to the dichroic ratio by the equation:[12]

$$S = \frac{N-1}{N+2}$$

and was calculated to be 0.467. This value is comparable to the level of LC alignment for conventional rubbed polyimide (PI) surfaces.

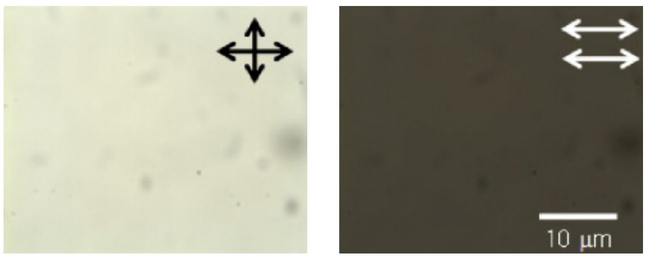

Fig. 6. (Color online) POM image under crossed polarizer and parallel polarizer geometry.

4.4 LC device

Next, two imprinted layers coated with IZO were arranged to form a 90° TN cell with 6 µm thickness. By crossed polarizer geometry, normally white state represents the well-aligned TN cell. On the other hand, normally black state observes under parallel polarizer geometry. From Fig. 6, we could conclude that well-aligned TN was accomplished using our imprinted layers coated IZO. Electro-optical characteristics of our TN cell were also evaluated. The voltage–transmittance characteristics of the LC cells were measured using an electro-optical measurement system (Sesim). Normally black TN geometry with parallel polarizers was employed in order to evaluate the initial black level. The observed black level was the level as the lowest detecting limit (dark current < 10 mV)[13] of the measurement system used, which indicates that a perfect 90° TN cell was fabricated. As shown in Fig. 7(a), the dark state of the 90° TN cell was changed to the white state as the applied voltage was increased from 0 to 10 V. The electro-optic operation had analog grayscale capability with a high contrast ratio of more than *ca.* 500 : 1 between the dark and white states. Figure 7(b) shows the result of the voltage holding ratio (VHR) measurement of the 90° TN cell on our imprinted layers coated with IZO. This characteristic was measured using a VHR measurement system (Toyo 6254). The obtained VHR of the 90° TN cell was above 97%. This VHR characteristic is also almost the same as that of a commercial PI layer. So far, studies have confirmed that the electro-optical performances of the TN

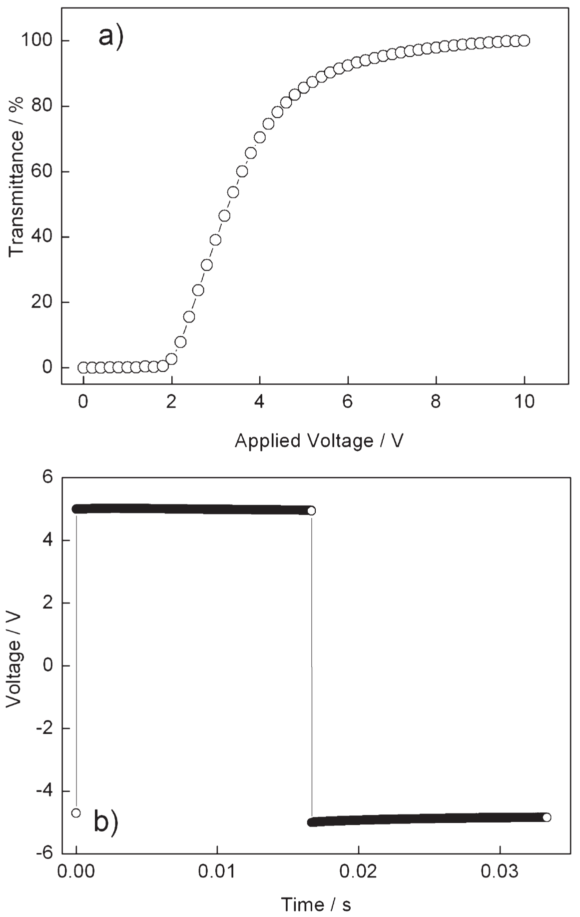

Fig. 7. (a) Electro-optical switching curve and (b) VHR profile for our TN cell.

LC cell can be maintained at a constant level for at least 1 month.

5. Summary

In conclusion, nanoscale grating patterns coated IZO layers were successfully fabricated using the UV-NIL technique and sputter deposition process. The nanoscale groove coated IZO that was prepared in this experiment could play an important role in alignment layers and conducting electrodes. We confirmed that the observed order parameter is comparable to the level of LC alignment on a conventional rubbed PI surface. We also confirmed that the 90° TN LC cell with our nanopattern coated IZO layer exhibited stable and reliable electro-optical performance. The technique discussed in this study opens a new gateway for novel LC devices, especially flexible plastic LC devices.

Acknowledgements

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