Liquid Crystal Alignment on Patterned Micro-grooved Polyimide Surfaces

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Abstract

In this work, a soft embossing method is proposed to fabricate microgrooves on polyimide surfaces. Apply these resulting patterned micro-grooved polyimide surfaces as the liquid crystal alignment layers. The director of liquid crystal molecules aligns perfectly along the direction of microgrooves.

1. Introduction

In the liquid crystal display (LCD) industry, the unidirectional mechanical rubbing process on polymer-coated substrates with a velvet cloth is almost exclusively applied to align liquid crystals.[1] The rubbing induces grooves in the polymer surfaces and the liquid crystal molecules would align along the direction of the grooves.[2] On the other hand, the rubbing process also creates dust and electrostatic charge, that deteriorate the display quality. To resolve these problems, non-rubbing methods have been under intensive investigation, such as photo-induced liquid crystal alignment by polarized light exposure[3], ion-beam etching[4] and excimer laser beam ablation.[5] But all these methods are related to either poor thermal stability, low anchoring energy or a chemical ablation process, which still lead to the debris contamination of the polymer film surface, limiting their application for liquid crystal display devices. Here we proposed a non-rubbing "soft embossing" method, which could produce large area reliable periodical grooves easily and rapidly on the polymer-coated substrates to induce the alignment of the liquid crystal molecules without the disadvantages of the rubbing process.

This technique combines the key features of soft lithography[6] and nanoimprint lithography[7]; that is, it combines the utilization of an elastomeric (polydimethylsiloxane) PDMS mould, which could make complete conformal contact with the substrate, even for substrates with curved surfaces, and a high throughput imprinting process. This patterning technique exhibits good pattern fidelity for the fabrication of large-area microstructures; it also obviates the need for the extreme high pressures needed in nanoimprint lithography. Compared to conventional photolithography, soft embossing with an elastomeric PDMS mould has several advantages, especially for pattern-sensitive materials such as polymers; it is less costly, has no optical diffraction limit, allows control of the chemistry of the patterned surface, and is able to pattern a large area. As a result, we demonstrated the fabrication of patterned micro-grooved polyimide alignment layers by soft embossing process to prevent form the problems encountered with the conventional rubbing process.

2. Experimental

2.1 Materials

Liquid polyimide prepolymer (IPA-5310) was purchased from Chisso. Polydimethylsiloxane (PDMS, SylgardTM184, Dow Corning Co.), octadecyltrichorosilane (OTS, United Chemical), nematic liquid crystal 4'-n-pentyl-4-cyanobiphenyl (5CBs, Aldrich) were used as received. The indiumtin oxide (ITO) glass slides were cleaned by Piranha solution (a mixture 7:3 (v/v) of 98% H2SO4 and 30% H2O2) at 120 ^{0}C for 30 minutes before use.

2.2 Fabrication of Patterned Polyimide Alignment Layer

We first fabricated the patterned silicon masters by either photolithography or by the electron-beam method. Then the masters were dipped into octadecyltrichorosilane (OTS) solutions to minimize to adhesion between PDMS and the patterned silicon masters. After the pretreatment of these patterned silicon masters, the mixture of the PDMS prepolymer and the curing agent (10:1 by weight) was filling onto the patterned silicon masters. After thermal curing at 60 ^{0}C for 12 hours, we got the patterned PDMS molds by peeling off them from the silicon masters. Next we spin coated a layer of liquid polyimide prepolymer onto the clean indiumtin oxide (ITO) glass substrate. Then we embossed the patterned PDMS mold on this substrate and followed by prebaking at 90 ℃ for 10 minutes and postbaking to 220 ℃ for 30 minutes. After peeling off the PDMS mold, we fabricated the patterned polyimide alignment layer.

2.3 Images by AFM

Contact mode atomic force microscopic (Nanoscope IIIa, Digital Instrument, Santa Barbara) images were used to explore the surface topography of the patterned polyimide alignment layers. Silicon nitride tips (Digital Instrument) with a spring constant of 0.06 N/m were used to image samples under ambient conditions.

2.4 Liquid Crystal Cells

Liquid crystal cells were assembled by two patterned polyimide substrates with parallel groove direction. The two substrates were kept apart form 10 μm by inserting Mylar films (DuPont Films) at the two longer edges. The filling of the 5CBs was by capillary. After the 5CBs were filled, the edges of the cells were sealed by glues. Next, the cells were heated to about 40 ^{0}C for 5 minutes to reach the isotropic phase of 5CBs and then cool down at room temperature to get into nematic state.

2.5 Analysis of Optical Textures

A crossed polarized optical microscope (Zeiss) was used to observe to textures of the liquid crystal cells. A digital camera (Canon) that attached to the microscope captured the images of the optical appearance of 5 CBs.

3. Results and Discussion

We fabricated microgrooves on polyimide surfaces by soft embossing method, which is schematically described in Fig. 1. This approach provided a convenient and rapid way to pattern polymer-coated surfaces. Fig. 2 shows an image of atomic force microscopy for the resulting patterned micro-grooved polyimide-coated surface on ITO glass with reliable periodical grooves.

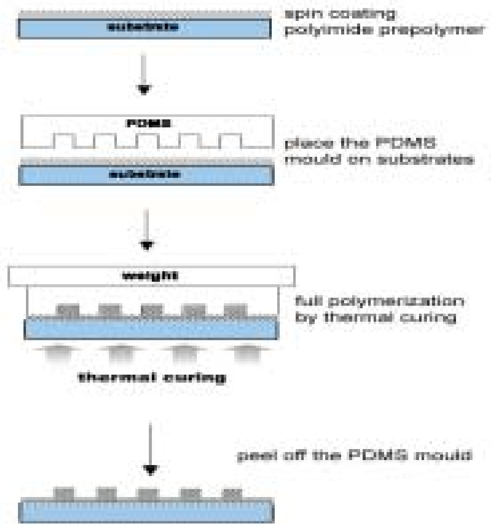

Fig. 1 The schematic representation of the soft embossing process.

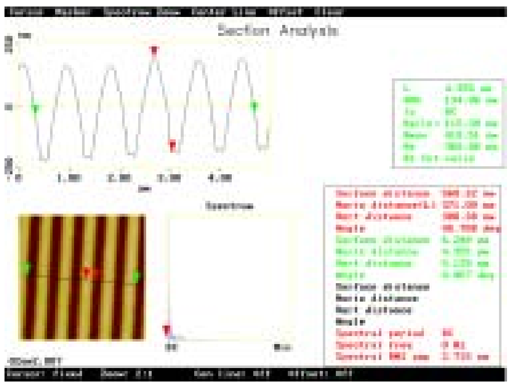

Fig. 2 The image of atomic force microscopy for the patterned polyimide surfaces.

The alignment of the nematic liquid crystals, 4’-n-pentyl-4-cyanobiphenyl (5CBs) on these patterned polyimide alignment layers was observed by optical polarized microscopy with crossed polarizer. The liquid crystal cells were composed of two patterned polyimide substrates with parallel groove direction and a 10 μm cell gap. The filling of the 5CBs was by capillary. Figure 3 shows the optical micrographs taken between crossed polarizers. As shown in Fig. 3(a-d), there is a uniform alignment of 5CBs on the patterned polyimide alignment layer even the width of the grooves is up to 2 µm. We suggest that the liquid crystal molecules tend to align homogenously along the groove direction. When we further increased the groove width to 10 µm, we found that the liquid crystal alignment is not so uniform and it shows several micro-domains (Fig. 3(e-f)).

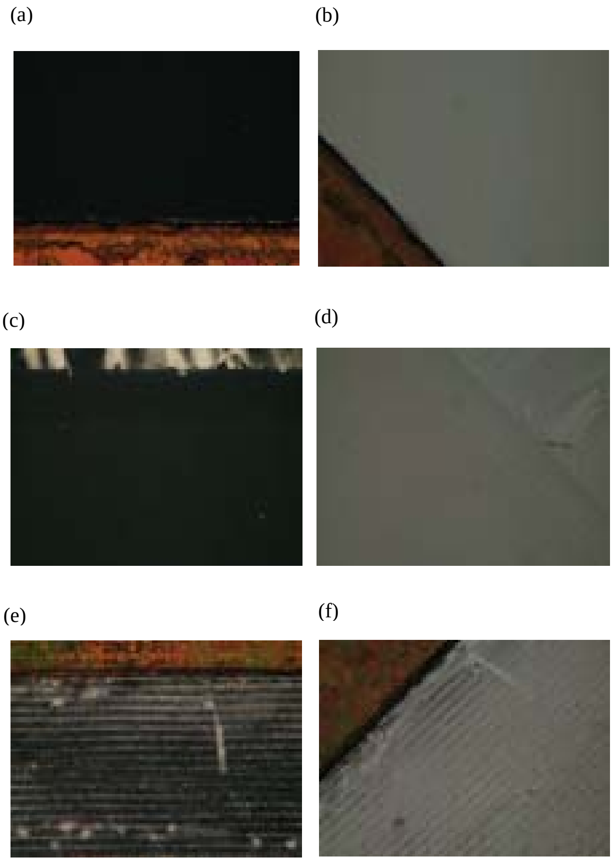

Fig. 3 The cross polarized optical microscopy of patterned polyimide liquid crystal cells. (a) the pattern line and space is 0.45 µm, and the pattern stripes are parallel to one of the polarizers (0 degree), (b) the pattern line and space is 0.45µm, and the cell is rotated for 45 degree, (c) the pattern line and space is 2 µm, and the pattern stripes are parallel to one of the polarizers (0 degree), (d) the pattern line and space is 2µm, and the cell is rotated for 45 degree, (e) the pattern line and space is 10 µm, and the pattern stripes are parallel to one of the polarizers (0 degree), (f) the pattern line and space is 10 µm, and the cell is rotated for 45 degree

We further measured the quality of anchoring of the patterned polyimide liquid crystal alignment layers fabricated by the soft embossing process. We assembled the cells with a cell gap of 10 µm and the alignment surfaces were perpendicular to each other: one surface with the patterned polyimide and a conventionally rubbed polyimide counter plate. The cell rotation method[8] was used to calculate the surface anchoring energies by detecting the twist angle angleψof liquid of liquid crystal molecules in the liquid crystal cell according to the following equation:

$$\mathbf{W}_{\phi} = \frac{2\mathbf{K}_{22}\phi}{\mathbf{d}\sin 2\phi} \qquad (1)$$

where d is the cell gap and K_{22} is the twist elastic constant of the liquid crystal molecule. This method was based on the twist effect of the liquid crystal molecules between two substrates in the cell, so the anchoring energy indicated the comprehensive effect of the alignment layer on the liquid crystal molecules. We found that the patterned polyimide alignment layers show higher anchoring energies (1.1×10^{-4} J/m^2) than those of the conventional rubbed polyimide surfaces (1.7×10^{-5} J/m^2 in this work). This is due to the deep groove depth of the patterned polyimide surfaces (380 nm) compared with the rubbed polyimide surfaces. (In this work, the rubbed polyimide groove width and depth is 30 nm and 4 nm, respectively.).

The soft embossing process is a novel approach for the fabrication of liquid crystal alignment layers. This process could produce large area reliable periodical microgrooves easily and rapidly on the polymer-coated substrates to induce the alignment of the liquid crystal molecules without the disadvantages of the rubbing process. It also has a great potential for the fabrication of the liquid crystal alignment layers with simple production procedure and high anchoring ability. Furthermore, this method is not only applicable to homogeneous alignment needed for the twisted nematic (TN) cells or in-plane switching (IPS) cells but also to the multi-domain vertical alignment (MVA) cells used in the wide viewing angle process. In the liquid crystal display industries, the conventional photolithography is applied to fabricate the bump structures needed for the MVA cells to enhance the viewing angle[9]. On the other hands, the soft embossing method provides an alternative way to fabricate the bump structures. In addition, we could design the pattern of the PDMS moulds to produce patterned liquid crystal orientations over small areas. One of the techniques for the improvements of viewing angles in flat panel displays is to divide each pixel into subpixels, where each subpixel is defined by different orientations of the liquid crystal.[10] Note that the soft embossing method is also capable of patterning the liquid crystal alignment layer even on curved surfaces. We expect that this simple and convenient method should simplify the production procedures and bring down the costs in the LCD industry.

5. Conclusion

In conclusion, the soft embossing process is not only preventing the disadvantages associated with the rubbing process but also providing extensive applications in the liquid crystal display technology. We expect that this simple and convenient method should simplify the production procedures and bring down the costs in the LCD industry.

6. References

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