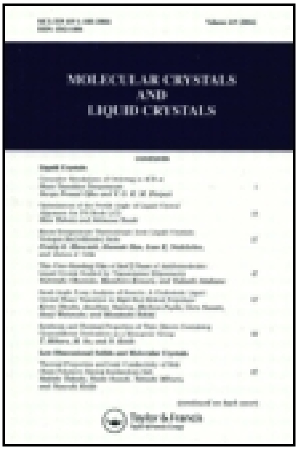

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Pretilt Control of a Nematic Liquid Crystal on a Selectively Patterned Homeotropic Layer Over a Homogeneous Layer

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We demonstrated the precise control of the pretilt of a nematic liquid crystal (NLC) on a selectively patterned homeotropic layer over a homogeneous alignment layer through a single photolithography process. Depending on the surface modulation parameters such as the periodicity and the relative dimension between two different patterns, the inhomogeneous substrate with periodic homeotropic and homogeneous patterns produces the pretilt angle of the NLC from zero to several tens degrees. Two different, homogeneous and homeotropic aligning forces for the NLC at the substrate are transferred into the bulk from the surface and result in an intermediate state of the pretilt depending on the surface modulation parameters.

Keywords: nematic liquid crystal; pretilt control; selective patterning; wide viewing

INTRODUCTION

Recently, various techniques for controlling the pretilt of a liquid crystal (LC) have been developed to tailor the electro-optic (EO) properties of the LC for device applications. For producing a wide range of the pretilt angles of the nematic LC (NLC), the oblique evaporation of silicon oxide [1,2], the microrubbing process by a metallic sphere [3], and the use of a micro-textured relief structure created using an atomic force microscope (AFM) [4,5] have been employed. Those methods are based on the manipulation of topographical surface

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interactions imposed on the LC molecules, and thus involve the alignment instability and the difficulty in the precise control of the pretilt.

In this paper, we demonstrate a new approach to the precise control of the pretilt of a NLC on a selectively patterned homeotropic layer over a homogeneous alignment layer through a single photolithography process. Depending on the periodicity and the relative dimension between two patterns, an alternating homeotropic-planar (AHP) alignment substrate having periodic, homeotropic and homogeneous patterns was found to produce the pretilt angle of the LC from zero to several tens degrees. Moreover, the pretilt of the NLC on the AHP alignment substrate was linearly proportional to the relative ratio between two different alignment areas. Numerical simulations were carried out within the continuum theory [6], containing the surface anchoring energy in the the Rapini-Papoular form [7], to describe such pretilt behavior of the NLC.

BASIC CONCEPT

The basic concept in our pretilt control scheme is to use two competing alignment forces, one of which gives the homogeneous alignment and the other the homeotropic alignment. For relatively large sizes of two types of patterns, there exist two different domains producing separately the homogeneous and homeotropic alignment. However, as the pattern sizes decrease, two alignment forces tend to compete to each other and result in an intermediate state having a certain pretilt angle in the bulk whereas they produce an inhomogeneous director field on the surface. This is because the resultant surface-induced inhomogeneity decays to become uniform within a distance of about $\lambda/2\pi$ from the surface [8,9]. Here, λ is the period of the surface pattern. In this study, the cell thickness is about 10 μm and the period λ is varied from 2 to 30 μm.

The magnitude of the pretilt angle can be varied with varying the relative dimension between two patterns. For example, when the homeotropic pattern is larger than the homogeneous pattern, a higher pretilt can be obtained. The other case is also valid since the relative anchoring energy governs primarily the magnitude of the pretilt.

EXPERIMENTS

The AHP substrate was prepared through a single photolithography process. Two commercial aligning agents, JALS-203 and JALS-146-R50 (Japan Synthetic Rubber Co.), were used as the homeotropic and homogeneous alignment layers, respectively. A homogeneous alignment layer was first spin-coated on an indium-tin-oxide coated glass substrate, and subsequently baked at 160°C for 2 hours. A positive photoresist AZ-1512 was then coated on the homogeneous alignment layer and the ultraviolet (UV) light was irradiated through a photomask. The UV irradiated area was removed after developing the photoresist. A homeotropic alignment layer was then spin-coated and baked at 160°C for 2 hours. The homeotropic layer only on the photoresist was selectively removed. As a final step, the patterned substrate was unidirectionally rubbed along the direction perpendicular to the striped patterns.

The period λ of the patterns on the AHP substrate was varied from 2 to 30 μm. One of the substrates used for the LC cell was the AHP substrate and the other was either a homeotropic substrate or a planar substrate for the LC alignment. The cell gap was maintained using glass spacers of 10 μm thick. A nematic LC of ZLI-2293 from Merck was filled into the cell by capillary action in the isotropic state. The LC cell was cooled down to room temperature at the rate of 3°C/min.

RESULTS AND DISCUSSION

We first examine the surface morphologies of homeotropic and homogeneous layers, and describe the LC alignment quality on the AHP substrate. The AFM image of the AHP substrate was shown in Figure 1.

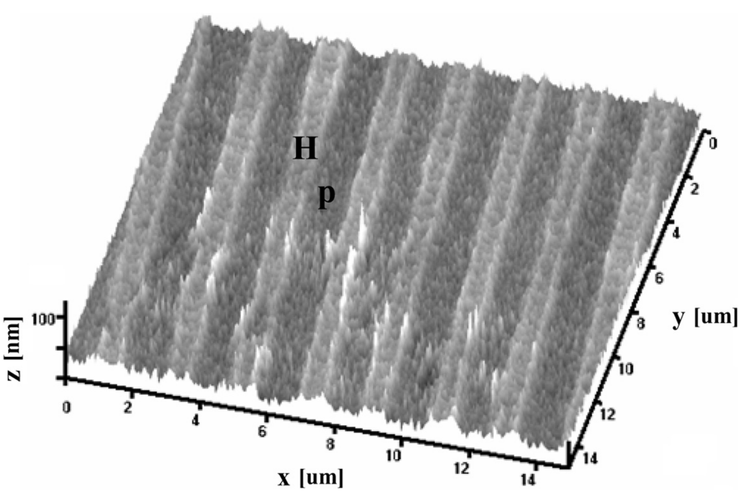

FIGURE 1 The AFM image showing the surface morphologies of the AHP substrate. The homeotropic patterns were produced on the underlying homogeneous layer.

The period of the patterns is 2 μm. The patterns of the homeotropic layer were well defined on the homogeneous layer. Using such AHP substrates as bottom substrates, two types of the LC cells, one of which has a homogeneous top substrate and the other has a homeotropic substrate, were fabricated to explore the aligning capability of the AHP substrate. Figure 2 shows microscopic textures of the LC, observed with a polarizing optical microscope (Optiphot2-Pol, Nikon) under crossed polarizers, and the corresponding LC configurations. Figure 2(a) represents the LC configuration using a top substrate with the planar alignment (PA), where the alternating hybrid-planar alignment (HA-PA) was produced. Figure 2(b) represents the LC configuration using a top substrate with a vertical alignment (VA), where the alternating hybrid-vertical alignment (HA-VA) was achieved.

We now describe how the period λ of the surface patterns on the AHP substrate influences the LC alignment and the pretilt when a homogeneous top substrate is used. Figure 3 shows microscopic textures of the LC on the AHP substrates with the period λ, varying from

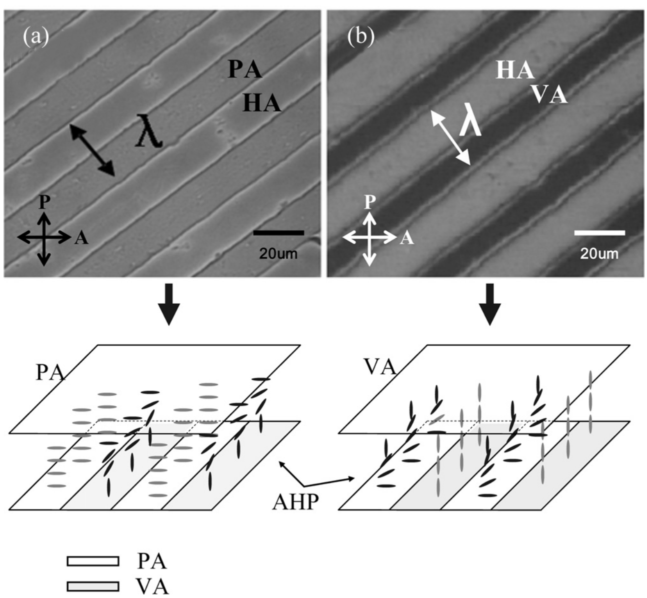

FIGURE 2 Microscopic textures of the LC on the AHP substrate with $\lambda = 30\,\mu m$, observed with a polarizing optical microscope under crossed polarizers, and the corresponding LC configurations: (a) an alternating hybrid-planar alignment (HA-PA) and (b) alternating hybrid-vertical alignment (HA-VA). The polarizer and the analyzer are represented by P and A.

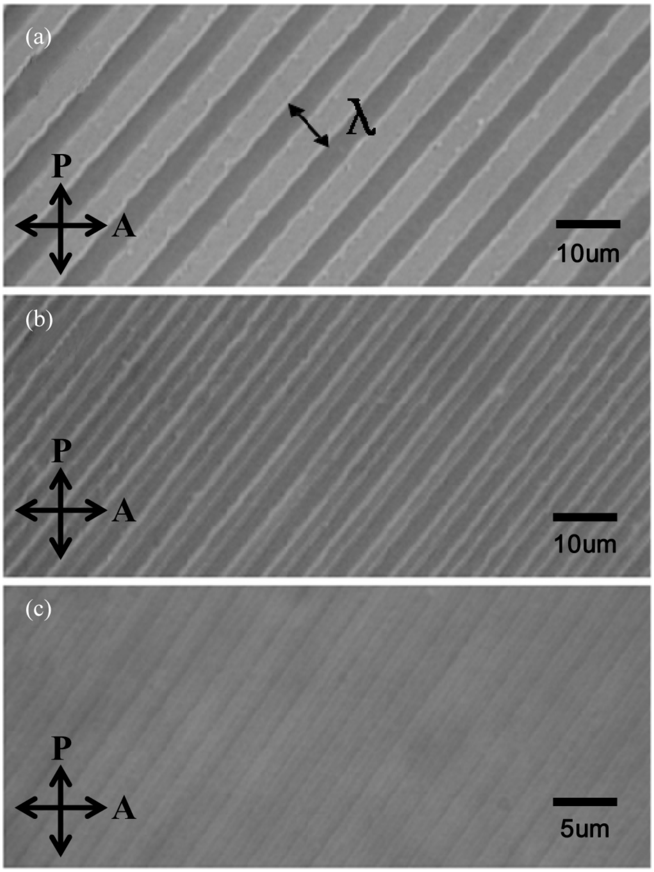

FIGURE 3 Microscopic textures of the LC on the AHP substrate with the period λ, varying from 2 to 10 μm when a homogeneous top substrate was used: (a) $\lambda = 10\,\mu m$, (b) $\lambda = 5\,\mu m$, and (c) $\lambda = 2\,\mu m$.

2 μm to 10 μm. Clearly, there exist two distinct domains of the homogeneous and homeotropic alignment for relatively large sizes of the patterns ($\lambda = 10\,\mu m$) as shown in Figures 3(a) and 3(b). Note that for the case of $\lambda = 5\,\mu m$, in addition to two well-defined boundaries, an additional intermediate region in each domain was developed as shown in Figure 3(b) due to two competing alignment forces. For small sizes of the patterns ($\lambda = 2\,\mu m$), the intermediate regions became to cover the whole sample and thus the average pretilt in the bulk appeared as shown in Figure 3(c). The uniform molecular tilt in the bulk was observed in our LC cell of 10 μm thick, fabricated with the

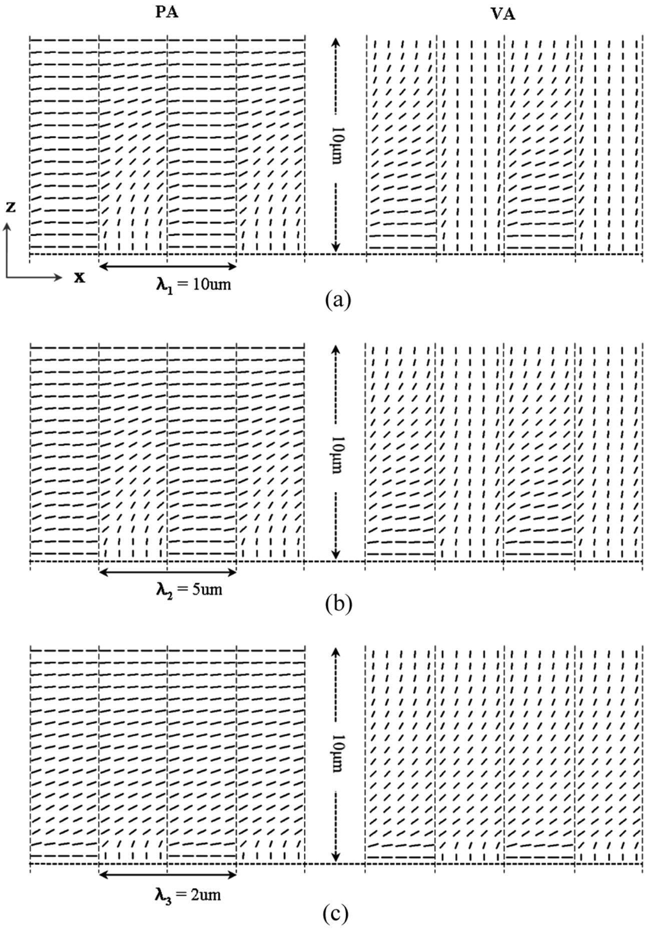

FIGURE 4 Simulated LC director patterns: (a) $\lambda_1 = 10\,\mu m$, (b) $\lambda_2 = 5\,\mu m$, and (c) $\lambda_3 = 2\,\mu m$.

AHP substrate with $\lambda = 2\,\mu m$. For comparison, numerical simulations based on the continuum theory [6], containing the surface anchoring energy in the Papini-Papoular form [7], were performed with literature values of the material parameters of the LC used [10], the elastic constants of $K_1 = 12.5 \times 10^{-12}$ N, $K_2 = 7.3 \times 10^{-12}$ N, and $K_3 = 17.9 \times 10^{-12}$ N. The surface anchoring energy used in simulation was $W = 1 \times 10^{-4} Jm^{-2}$ for both the homeotropic and homogeneous alignment [11]. The relaxation method [12] was used for the simulations. The first column in Figure 4 represents the LC configurations

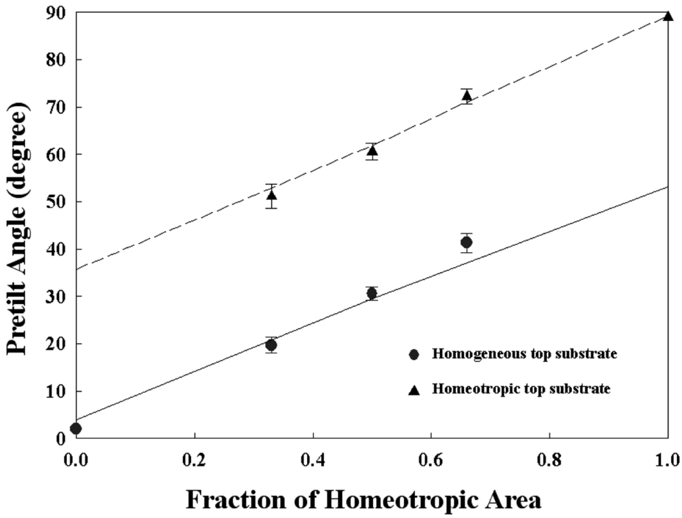

FIGURE 5 The pretilt angle of the NLC as a function of the fraction of the homeotropic area. Filled circles and filled triangles represent the experimental data for the homogeneous top substrate and those for the homeotropic top substrate, respectively. The solid and dashed lines denote the simulation results.

using top substrates with the PA and the second column those using top substrates with the VA. It is clear that for two cases of $\lambda = 10$ and $5\,\mu m$, there exist distinct boundaries between homogeneous and homeotropic domains irrespective of the LC alignment on the top substrate. For the case of $\lambda = 2\,\mu m$, however, the uniform molecular tilt in the bulk is observed as shown in Figure 4(c). The LC director patterns in the numerical simulations agree well with the experimental results.

We now describe the change in the pretilt of the LC as a function of the fraction of the homeotropic area on the AHP substrate for two different cases of a homogeneous top substrate and a homeotropic top substrate. Figure 5 shows almost a linear relationship between the pretilt angle and the homeotropic fraction on the AHP substrate. It is interesting to note that the pretilt angle varies from 0° to about 40° for the homogeneous top substrate (denoted by filled circles) while it varies from 90° to about 50° for the homeotropic top substrate (denoted by filled triangles). The above features are in good agreement with our simulation results for the homogeneous top substrate and the homeotropic top substrate, represented by a solid line and a dashed line, respectively. The homeotropic/homogeneous ratio was $1/2\,\mu m$, $1/1\,\mu m$, and $2/1\,\mu m$, giving the fraction of the homeotropic region as 0.33, 0.5 and 0.67, respectively.

CONCLUSION

We have demonstrated a new approach to the control of the LC pretilt on a selectively patterned homeotropic layer over a homogeneous layer. For a relatively small period of the alternating homeotropic and homogeneous patterns, the uniform pretilt of the NLC in the bulk was produced. The pretilt angle was varied as large as several tens degrees either from 0° (homogeneous alignment) or from 90° (homeotropic alignment) with adjusting the periodicity and the relative dimension between two alternating patterns. It was found that the LC pretilt is almost nearly proportional to the fraction of the homeotropic area on the AHP substrate. The selective patterning technology presented here would be highly applicable for producing various LC-based devices that require multi-pretilt structures of the LC alignment.

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