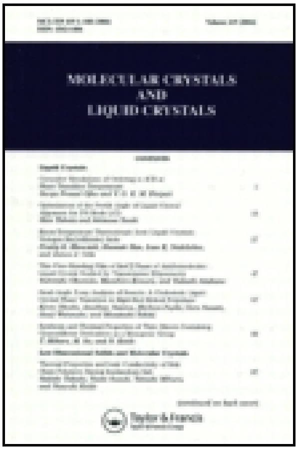

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Liquid-Crystal Alignment on Anisotropic Homeotropic-Planar Patterned Substrates

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The development of patterned surfaces for liquid crystal (LC) alignment has attracted much attention because it is applicable to bistable displays allowing the complete control of LC alignment. In this work we propose a method of preparing patterned substrates for LC alignment combining two surface treatments that lead to alternating homeotropic–planar alignment potentials. By superimposing two similar patterned substrates with crossed directions of treatment, a twisted nematic texture was observed in the regions of planar alignment in both surfaces, indicating the possibility of technological applications.

Keywords: anchoring energy; atomic-force microscopy; liquid crystal; surface treatment; textured substrates

INTRODUCTION

The optical and dielectric properties of liquid crystals (LC) have applications in electrooptical devices, such as LC displays. The operation of such devices depends on the delicate balance between bulk and surface interactions, which requires a good control of the LC alignment. It is generally accepted that two main factors contribute to the surface-induced LC alignment: i) the intermolecular interactions between the substrate and the LC molecules and the ii) the steric interactions caused by the substrate topography.

Although many surface treatments have been proposed to control LC alignment and a number of studies have been devoted to understanding the nature of surface interactions, the effective adopted orientation is hard to predict in some cases. Because of the complexity of the surface interactions, a phenomenological approach has been

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proposed where the surface interaction is described by an anisotropic surface energy Fs [1]. In the simplest expression for Fs, the substrate is characterized by an easy axis $\mathbf{n}_0$ and an anchoring strength w; $Fs = -(w/2)(\mathbf{n}.\mathbf{n}_0)^2$, where $\mathbf{n}$ represents the actual orientation of the LC molecules at the surface.

Recently, some studies have examined the alignment induced by inhomogeneous substrates [2–4], where the easy axis direction varies along the surface. Such patterned surfaces are applicable to bistable devices, allowing a complete control of the LC alignment. The alignment of LCs in a binary surface consisting of alternating homeotropic and random planar regions has been investigated, opening interesting possibilities of new applications in display and photonic technologies [4]. In the cited reference, the homeotropic alignment was achieved by self-assembled monolayers of octadecyltriethoxysilane (OTE). In the regions of the film exposed to UV radiation, the bond between the silane group and the alkyl chain is broken and the film can be partially removed, resulting in a random planar orientation [5].

In this article, we propose a method of creating a patterned surface with alternating homeotropic and homogeneous planar regions. The homogeneous planar LC alignment was achieved after UV radiation of the OTE film, drawn on unidirectional treated substrates. The innovation of this work, compared to the previous one [4], consists in obtaining strong homogeneous planar LC alignment in the irradiated areas, favoring the application in technological devices. The surface topography was examined by atomic-force microscopy (AFM). By optical observations it was possible to determine the LC alignment and to estimate the LC anchoring energies.

EXPERIMENTAL METHODS

Two types of surface treatments were applied to the glass plates to induce planar orientation: i) unidirectional rubbing of the glass with a velvet cloth and a solution of silica grains (approximately 250 nm in diameter) and ii) unidirectional deposition of a Teflon film. In both cases the purpose of the surface treatment is to develop an anisotropy in the substrate, creating an easy axis in the plane of the surface. The unidirectional deposition of Teflon film was achieved by gliding a Teflon bar on the heated glass plates. Three different heating temperatures were used: 130°C, 150°C, and 170°C. The topography of the substrates before OTE deposition was investigated by atomic-force microscopy using a Nanoscope IIIa (Digital Instruments) in contact mode, at 2.97 Hz scanning rate and 256×256 lines.

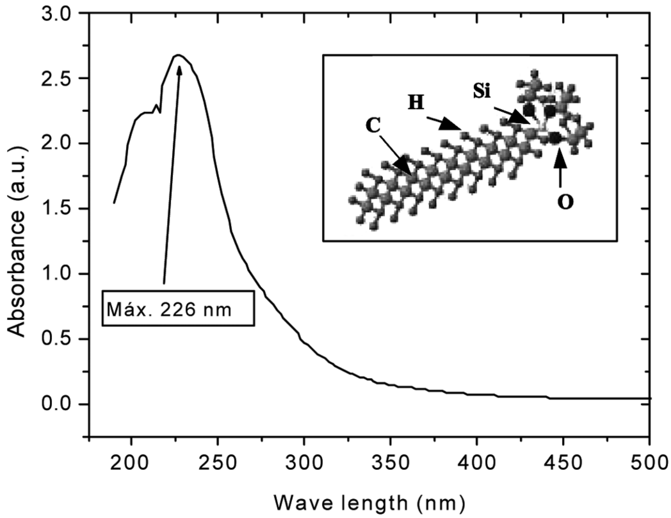
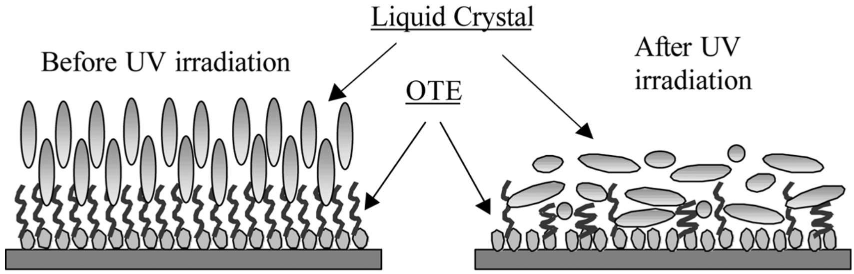


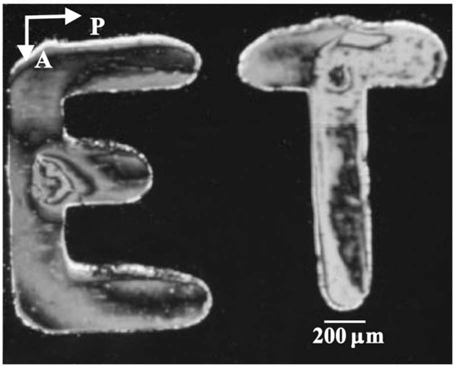
FIGURE 1 Molecular structure of the OTE molecule and the absorption spectrum of OTE films.

The homeotropic alignment was achieved by deposition of self-assembled monolayers of OTE [$CH_3(CH_2)_{17}Si(OC_2H_5)_3$] on glass plates that could be previously treated by one of the methods discussed previously. The structure of the OTE molecule and the absorption spectrum of an OTE film are shown in Fig. 1, where an absorption band is observed in the UV region, with a maximum of $\approx$226 nm. The OTE was acquired from the United Chemical Technologies, Inc., Bristol, PA, and the films were prepared by dipping the treated glass plates in a solution of toluene containing 5% in volume of OTE and using 0.5% of decylamine as catalyst. The glass plates were sonicated in the solution during 1 h, followed by a 30-min soak in the same solution. This procedure was obtained from Ref. [6], and this process allows the deposition of an OTE monolayer attached to the glass surface by the hydrophilic heads. The plates were then dried in an oven at 80°C during 15 min for complete solvent evaporation.

Some regions of the films were irradiated with a 1000-W Hg(Xe) arc lamp (Oriel corporation, 6293), and immediately after the irradiation the glass plates were rinsed with ethanol to remove residues. The UV lamp presents a wide emission spectrum with a well-pronounced peak around 245 nm, corresponding to 3.0% of the total lamp radiance. In the irradiation process, the sample was positioned at a distance of 20 cm from the collimating lens with effective incident power of



(a)



(b)

FIGURE 2 (a) Schematic representation of the LC alignment induced by an OTE self assembled monolayer, before and after UV exposure. (b) LC texture between crossed polarizers. The bright areas correspond to the irradiated areas in the film, leading to a random planar LC alignment. The dark regions correspond to homeotropic alignment.

$200\,mW/cm^2$ in the plane of the film. After some tests we observed that under such conditions 20 min. of light exposure was needed for complete OTE removal. Metal masks were used to protect regions of the film from being irradiated. The alignment of LC molecules in contact with self-assembled monolayers of OTE is shown schematically in Fig. 2a, in irradiated and nonirradiated regions. An example of the resulting LC alignment is shown in Fig. 2b, for a cell fabricated with two bare glass plates coated with OTE films, and in one of them some regions (identified by the ET letters) were previously exposed to UV light. The bright areas, seen between crossed polarizers, correspond to the regions where the OTE film was partially removed after exposure to UV light, leading to a random planar alignment.

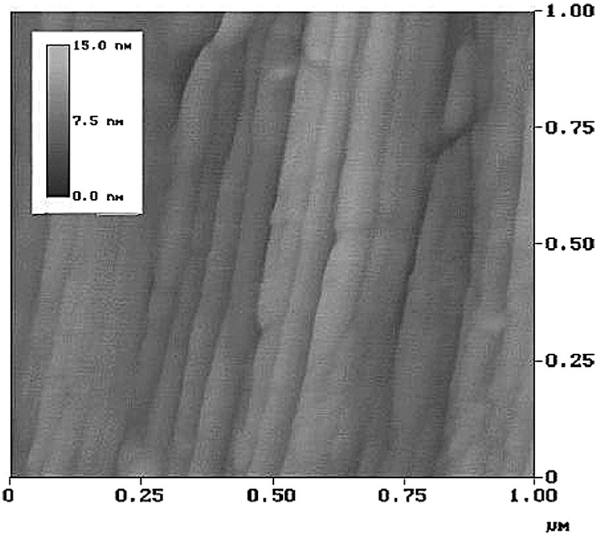
In the rubbed-glass substrate the OTE molecules self-assemble, as is shown in Fig. 2a, attached to the glass by the silane group. While in the glass coated with Teflon film, it is expected that the OTE molecules attach to the film by the hydrophobic tails. After the OTE deposition, some areas of the films were irradiated with UV light using a mask with equidistant stripes 100 mm wide, resulting in a periodic grating. The obtained patterned substrates, combining homeotropic and planar alignments, were used to fabricate cells (approximately 23 μm thick) that were filled with 5CB (Merck). The LC was inserted in the cells at room temperature. The LC texture images were captured with a digital camera coupled to a microscope.

RESULTS AND DISCUSSIONS

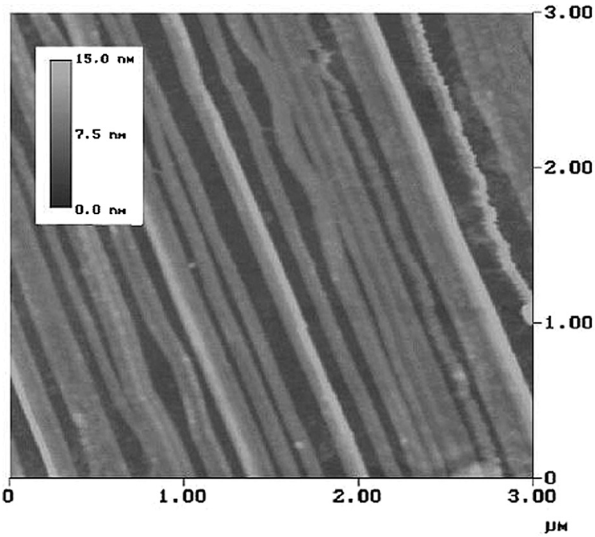
The AFM images of the substrates treated to induce planar alignment are shown in Fig. 3. It is observed that the unidirectional rubbing of the glass plates with silica grains generated superficial grooves, on average, along the rubbing direction (Fig. 3a), with a typical depth of about 2.0 nm and an average periodicity of 60 nm. The mean roughness of the surface is 1.2 nm. For the Teflon film, it was observed that the films drawn at 130°C and 150°C exhibit well-defined superficial grooves, along the gliding direction. The grooves are homogeneously distributed over the surface, with typical depth of 3–5 nm, approximately regularly spaced with periodicity about 200 nm. The mean roughness of the Teflon film is 2.0 nm. The topography of a Teflon film drawn at 150°C is shown in Fig. 3b. When the film is drawn on the glass plate at 170°C, no defined channels were observed at the surface. It is worth underlining that the topography of the Teflon film obtained for the temperatures investigated in this work is very reproducible.

When both treated substrates were coated with OTE and then used to build LC cells, a uniform homeotropic alignment could be observed under a polarizing microscope. It is particularly interesting in the case of the hydrophobic Teflon treatment, where we suggest that the homeotropic alignment can only be achieved with the formation of a bilayer structure. So, the hydrophobic tails are in contact with the LC.

The textured substrates, prepared as described in the previous section, were used as boundary surfaces to mount cells, setting the rubbing or the gliding directions perpendicular to each other at the two surfaces, as illustrated by the scheme in Fig. 4 for rubbed-glass surfaces with silica grains. Therefore, it was possible to get a set of three different combinations with respect to the surface alignment direction: planar–planar (P–P), planar–homeotropic (P–H), and



(a)



(b)

FIGURE 3 AFM images of substrates treated to induce planar alignment: (a) unidirectional rubbing of the glass surface and (b) Teflon film drawn at 150°C.

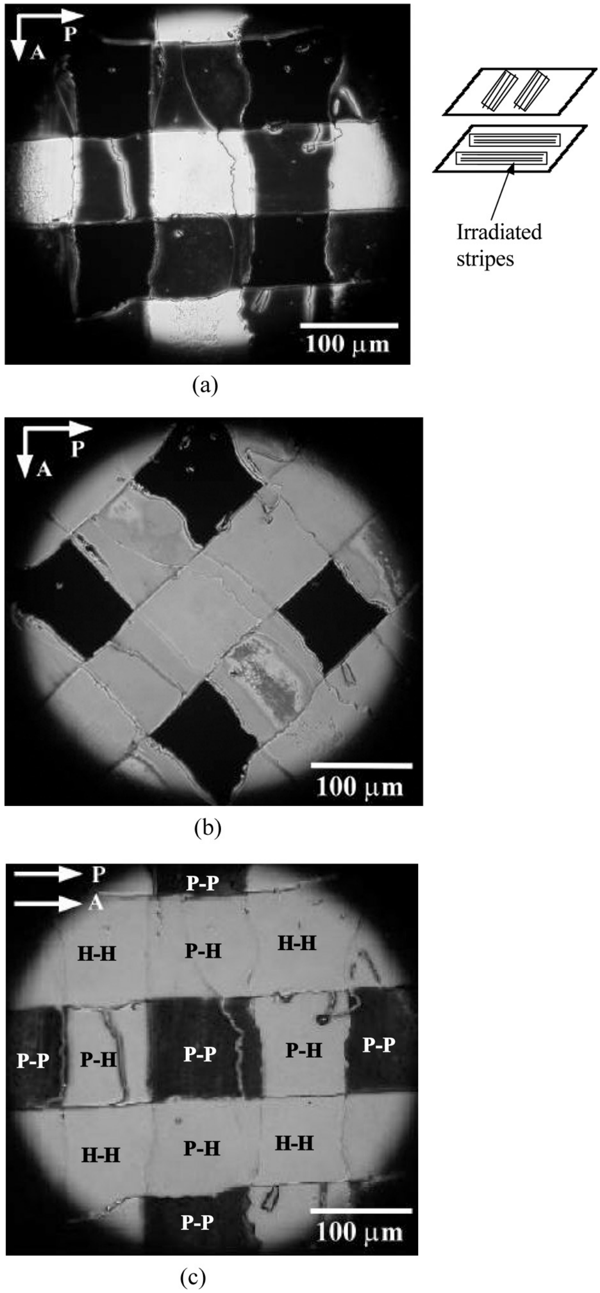


FIGURE 4 LC alignment areas after UV irradiation, induced by glass plates rubbed with silica grains before OTE film deposition. (a) Crossed polarizers, (b) the same of (a) with the sample rotated 45°, and (c) parallel polarizers.

homeotropic–homeotropic (H–H). The effective alignment induced by the LC was obtained from optical observations.

The texture of the cell observed between crossed polarizers is shown in Fig. 4a and 4b. When the cell is rotated, it is possible to identify the H-H regions that remain dark. The regions identified with P–H in Fig. 4c correspond to combination of planar and homeotropic alignments, with a bend distortion along the thickness of the sample.

In the regions where there is planar alignment at both surfaces, a 90° twist is expected for strong anchoring in both surfaces. These regions are identified in Fig. 4c as P–P, corresponding to dark regions when the polarizer and analyzer are set parallel to one of the planar aligning directions and bright regions between crossed polarizers independent of the sample position (Fig. 4a and b). The azimuthal anchoring energies of these substrates were estimated with the hybrid twisted-cell method, using a rubbed PVA (Polyvinyl Alcohol) film at the opposite side [7]. This planar alignment presents strong anchoring properties and the same order of magnitude as the rubbed PVA ($W = 1.5\times\ 10^{-5} J/m^2$), which favors the application in electrooptical devices.

Another important result from this work is the possibility of technology applications, where electrical contacts usually are applied using ITO-coated glass substrates. The surface rubbing of silica grains can remove the ITO (Indium Thin Oxide) film and to prejudice the display operation. In this case, the OTE deposition on the Teflon-treated surface can be a good alternative. It is important to remember that a tilt angle at the surface is required to avoid the degeneracy in the LC alignment from planar to the applied electric-field direction, but according to Ref. [8], it should be achievable by performing oblique irradiation of the OTE film. Therefore, by using masks to create periodic irradiated structures as shown in Fig. 4, the P–P regions will result in local active electrooptical devices for technological applications.

CONCLUSIONS

We have presented a method of preparing patterned substrates combining planar and homeotropic alignments that can be applied in the design of electrooptical devices. The surface treatments used to induce planar alignment result both in strong anchoring, with anchoring strength comparable to the PVA commonly used in the fabrication of displays. For applications in electrooptical devices the rubbing of the glass has the disadvantage of removing the ITO film necessary for electric contacts. The deposition of Teflon films is cleaner than the rubbing and appears as a good alternative for inducing planar alignment, with the advantage of good reproducibility. The Teflon-treated substrate has also been applied to orient lyotropic LC [9].

It was also observed that when the deposition temperature of the Teflon film was increased from 150°C to 170°C, the formation of channels was reduced on the film. This suggests that controlling the temperature deposition would result in surfaces of different topographies and different anchoring strengths. Another interesting observation was that the coating of OTE on the substrates (rubbed glass and Teflon film) resulted in an effective homeotropic alignment, despite the hydrophobic character of the Teflon film.

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