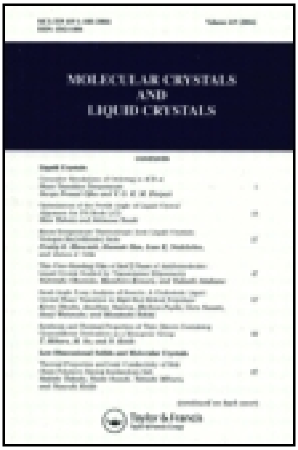
MOLECULAR CRYSTALS AND LIQUID CRYSTALS

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Temperature Dependence of the Buried Glass-Smectic Liquid Crystal Interface

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Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2001, Vol. 364, pp. 419-425
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Temperature Dependence of the Buried Glass-Smectic Liquid Crystal Interface

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We have studied the temperature behavior of the buried Glass-Liquid Crystal Interface for 8CB films of varying thickness deposited into a grated surface, using grazing incidence X-ray scattering. Our results indicate the presence of both a chevron structure and a structure similar to the helical twist-grain-boundary (TGB) phase the evolve as a function of temperature. We find that smectic order is preserved at temperatures well above the smectic A – nematic transition, especially in films of intermediate thickness. A depth analysis of the films indicates that the intensity of the scattering peak increases close near the center of the intermediate thickness films. This evolution is accompanied by a rotation of the smectic layers due to flow in the sample.

Keywords: interface structure; confinement; grazing incidence X-ray scattering; competing interactions; TGB structure; chevron structure

INTRODUCTION

A smectic liquid crystal film confined between two competing aligning surfaces can divide into regions or multilayers of varying smectic layer orientation[1-7]. This is a result of the requirement that the ordered layers rotate to satisfy the boundary conditions at each surface[5-7]. The size and number of these regions depend on the type of liquid crystal, the film thickness, the film's thermal history and the type of aligning surfaces used. The observed property variations depend on a number of parameters, including the nature of the confining surfaces, the interaction of these surfaces with the specific LC material, the topographical shape of the substrate, the size of the confined LC volume, and the presence of external fields[6].

This paper is concerned with the study of the alignment of liquid crystals on substrates made up of micrometer and submicrometer size channels. Specifically, we are concerned with deviations from the LC bulk structure at the LC-substrate interface and how these affect the sample overall. Work on well defined channel substrates enables us to measure cleanly the evolution of bulk film alignment within a cell as well as to measure the effects of confinement imposed by the channels[4,7,8]. In addition, we are able to directly measure the variations in confinement conditions as a function of cell thickness, which result in the onset of new molecular orientations[9,10]. By studying the structure of the cells as a function of depth, we are capable of measuring directly the effects of the onset of new orientations on the structure of the entire cell.

We present the results of a grazing incidence X-ray scattering study of 8CB smectic liquid crystal films deposited on substrates consisting of channels with depths ranging from 0.1 to 0.5 μm. In this study, the temperature was varied between room temperature up to 5° above the smectic A to nematic transition of 306.6°K. Our results indicate that the alignment close to the glass-liquid crystal interface persists to temperatures near 310°K for samples deposited on channels 0.5 μm deep. Shallow channels 0.1 μm deep induce a book-shelf geometry. Deeper channels give rise to distortions in the molecular structure which give rise to the presence of chevron structures in the cells, as well as structures resulting from the presence of dislocations in the cells, such as the (induced) twist-grain boundary (TGB) phases[6, 11,12]. Both structures evolve as a function of temperature in the films.

EXPERIMENTAL

The ability to observe, study and analyze the different regions within a layered LC film through a (solid) substrate is essential to study the properties of LC cells, such as those present in devices and device prototypes. To achieve this, we used 0.22 mm thick substrates and X-ray energies between 9.4 and 10 KeV. The penetration depth for this glass substrate at the above wavelengths is in the order

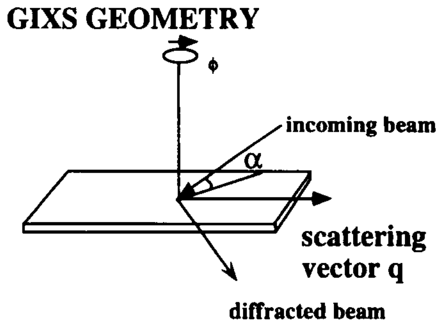

FIGURE 1. Geometry of the GIXS experiment used to study the structure of the LC interface through the substrate.

of 280 μm, or 0.28 mm. This ensures the ability to measure the glass-liquid crystal interfacial region with the glass substrates used.

We use the grazing incidence x-ray scattering technique (GIXS) to measure the structure of the interface. The geometry of the experiment is illustrated in Figure 1. The experiments were performed at the National Synchrotron Light Source in Brookhaven National Laboratories, beamlines X22B and X18A, using 1.308Å and 1.24Å X-rays, with a resolution of $2\times10^{-3}\ q_o$ ($q_o = 2\pi/\lambda$) with a divergence of 0.01°. The beam spot size was 2 mm^2. The incidence angle α was varied by changing the angle χ of the four circle diffractometer, using the relationship,

$$\sin\alpha = \sin\chi\sin\theta. \qquad (1)$$

Films of octylcyanobiphenyl (8CB) were deposited over channel gratings that were photolithographed on 0.22mm thick cover slip glass[11,12]. The sample size is varied systematically with the use of a high precision 0.5μl resolution pipette set to dispense 10μl of material at a time. The samples were placed with the substrate facing the beam, with the channel axis perpendicular to the beam on the four circle Huber diffractometer when $\phi = 0°$.

RESULTS AND DISCUSSION

We show the results of a series of X-ray scattering scans taken on a 70μm film deposited on a 5 μm deep channel grating using 1.24Å X-rays, in Figures 2 and 3. Figure 2 shows data taken at room temperature. Figure 3 shows data taken 1.7° above the smectic-nematic transition temperature. Each set of data were taken by varying the incidence angle as described above, between 0° and 0.5°. The highest angle of incidence corresponds to a depth of 20 μm. We note that the azimuthal angle ϕ varies as the incidence angle increases, indicating the presence of a TGB structure inside this sample. This structure persists above the smectic A – nematic phase transition, and is observable to temperatures as high as 312°K, 5.7° above the nematic-smectic A phase transition. A comparison between Figures 2 and 3 shows that the azimuthal angle varies as a function of temperature. Other samples deposited on 0.5 μm deep channels exhibit both a chevron structure as well as a TGB structure, which persists above the transition temperature.

In contrast, all samples deposited on shallow ($\leq$ 0.34 μm deep) channels exhibit a bookshelf geometry in the alignment of the smectic A layers. This is shown in Figure 4, which shows the results of a depth measurement on a 138 μm thick film deposited on 0.1 μm deep channels. These data sets were taken using 1.308Å X-rays. We note that the smectic A layers align parallel to the direction of the channels in these samples, indicating a weaker influence of the channels in sample alignment. The weaker influence results in a loss of alignment above the transition temperature. Samples deposited on gratings less than 0.34 μm deep do not exhibit persistence of liquid crystal alignment above approximately 0.2°K above the transition. We note that there is a small variation in the azimuthal orientation of the smectic layers.

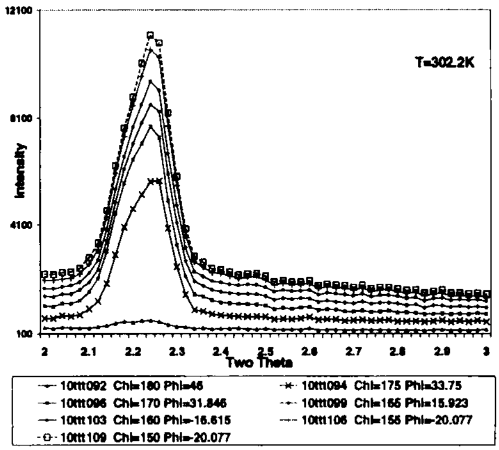

FIGURE 2. X-ray scattering scans taken as a function of depth on a 70 μm at T = 302K.

We have shown previously that alignment of the smectic A layers above the grating channels can in turn affect the alignment within the gratings[9,10]. The present results suggest that the interplay between channel depth and the ability to align the smectic A layers within the channels plays a role in the persistence of smectic ordering above the transition into a nematic phase. Deeper gratings, where the region within the channels exhibit a disordered or tilted phase in fact exhibit a suppression of the transition temperature for thick samples, such as those studied in this work[13]. We conclude that for the 8CB films in the thickness range studied, a channel depth in the order of 0.5 μm represents the optimal depth at which order can persist to temperatures well above the smectic A – nematic transition. Secondly, distortions in the size and orientation of the layers, which give rise to structures such as the chevron structure require the presence channels depths in the order of 0.5 μm or more exist in a film. As seen in Figure 4, this may not be the case with the TGB phases, which are predominantly a result of competing boundary conditions within the film. Work is in progress currently to compare our results numerically with models of smectic-A liquid crystal alignment in reduced geometries[14,15].

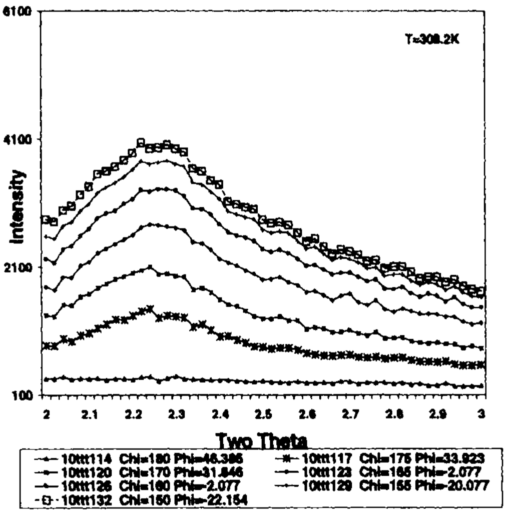

FIGURE 3. X-ray scattering scans taken as a function of depth on the same sample as Figure 2 at T = 308K.

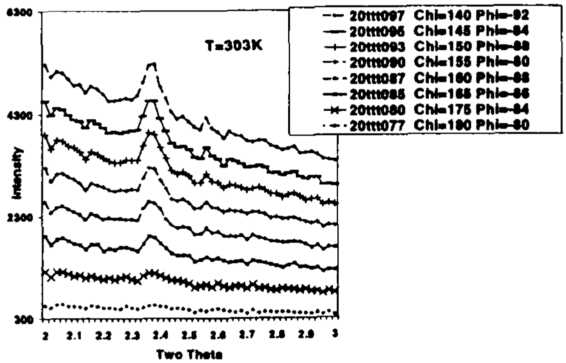

FIGURE 4. X-ray scattering scans as a function of depth for a 138 μm sample deposited on 0.1 μm channels. T = 303K, and the X-ray wavelength is 1.308Å.

ACKNOWLEDGEMENTS

This work was supported by NSF Grant No. ECS-95-30933. Work at the NSLS is partially supported by the U.S. Department of Energy.

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