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Quenched disorder of a nematic liquid crystal under a magnetic field

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ABSTRACT

We report measurements and theoretical predictions on the effect of an aligning magnetic field on the orientational disorder of a nematic liquid crystal in contact with isotropic solid substrates. Different types of substrates present a similar disorder and a similar dependency on the magnetic field amplitude, i.e. a decreasing of the angular distribution widths and spatial correlation lengths. Measurements are in qualitative agreement with a theory where the orientational disorder emerges from the competition between the aligning magnetic torque and the disorienting thermal fluctuations during the adsorption of the liquid crystal molecules on the substrate.

1. Introduction

Quenched disorder refers to a disorder which does not depend on time. It is ubiquitous in solid condensed matter as it is related to unavoidable defects in ordered materials. It is also observed with liquids when they are confined in porous systems such as gels with high surface/volume ratio. Structural disorder can indeed strongly affects both the wetting dynamics during the adsorption of a fluid [1] or the phase behavior of a Liquid Crystal (LC), which has been largely explored [2]. Experimentally it has been shown that the resulting Orientational Quenched Disorder (OQD) decreases the discontinuity of the nematic-isotropic transition [2] and can even promote glassy dynamics [3,4]. Such behaviors are typically explained with Ising models using random orienting fields accounting for the coupling between the LC orientation and the gel rough walls [5]. Controlling and characterizing such a strong OQD is not easy as the bulk disorder typically depends on the used disordered gel, its pores size and wall roughness. However, the effect and signature of OQD on substrates can be also directly observed in planar LC cells even if the disorder is much less pronounced. We have shown in Ref. [6] that a weaker OQD disorder was indeed present on the surface of a broad set of flat orienting layers around their main easy-axis. Similar signatures could be found on substrates having very different roughness and physico-chemical properties [6]. The easiness of OQD characterization in the simple geometry of planar cells has allowed us to propose a common origin for OQD. It should mainly result from the quenching of thermal director fluctuations on the solid confining walls via LC molecular adsorption [6].

In this paper, we show that surface OQD is also present when the aligning field originates from the bulk and is therefore free of any microscopic disturbances. We have measured the resulting OQD on two initially isotropic orienting layers but of very different origins and features. One is made of Indium Tin Oxide (ITO), the other of fluoro-poly(vinyl)-cinnamate polymer (PVCN-F) irradiated with unpolarized UV light. We have explored the OQD dependence on the amplitude of an applied magnetic field.

2. Methods and materials

2.1. Materials and substrates

We use the nematic liquid crystal 4-Cyano-4'-pentylbiphenyl (5CB) purchased from Synthon-Chemicals. Glass substrates with three different anchoring layers made of Glycerin, Indium Tin Oxide (ITO) or Poly(vinyl-4 fluorocinnamate) (PVCN-F) irradiated with non-polarized light are prepared. All these layers promote the same completely degenerate azimuthal anchoring for 5CB but they strongly differ by their physico-chemical properties. First, glycerin is a liquid while the two others are solid materials. Secondly ITO is a stiff inorganic layer with a flat surface while the polymer PVCN-F forms a soft layer with a rough surface.

The glycerin (anhydrous glycerin, Fluka) layer is prepared by spin coating it on a cleaned glass slide at 3000 rpm during 30 s. 5CB is

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then spin coated at 1000 rpm on the top of this thin layer for 20 s. In this way, a hybrid geometry is obtained due to the spontaneous homeotropic anchoring at the air/5CB interface. The thickness of liquid crystal layer is estimated by the measurement of birefringence optical retardation and is close to 1 μm. Standard Indium Tin Oxide (ITO) layers, of thickness about 100 nm and deposited on glass plates, are cleaned by a sequential application of acetone and ethanol, and rinsed with Millipore distilled water. The plates are then dried at 300 °C during 90 min in an oven. For the deposition of PVCN-F, glass plates are cleaned by ethanol and sulfuric acid for 10 s, rinsed with Millipore distilled water, and dried at 300 °C during 90 min in an oven. A PVCN-F polymer solution at 10g/l in dichloroethane is then spin-coated at 3000 rps during 10 s. Finally the film is baked for 80 min at 80 °C. The obtained layer is then irradiated with unpolarized UV light with intensity $I_{UV} \approx 5\text{mW/cm}^2$ during one minute. UV irradiation promotes cross-linking, renders such PVCN-F films stable against dissolution in 5CB and gives a zero pretilt angle [7].

Both ITO and PVCN-F anchoring plates are assembled with a homeotropic counter-plate. The latter is obtained by spin-coating a silane solution (0.1% v/v of 3-(trimethoxysilyl) propyldimethyl octadecyl ammonium chloride in methanol) on a glass slide and baking for 1 h at 110 °C [8].

Cells thicknesses are controlled with mylar film spacers in the 10μm–18μm range. The cells are then filled with 5CB heated in its isotropic phase at 60 °C in the presence of an external magnetic field parallel to their confining plates and subsequently cooled down to room temperature. After reaching the room temperature, the magnetic field is switched off and the nematic samples are optically analyzed under a polarizing microscope equipped with a $1024 \times 768\ \text{px}^2$ CCD camera.

2.2. Characterization of the disorder

In order to access the easy-axis disorder of a substrate we used a method developed by us and described in detail in Refs. [9,10]. Rotating simultaneously the crossed polarizers, we record the intensity and extract for each pixel of the sample image the angle $\varphi_m = \varphi_v/2$ corresponding to the orientation with minimum transmitted intensity. The spatial and time resolutions of each map measurement are respectively 0.22 μm and 333 ms. Statistical properties of the orientational disorder on each layer are extracted from the angular distribution and the spatial autocorrelation function of the director orientation maps φ_v. The angle φ_v would be exactly the surface director orientation φ_s in frozen bulk sample with an adiabatic transmission of the light [9]. In the general case, it is close to this value. The main statistical features of the surface director orientation φ_s and the easy axis φ_e azimuthal maps can nevertheless be reconstructed from φ_v-maps taking into account possible anchoring effects and bulk director twist distortions. Note finally that the measurement of φ_v is sensitive to the exposure time τ of the measurements (see below) due to the temporal bulk fluctuations which dynamically alter the light intensity.

In order to estimate the experimental resolution of the surface director angle φ_v we measured it on glycerin. The liquid character of such an alignment layer indeed prevents the establishment of quenched disorder and the surface director angular distribution only results from the measurement method which gives an upper estimate of the angular resolution of our approach.

The global orientation of 5CB on a glycerin layer is quite good at large scale after the spin coating deposition. Fig. 1 shows a typical angular map. Due to the planar degenerate anchoring on glycerin the 5CB however forms a multi-domains configuration (domains size of a few hundreds of microns) with quite a homogeneous planar orientation in the center of each domain. We measured the φ_v maps in these homogeneous areas. In Fig. 1a, such a map is shown. Note the appearance of a domain boundary in the right-up corner of the picture.The measured director indeed gradually changes its orientation on the scale of the picture. To remove these smooth long-wavelength contributions, we fit the map with a fourth order polynomial function and subtracted it from the map. The resulting map $\varphi_v'(x,y)$, which accounts only for the short-wavelength deviations is shown in Fig. 1b.

In Fig. 2, we show the histogram of the φ_v'-distribution with an exposure time $\tau = 20$s. The histogram is well fitted by a Gaussian distribution, whose width is $\sigma_{\varphi_v'} = 0.05°$. The dependence of the standard deviation $\sigma_{\varphi_v'}$ on τ is presented in Fig. 2b. It is due to the time fluctuations of the director which broaden the histogram. Increasing the exposure time results in a better average of bulk thermal fluctuations, a rapid convergence of φ_m on each pixel and a consequent decreasing of the distribution standard deviation. At larger exposure times, $\sigma_{\varphi_v'}$ converges typically to 0.04° which can be considered the angular resolution of the method.

3. Experimental results

We have performed measurements of the orientational disorder on the hybrid cells with ITO or PVCN-F layers. The cells were filled in isotropic phase and cooled down at room temperature in a strong

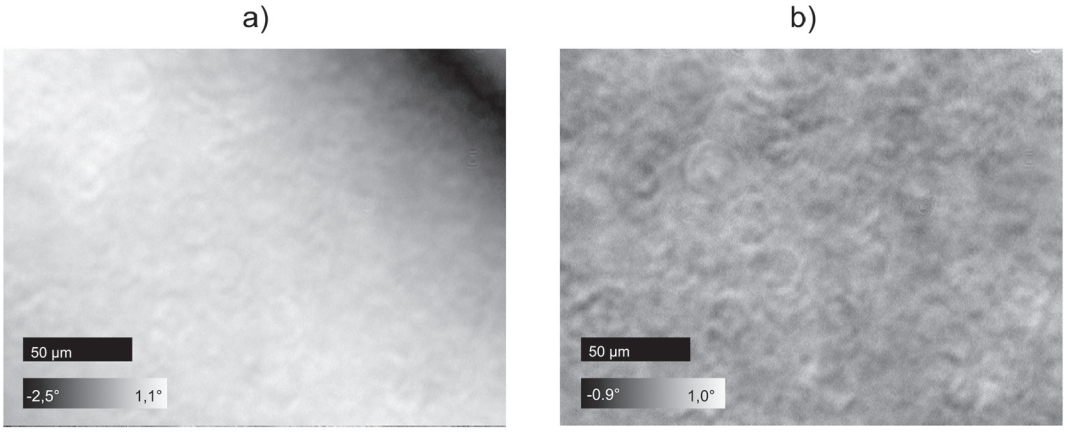

Fig. 1. a) Grayscale $\varphi_v(x,y)$-angular map on a Glycerin surface measured with the exposure $\tau = 5$s and b) Grayscale $\varphi_v'(x,y)$-angular map after removing the smooth spatial contribution due to the multi-domain structure of the surface.