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

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Version of record first published: 04 Oct 2006

To cite this article: Jeong-Seon Yu & Sin-Doo Lee (1998): Surface Potential Effect on the Growth Pattern of the Smectic A Phase of Liquid Crystals, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 316:1, 219-222

To link to this article: http://dx.doi.org/10.1080/10587259808044495

Mol. Cryst. Liq. Cryst., 1998, Vol. 316, pp. 219–222
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Surface Potential Effect on The Growth Pattern of The Smectic A Phase of Liquid Crystals

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A new approach to the pattern formation of the smectic A (Sm A) phase grown from the isotropic state is described in terms of the effective correlation of the molecules on a substrate with anisotropic surface interactions. Using the liquid crystal cells twisted by 90°, it is demonstrated that anisotropic surface interactions predominantly govern the pattern formation of the Sm A phase.

Keywords: pattern formation, smectic A, correlation function

INTRODUCTION

In liquid crystals (LCs), the pattern formation for the isotropic-smectic A (Sm A) phase transition is different from that for the isotropic-nematic transition since the layered structure is involved. It has been reported that some LC compounds grow in length with long filaments in the bulk near a direct isotropic-Sm A phase transition[1,2]. For this pattern forming process, some theories have been developed to describe the equilibrium shapes of Sm A nuclei grown from the isotropic phase[2]. However, the effect of anisotropic surface interactions on the growth pattern of the Sm A has not been explored so far.

In this work, a new approach to the pattern formation of the Sm A phase grown from the isotropic phase, based on the intermolecular inter-

actions in terms of the length scale related to the effective correlation, is presented together with the experimental results.

EXPERIMENTAL

The LC material studied was $C_9O\phi C{\equiv}CCOO\phi\phi COOC_3H_7$ where ϕ denotes the phenol. This material is chiral and undergoes the isotropic - Sm A phase transition at 70.8 °C. Two different, parallel and 90° twisted, cell geometries were used in our study. The LC was sandwiched between glass plates separated by spacer with 1.5 μm thickness. For the homogeneous alignment, the glass plates were coated with polyimide (AL3046), followed by unidirectional rubbing. For the temperature control, we used a hot stage (Mettler FP90) and the temperature fluctuations were 0.05 °C.

RESULTS AND DISCUSSION

We discuss the formalism of our approach to the pattern formation which contains the effect of anisotropic surface interactions. For the first-order phase transition such as the isotropic to the nematic or Sm A transition, the correlation length becomes finite while that for the second-order transition diverges[3].

Let us consider the total free energy F as a sum of the surface anchoring energy (F_1), the elastic energy[4], and the interactions between the molecules. For simplicity, $F_1 = W\sin^2(\phi - \phi_o)$ where ϕ_o denotes the easy axis and W the anchoring strength. In fact, the Sm A phase is found to grow along the easy axis of ϕ_o. For the 90° cell with two identical, top and bottom, substrates rubbed unidirectionally, the nucleation sites on the two substrates are equally probable.

Let us assume that the intermolecular interactions within the layer (intra-layer) and between the layers (inter-layers) of the Sm A phase are described in term of the correlation function as $F_3 = -J(T)S_{ij}(r_{ij})$ with

$J(T)$ the temperature-dependent coupling constant and r_{ij} the distance between the $i-$th and $j-$th molecules. Here, the correlation function $S_{ij}(r)$ is given by $e^{-\alpha r}$ for the intra-layer molecules and $r^{-\eta}$ for inter-layer molecules with α and η are the relevant exponents. For numerical simulations, the directions of the intra- and inter-layer molecules in the Sm A phase are denoted by x and y in a 2-dimensional map. As a consequence, $F_3(T,x,y) = -J(T)\sum_{x',y'} f(x'-x, y'-y)$, where the coupling constant $J(T) = a[(T_c - T)^{\beta} + \delta]$ and the function $f(x,y) = e^{-\alpha|x|}/(\mid y \mid + b)^{\eta}$. Here, T_c is the isotropic-Sm A transition temperature during cooling, and a, b, β, and δ are the constants.

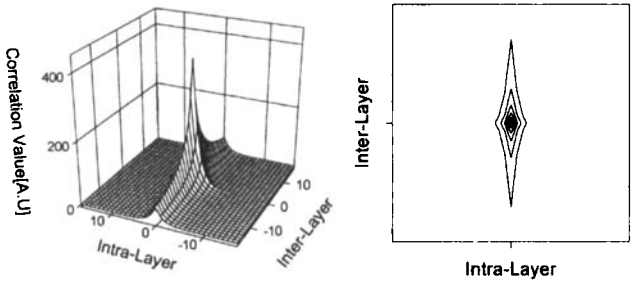

FIGURE 1. The inter- and intra-layer correlation.

Figure 1 shows the correlation function $f(x,y)$ as a function of x and y, which resembles the microscopic patterns observed near the isotropic-Sm A transition in our sample. Above T_c, all nucleation sites belong to the isotropic state while on approaching T_c, the sites of the Sm A phase grow in a random fashion. For the 90° twisted cell with different surface interactions, however, the sites on one of the two surfaces are dominant along the easy axis. This is clearly seen in the top photos of Figure 2. Our simulation results are presented in the bottom of Figure 2. Clearly,the numerical results share some common features with the microscopic patterns observed experimentally.

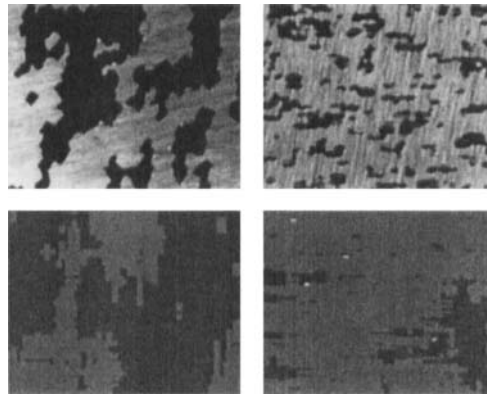

FIGURE 2. The effect of the surface potential (experimetal and simulation results). The top left for both surfaces rubbed strongly and the top right for one surface rubbed strongly and the other rubbed weakly. The bottom left for the relative surface strength of 1:1, and the bottom right for 1:3.

This work was supported in part by Ministry of Education of Korea through BSRI 97-2415.

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