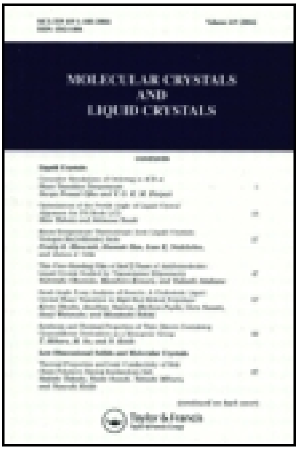

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Optical Control of the Alignment of a Liquid Crystal in the Smectic A Phase

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Optical Control of the Alignment of a Liquid Crystal in the Smectic A Phase

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The possibility to regulate the texture of a liquid crystal in the smectic A phase with the help of a photosensitive substrate was investigated. It is shown that the light-induced realignment of the director configuration can persist in a nematic-smectic A phase transition and cause rearrangement of the smectic layers within the illuminated area. The ratio between the azimuthal anchoring strengths on the photosensitive and rubbed polyimide plates is estimated.

Keywords: smectic liquid crystal; photoalignment

INTRODUCTION

In recent years, new techniques were developed to control surface alignment of liquid crystals with the help of polarized light. This method attracted considerable interest because it enables a number of important applications, such as high-density optical storage or the construction of sophisticated electrooptic devices.

To produce planarly aligned liquid crystal films by optical means, photosensitive polymer layers are used. One scheme is to illuminate the layer by polarized UV radiation, which either creates direction selective crosslinking or selectively breaks up polymer chains[1,2,3]. A different approach is to incorporate azo dyes into a polymer matrix[4,5]. Polarized light induces in this system an anisotropic orientational distribution of the dye molecules, the preferred axis being perpendicular to the electric vector of the optical field (Weigert effect[6]). In both cases, the anisotropy generated in the polymer network is associated with a surface anisotropy that is sufficient to align the liquid crystal molecules attached to the layer.

Until now, research has been focused on nematic liquid crystals. We began to investigate the question, whether it is possible to control the texture of smectic phases by similar optical methods. In the present paper, we report our first results in connection with this problem. We show that the light-induced realignment of the director configuration can, to some extent, persist in a nematic-smectic A phase transition and cause rearrangement of the smectic layers within the illuminated area. In particular, we demonstrate that periodic structures, generated by a polarization grating, can give rise to permanent layer undulations when the sample is cooled to the smectic A phase. From our measurements, we estimate the azimuthal anchoring strength on the photosensitive plate.

EXPERIMENTAL

We studied the liquid crystal octyl cyano biphenyl (8CB) purchased from BDH. The smectic A-nematic phase transition occurred at 32.2°C, while the clearing point was at 38.5°C. Wedge shaped cells were used, in which the gap varied from zero to 13μm. One plate was coated with a polyimide layer (Du Pont PI 2555) and rubbed unidirectionally to assure standard planar anchoring. The other plate was coated with a filtered and saturated solution of Disperse Orange 3 (Aldrich Chemicals) azo dye in a polyamic acid solution and subsequently heat treated for 2 hours to complete imidization. The cells were filled with the liquid crystal in the isotropic phase. Prior to illumination, in both nematic and smectic phases a homogenous planar alignment was formed, the director being parallel to the rubbing direction.

In the experiments, the liquid crystal samples were exposed to the 488nm line of an Ar laser at a temperature of 60°C. Two types of illumination were investigated. In the first setup, the effect of a single unfocused beam, with a power around 100mW was studied. To avoid the formation of domains with opposite sense of twist, the polarization direction was rotated by a small angle (5-10 degrees) with respect to the rubbing direction. The reorientation was detected with a He-Ne probe beam and also checked using a polarizing microscope. To obtain quantitative information on the process, we determined the polarizer and analyzer positions at which maximum extinction occurred.

In the second setup, the pump was spilt into two beams with equal power. The beams were orthogonally polarized and brought together at the sample under an angle of 2°. In this way a polarization grating was formed in which the polarization direction of the beam varied between 45 and -45 degrees with respect to the rubbing direction. The total power was again around 100mW and no focusing lens was used. The resulting periodic structure was tested again both by a He-Ne laser, via the measurement of the intensity of the diffraction peaks, and by direct observations under the microscope.

RESULTS

a. Uniform illumination

In the nematic phase irradiation by the Ar laser beam did not cause reorientation on the undoped, rubbed plate. The alignment angle on the dyed plate (i.e. the twist angle of the cell) as a function of irradiation time is shown in Fig.1 for different sample thicknesses. It is remarkable that there is no significant thickness dependence, even for short irradiation times, where the twist angle is far from saturation.

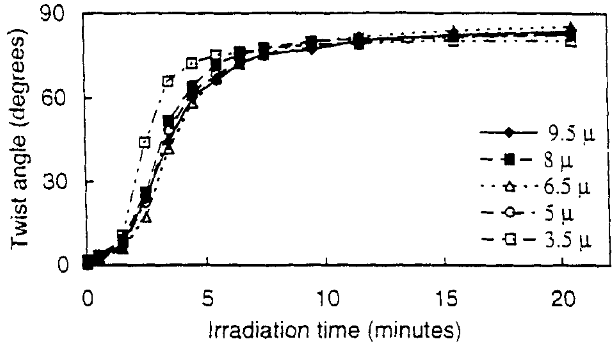

FIGURE 1 Twist angle as a function of irradiation time for different sample thicknesses. Measurements taken at 37.2 °C.

In the smectic phase, extinction could be achieved between crossed polarizers, indicating that there was no twist deformation in the sample. This observation is in contrast to those reported by Patel[7]. In the irradiated region, however, the director was rotated by a certain angle with respect to the rubbing direction, as demonstrated in the photographs shown in Fig.2. An example of the director angle in the smectic phase as a function of irradiation time is shown in Fig.3.

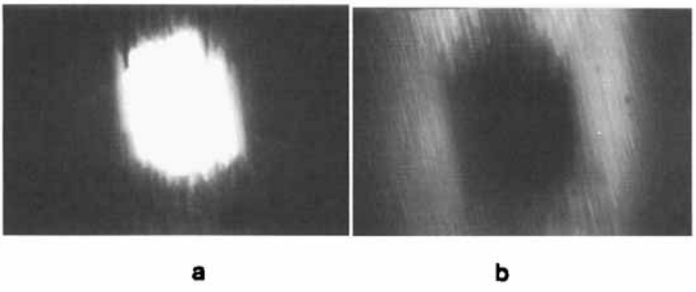

FIGURE 2 Polarizing microscope photographs of an irradiated spot at 31°C. Irradiation time 5 minutes. Polarizer and analyzer are crossed in both cases. In photo a; the rubbing direction is parallel to the polarizer while in b; the sample is rotated to obtain extinction.
(See Color Plate XVI at the back of this issue)

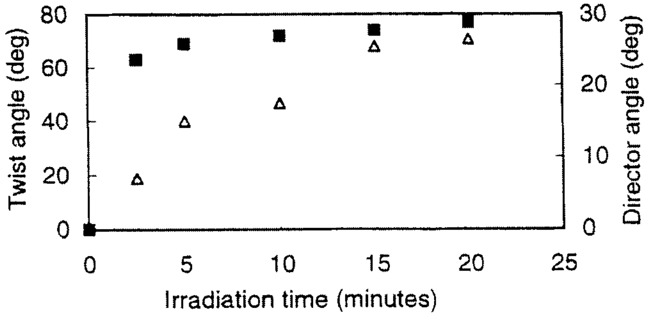

FIGURE 3 ■: Twist angle, measured at 37.2 °C. Δ: Director angle relative to the rubbing direction, measured at 31 °C. In a test measurement, where a twisted cell was constructed using two rubbed polyimide plates, the director angle in smectic A was 45 degrees.

b. Polarization grating

Two geometrical configurations were studied; in the first geometry the grating vector (i.e. the difference between the wave vectors of the two beams) was perpendicular, in the second one it was parallel to the rubbing direction. After irradiation, in the nematic phase, sharp diffraction spots were observed, confirming that periodic director deformation was created in the sample.

The diffraction efficiency of the first diffracted peak is shown in Fig.4, for both geometrical arrangements as a function of the temperature. Corresponding photographs, taken in the polarizing microscope are shown in Fig. 5. As it can be seen, the diffraction efficiency dropped abruptly at the nematic-smectic A phase transition. In the first geometry, however, it did not vanish completely, while in the second one it became undetectable. The same feature can also be seen from the photographs; in the second geometry there is no trace of the periodic structure in the smectic phase.

It should be noted that when the sample was re-heated to the nematic phase, a slow and incomplete recovery of the initial twisted structure was observed. In the present paper we do not deal with this aspect of the problem. Finally, we mention that very faint, but unambiguous diffraction spots were visible even in the isotropic phase; these originated most probably from the polyimide layer itself.

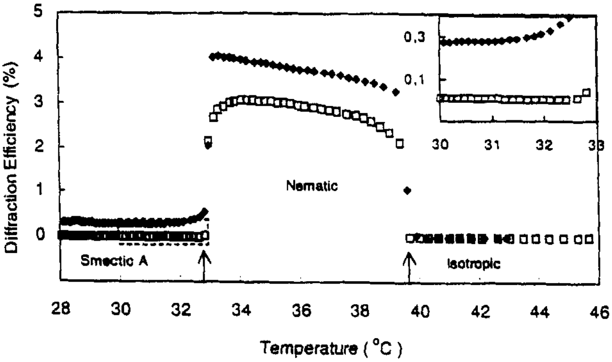

FIGURE 4 Diffraction efficiency of the first diffracted spot as a function of temperature. Irradiation time 10 minutes.

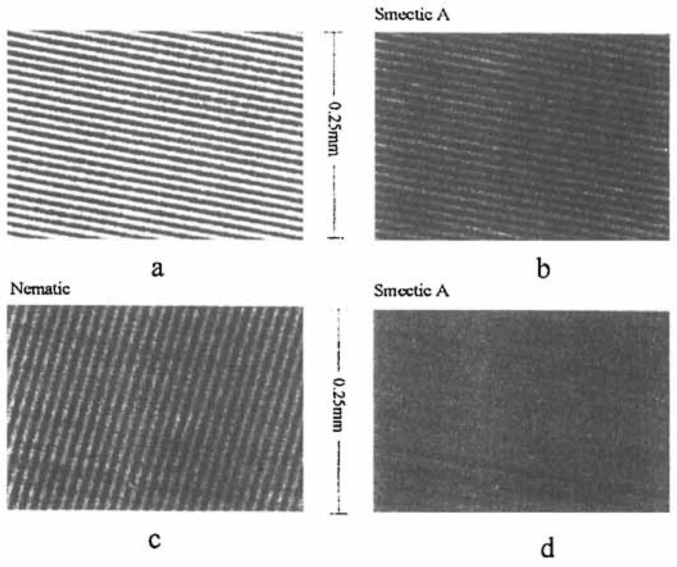

FIGURE 5 Periodic structures induced by the polarization grating. a and b: the grating vector perpendicular to rubbing direction at 37.2°C and 31°C respectively; c and d: the grating vector parallel to rubbing direction at 37.2°C and 31°C respectively.

INTERPRETATION

Although our investigations are in an initial stage, some conclusions about the azimuthal anchoring properties at the photosensitive plate can be already drawn from the observations.

The fact that in the nematic phase, for a fixed illumination time, the twist angle does not depend on the sample thickness -at least in the range investigated- indicates that the surface torque arising from the bulk twist deformation is negligible compared to the surface torque originating from the short-range interactions between the liquid crystal molecules and the substrate. In other words, the anchoring strength on the dyed plate is relatively strong, i.e. the extrapolation length cannot exceed significantly 1 μm, even in the unilluminated state.

Regarding the actual dependence of the twist angle on the irradiation time (Fig. 1), we propose that it is a result of the competition between two orienting mechanisms. The first one is the effect of the photoinduced anisotropy in the dyed polyimide layer, as described in the Introduction, The second one may originate from the so-called "surface memory effect" [8,9], which is also responsible for the initial orientation of the cell. There are evidences that even well above the clearing point, the liquid crystal molecules, adsorbed to the interface, exhibit a finite orientational order [9]. This monomolecular layer tends to stabilize the planar orientation, counteracting the first mechanism. The strength of the dye effect, however, increases continuously with irradiation time, causing a gradual rotation of the director on the photosensitive plate.

The observation of director reorientation at the nematic-smectic A phase transition may give an indication of the ratio of the azimuthal anchoring energies at the photosensitive and the rubbed plates. The measured director angle is equal to the rotation of the director on the rubbed plate. As there is no twist in the smectic A phase, the corresponding rotation on the dyed plate is equal to the difference between the twist angle in nematic and the director rotation at the rubbed plate. The rotations undergo in the opposite sense and we may assume that the ratio of their magnitude is inversely proportional to the ratio of the corresponding anchoring strengths. According to this idea, the increase of the director angle in the smectic A phase with irradiation time reflects the increasing azimuthal anchoring energy at the dyed plate. The ratio of the anchoring strengths, calculated on the basis of the data shown in Fig. 3, is shown in Fig. 6.

Finally, we explain the behavior of the periodic structures at the nematic-smectic A phase transition as follows. In the first geometry, the residual periodic structure, observed in the smectic phase correspond to layer undulations, in which only splay deformation is involved. It is well known that such undulations can be generated in smectic A phase using mechanical, thermal or optical methods [10,11]. In our case, undulations are "frozen in" upon cooling the sample from the nematic to the smectic phase and they are stabilized by surface reorientation. In the second geometry, the "frozen in" structure would imply bend deformation, which is inhibited because it is incompatible with the layered structure of the smectic A phase.

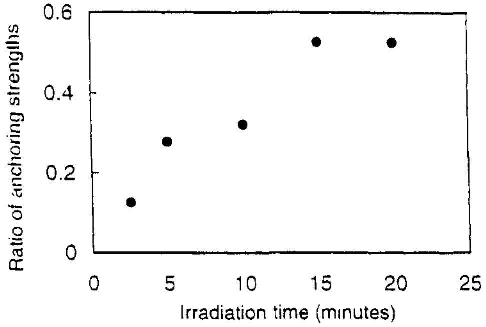

FIGURE 6 Ratio between the anchoring strength at the photosensitive and rubbed polyimide plates as a function of irradiation time.

Acknowledgements
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