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Optically induced periodic structures in smectic-C liquid crystals

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We explore periodic structures of smectic-C (SmC) liquid crystals, induced optically by a polarization grating. The studied cells contain a passive surface of rubbed polyimide and an active photosensitive substrate of azo-dye doped polyimide. In a nematic phase the director field can be periodic independent of the angle between the grating vector and the rubbing direction. In the SmA phase periodic structure can be induced only by layer undulations. The SmC behaves similarly to the nematic phase, but the director can rotate only on a cone, which results in a more complex geometry. The periodic pattern is superimposed with four different director and layer structures. In spite of the coexistence of the nonuniform structures the diffraction efficiency is better in the SmC, than in the nematic phase.

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INTRODUCTION

Basically there are two fundamentally different mechanisms of inducing easy axis for liquid crystals by optical means. One way is to create direction selective cross-linking or selectively breaking up photosensitive polymer chains [1]. Another approach is to incorporate azo dyes into a polymer matrix [2] and to induce an anisotropic orientational distribution of the dye molecules by polarized light. Research has mainly focused on nematic liquid crystals, but recently photoalignment of smectic-A phase was studied too. It was shown that a periodic structure could be written into the smectic-A phase, provided that the polarization grating is perpendicular to the rubbing direction [3].

In this paper we extended these studies to the smectic-C (SmC) phases, where the director is tilted with respect to the layer normal. In SmC liquid crystals the director can move on a cone given by the tilt angle $\theta$, therefore it is expected that this extra degree of freedom can facilitate the formation of a periodic structure. We studied 4-n-hexyloxyphenyl-4'-n-decyloxybenzoate having the phase sequence

$$Cr60^\circ C(44^\circ CSmB)SmC78^\circ CSmA82^\circ CN90.6^\circ CI,$$

and compared the structures formed in the different phases under different geometries.

EXPERIMENTAL ASPECTS

We made cells containing a passive surface of rubbed polyimide and an active photosensitive substrate of azo-dye (Disperse Orange 3) doped polyamide. For irradiation, the 488 nm line of an argon laser was used. The pump beam was split into two parts with equal power. The beams were orthogonally polarized and brought together at the sample under an angle of $\alpha^\circ$, the illumination was carried out at 94$^\circ$C in the isotropic phase of the liquid crystal. 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 around 200 mW and no focusing lens was used. The setup is shown in Fig. 1. The resulting periodic structures were observed under a polarizing microscope and probed with a He-Ne laser by measuring the intensity of the diffracted light peaks.

The textures, formed in the liquid-crystal phases after the optical alignment, depend on the angle $\alpha$ between the grating vector and the rubbing direction. We studied the two extreme conditions, i.e., when $\alpha = 0$ and $\alpha = 90^\circ$. The textures and the corresponding director structures are summarized in Fig. 2 and Fig. 3 for $\alpha = 0$ and $\alpha = 90^\circ$, respectively.

In all phases and in both geometries the periodicity (25.6 $\mu$m) is determined by the irradiation conditions. Textures of the nematic and smectic-A phases are similar to those observed previously [3]. In the nematic phase, periodic patterns can be written in both geometries, but the quality of the patterns is generally better for $\alpha = 0$. In the active surface the extinction direction alternates by $\delta_n = \pm 15^\circ$ with respect to the rubbing direction. In the smectic-A phase a periodic pattern is possible only when the grating vector is perpendicular to the rubbing direction ($\alpha = 90^\circ$) [3]. In this case the layers become undulated resulting in a modulation of the optical axis with respect to the rubbing direction by $\delta_{S_A} = \pm 5^\circ$.

In the smectic-C phase fairly regular stripe patterns appear in both geometrical arrangements. The temperature dependence of the modulation angle $\delta_{SC}(T)$ is shown in Fig. 4. The behavior strongly resembles the typical temperature dependence of the director tilt angle $\theta$ in the vicinity of the Sm-A-Sm-C transition. The temperature dependence of the modulation angle is basically the same in both geometries, but the measurement error is much larger for the $\alpha = 90^\circ$ case. In addition to the stripes, zigzag defects appear, too (see Fig. 2). Under uncrossed polarizer-analyzer conditions greenish and reddish domains coexist. They are typically not separated by the zigzag defects. The colors of the domains show the experimental setup to make polarization grating.