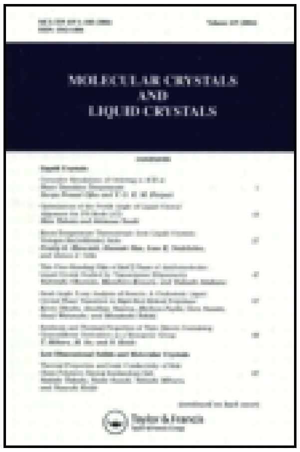

Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl17

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Version of record first published: 20 Apr 2011.

To cite this article: Gerd Hauck & Hans Dieter Koswig (1990): Alignment of Nematic and Smectic Liquid Crystals, Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics, 179:1, 435-444

To link to this article: http://dx.doi.org/10.1080/00268949008055387

Mol. Cryst. Liq. Cryst., 1990, Vol. 179, pp. 435–444
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Printed in the United States of America

ALIGNMENT OF NEMATIC AND SMECTIC LIQUID CRYSTALS

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Abstract Some remarks on the alignment of nematics are given. The orientation of smectic A-liquid crystals at different surface pretilt angles and for variable layer thickness has been studied.

INTRODUCTION

The alignment of liquid crystal (LC) phases is a fundamental question for well defined physical investigations and for applications in electro-optical devices. Although many results in this field has been published during the last years[1] and the alignment technology for nematic LCs is well established in the production of LC-devices many questions are open and arise again at the smectic phases. We present some new results on the alignment of nematic and smectic LCs which show that it is necessary to include into considerations of this problem more detailed informations on the nature of the LC-molecules, on the structure and behaviour of the orientational layers and on the interaction between the LC-molecules and the material of the orientational layers.

NEMATIC PHASE

The oblique vacuum deposition of anorganic materials and the coating with silan or polymer compounds with an additional rubbing or streching procedure are the well accepted alignment techniques for nematics. These techniques produce a homogeneous alignment for planar, tilted and homeotropic orientation. The results depend on the materials, not only on the material of the orientational layer, but also on the properties of the LC-molecules. At the time, the oblique deposition technique is the only one which is able to realize every desired tilted structure. The results of different alignment techniques has been often interpreted by a wavy surface topography with a preference of a special direction determined by the alignment process. Depending on the special structure of the grooves, the anisotropic nematic fluid assumes an oriented state of lowest free elastic energy, without any elastic strains inside. This means, the director arrangement of the nematic system is determined by the specific surface topography. The geometrical size of the LC-molecules is small in comparison with the dimensions of the grooves at the surface. An average process takes place which produces, through the region determined by the penetration length[2], an uniform orientation in the bulk of the nematic phase .

For polar cyano-biphenyl compounds the oblique SiO_x-deposition[3] gives, dependent on the deposition angle Θ, a planar molecular arrangement or a tilted one with a tilt angle φ (measured from the projection of the deposition direction on the substrate) of about 20 - 40°, as shown in Figure 1 for the mixture E5 (BDH)[4]. With a double oblique deposition it is possible to induce low tilt angles[5]. High tilt or homeotropic orientation are not possible in this way. However, for oblique deposition of Al_2O_3 we got high tilted and homeotropically oriented LC-layers (Figure 1)[6]. The different orientational behaviour has been normally

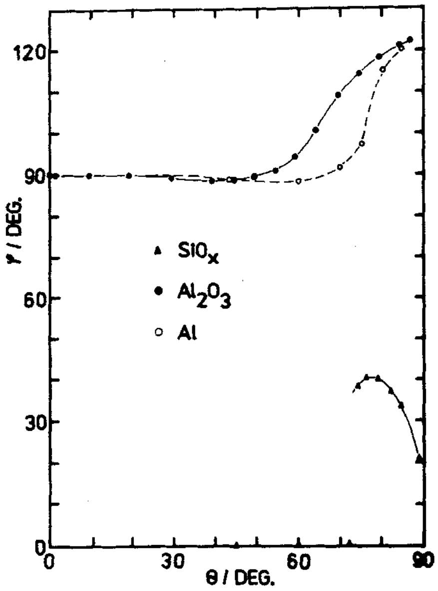

FIGURE 1. Tilt angle on obliquely deposited layers.

related to the differences in the surface topography: grooved surfaces or elongated structures for the amorphous SiO and a microcrystalline structure for Al_2O_3, typical also for other strong ionic compounds.

However, the oblique deposition of metallic Al produces a surface structure which is similar to that of SiO_x[7]. But the oxide at the surface of a very thin Al-layer (thickness 3 nm) induce also a high tilt arrangement for the same polar nematic compound (Figure 1). Therefore, it is not only the grooved surface that determines the orientation of the nematic compound. We have to assume an additional interaction process probably connected with the polar CN-groups of the nematic molecules and the specific molecular arrangement of the orientational layer.

Systematic investigations show that the alignment properties will be determined, at first, locally by the specific interaction mechanism between the LC-molecules and the surface material. The wavy surface structure stabilize or destabilize this local orientation by the anisotropic elastic strains. The bulk orientation results from the averaging of the local order. This effect will be strong in polar compounds and for strong interactions to the material of the orientational layer. Further work is in progess to get better insight in the stabilizing/destabilizing influence of the grooved surface.

Our results has been confirmed by investigations using Langmuir-films for the alignment[4-9]. These films show a high order in the molecular arrangement of amphiphilic polymers. No special grooved surfaces have to be used to explain the orienting action of such films. It results only from the distinguished position of special molecular groups in the film through a distinguished direction for the interaction with the LC-molecule.

SMECTIC PHASES

The orientational behaviour of smectic liquid crystals is much more complicated, although, in principle, all alignment techniques from the nematics can be used. These difficulties arise from the layer structure of smectic phases and the specific molecular arrangement inside the layer. In layer systems as smectic A, the molecular orientation is perpendicular to the layer and, therefore, the position of the layer is given by the molecular orientation. In tilted phases, such as smectic C, the orientation have to be discussed seperately for the molecules and for the layer.

We restrict our consideration to smectic A. A planar A-phase-configuration is given by a planar orientation of molecules and a perpendicular order of the layers to the substrate. The formation of the smectic A phase will be realized by decreasing the temperature from the nematic state through the transition point. Vacuum deposition techniques have to be used to get exact planar texture in the nematic case. We investigated the cooling process by observation of the texture and by the measurement of the mean tilt angle $\bar{\varphi}$ of the molecules to the substrate. The LC-compounds with nematic and smectic A phases used were:

K24:
4-cyano-4'-n-octylbiphenyl (BDH)
NPOOB:
4-nitrophenyl 4'-n-octyloxybenzoate (MLU Halle)
HOPDOB:
4-n-hexyloxyphenyl 4'-n-decyloxybenzoate (MLU Halle)

At exact planar orientation we observed some degrees below the transition point a change from a homogeneous planar texture of the A-phase to a planar one with parallel disclination lines, shown in Figure 2. These lines separate planar oriented areas which exitation positions between crossed polarizers differ by about 2°. This texture is connected with the evolution of cyclides. These areas could be observed after increasing the temperature above the transition point also in the nematic phase, without a change of the planar arrangement. This behaviour was independent of the LC-layer thickness in the range of d = 1 - 20 μm. The distance between the disclination lines increases with the increase of thickness.

This picture is changed drastically if we investigate structures with surface tilt. The results can be summarized:

- The change of tilt angle at the transition from the nematic to the smectic A phase is discontinuous.
- In the smectic A phase the tilt angle is smaller than in the nematic phase.
- The decrease of the tilt angle at the transition depends on the value of tilt in the nematic phase - for lower values the decrease is higher.
- The decrease of tilt at the transition depends on the molecular structure.
- The texture in the smectic A phase shows a thickness dependence.

Starting with a nematic structure with low tilt we

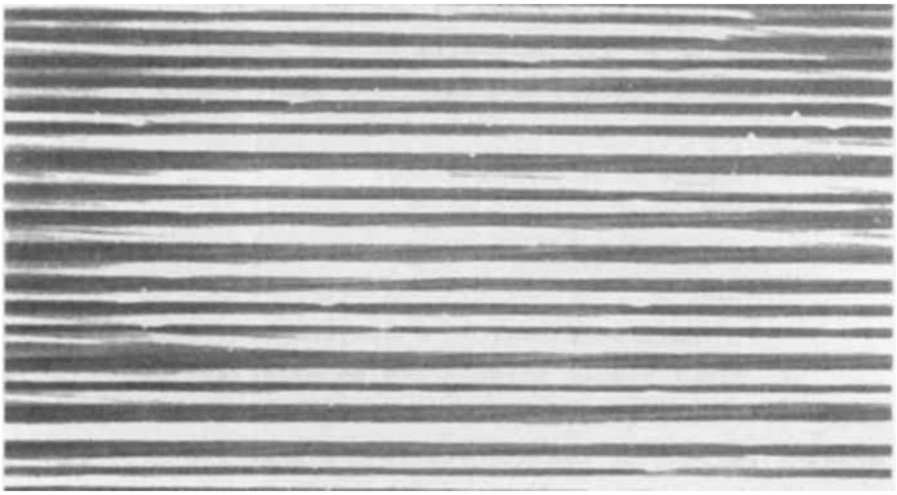

FIGURE 2. Line pattern in K24 at $\overline{\varphi} = 0''$.

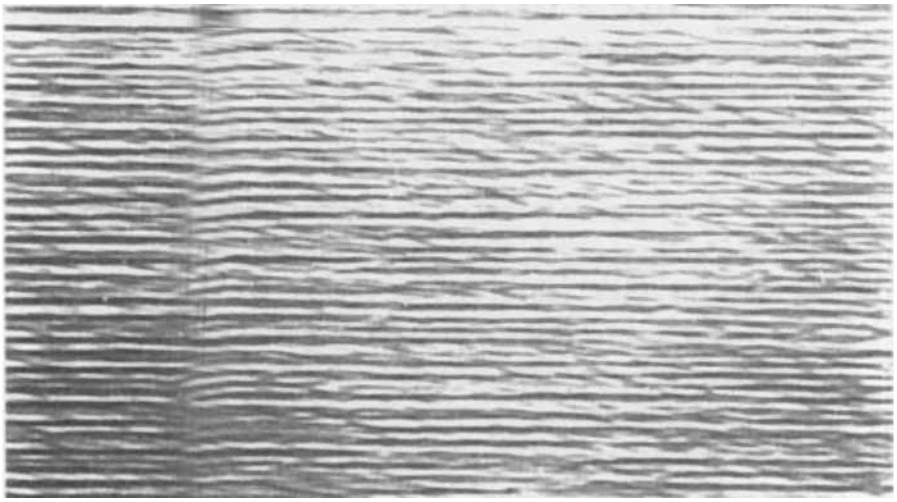

FIGURE 3. Distorted lines in K24 at $\overline{\varphi} = 2''$.

observed some degrees below the transition point again the formation of a regular pattern. But now, the disclination lines are disturbed and their density is higher (Figure 3).

FIGURE 4. Homogeneous pattern at $\overline{\varphi} = 24°$ and $d = 4\ \mu m$.

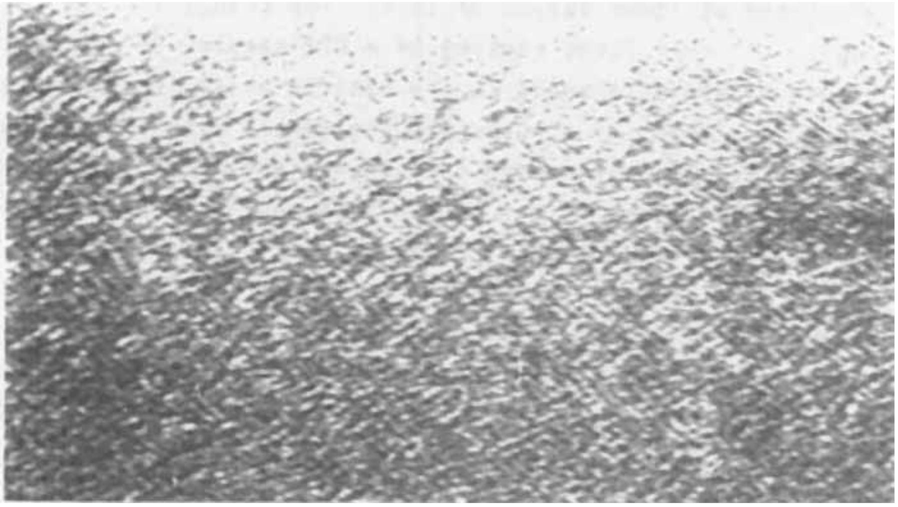

FIGURE 5. Texture in K24 at $\overline{\varphi} = 24°$ and $d = 15\ \mu m$.

For higher tilt angles the density of defects shows a further increase. Moreover, the formation of texture becomes dependent on the thickness: At small layer thickness no defined texture is visible (Figure 4) and at a higher one a chevron-like pattern could be observed (Figure 5). This behaviour is also shown in Table 1.

TABLE 1. Textures for different tilt angles and layer thickness.

d (μm)	$\bar{\varphi} < 15°$	$\bar{\varphi} > 20°$
< 5	lines	without
> 7	lines	chevron-like

A comparison between the tilt angles at room temperature is given for E5 (nematic) and for K24 (smectic A) in Table 2. The orientational layers for corresponding samples has been prepared in the same manner. Both compounds are cyano-biphenyls, similar each other. The smectic A phase has everywhere the smaller tilt, and this decrease is more developed at lower values of tilt. The change of the tilt angle at the first cooling of a K24-sample is shown in Figure 6. The tilt angle in the nematic phase is in the same range as that of a corresponding sample with E5 at room temperature. By increasing the temperature above the transition point again, we got higher tilt angles in the smectic and, also, in the nematic phase. In the nematic phase we could now observe the texture described for the smectic case, but with a somewhat smaller contrast, up to the transition to the isotropic phase. The jump of tilt at the transition depends on the LC-compound. In HOPDOB it is about 8°.

TABLE 2. Tilt angles for E5 (nematic) and K24 (smectic) at room temperature.

compound	tilt angles (deg.)				
E5	8	15	21	27	31
K24	2	5	12	24	29

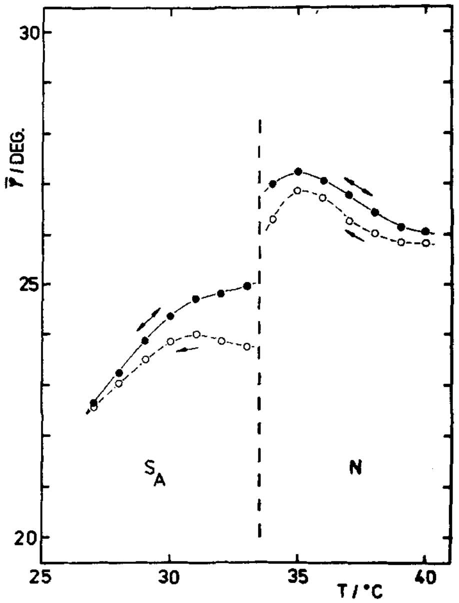

FIGURE 6. Mean tilt angle versus temperature for K24.

From the experimental observations we must conclude that in tilted smectic A phases irreversible rearrangements of the molecules have taken place at the surface which can not been destroyed in the nematic phase. This gives a change of the local orientation, and, as a consequence of the average process, we can observe a higher tilt angle also in the nematic phase. From this model we have to accept that the irreversible rearrangement takes place within the penetration length of the smectic A phase which is greater than that in the nematic phase[2]. The main part of this rearrangement has to be located immediately in the surface region because the textures exist also in the nematic phase.

The change of the tilt in smectic A phases and the thickness dependence of the texture yield further consequences in our understanding of alignment. If we assume strong anchoring condition for the molecules at the surface, we have to accept a splay deformation of the smectic layer in the surface region to realize a smaller mean tilt angle.

This is possible only above a critical thickness. Below this thickness the elastic energy of the smectic A layer prevents a splay deformation. A tilted layer structure results, as can be seen in the disclination-free homogeneous texture. Above the critical thickness the splay deformation in the surface region exists, and the smectic A layer tends in the middle of the sample to a more perpendicular position.

Weak anchoring effects may be another way for the discussion of the experimental results. But further investigations are necessary to give more insight in the mechanism of orientation and, also, in its correlation to special anchoring conditions.

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