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Milada Glogarová [a] & Jiří Pavel [a]
[a] Institute of Physics, Czech. Acad. Sci., Na Slovance 2, 180 40, Prague 8, Czechoslovakia
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THE BEHAVIOUR OF THIN SAMPLES OF FERROELECTRIC LIQUID CRYSTALS

MILADA GLOGAROVÁ and JIŘÍ PAVEL
Institute of Physics, Czech. Acad. Sci.,
Na Slovance 2, 180 40 Prague 8, Czechoslovakia

Abstract On a ferroelectric liquid crystal DOBAMBC transitions between helical and twisted structures are observed if changing the temperature. The twisted structure appears when the helical pitch becomes comparable to the sample thickness. From the switching process of the twisted DOBAMBC samples in an electric field the polarity of surface layers is determined. Low signal dielectric permittivity shows an increase below the transition to the ferroelectric phase, which is a consequence of the twisted structure deformation in the electric field.

INTRODUCTION

Recent experiments have shown that the structure of ferroelectric liquid crystals (these are chiral smectic C-Sm C*) in finite samples differs from the ideal helical structure, which is characteristic of the Sm C phase[1-7]. This effect was observed in planar samples, i.e. samples in plate-like cells with the smectic layers perpendicular to the sample plane. A surface anchoring of Sm C* molecules on the sample boundaries which is homogeneous along the surface plane unwinds the helical structure near the surface. The unwound surface layer is not compatible with the

space modulated Sm C* structure. In the samples with the thickness t higher than a critical thickness t_k both the structures are matched together by a system of 2π disclinations.[1,2,5-7] In the samples where $t < t_k$, the helix becomes unwound in the whole sample, so that the structure is homogeneous in the planes parallel to the sample plane.[3-8] The results obtained for a particular Sm C* mixture M (see Ref. 9) and for DOBAMBC and TDOBAMCC show that $t_k \approx p$ (p is the pitch).[4,6,8,10]

Because of the polar symmetry of Sm C* implying the existence of local macroscopic in-(smectic) layer dipole-moment $\vec{P} \perp \vec{n}$ ($\vec{n}$ is the director), the equivalent anchoring on both the sample surfaces gives different $\vec{n}$ directions at these surfaces (Figures 1a,b,c).[4-7] This fact leads to a twisted (TW) structure, namely $\vec{n}$ rotates along the sample thickness between the two anchored surface orientations (Figures 1a,b,c). This rotation is associated with a splay of the $\vec{P}$.[4] A twist of the light polarization plane along the sample thickness (similarly as in twisted nematics) provides evidence for the TW structure.

It was proved for the DOBAMBC helical samples and for the M-compound in helical and twisted samples that the surface anchoring is planar with $\vec{P}$ directed towards the sample bulk.[6] In Ref. 4 a tilted surface anchoring was suggested for the thin non-helical samples (Figure 1b).

In this contribution the onset of the TW structure on approaching the limit $t \rightarrow t_k$ is investigated for DOBAMBC. In the TW samples a

response to a d.c. electric field and the dielectric properties are studied.

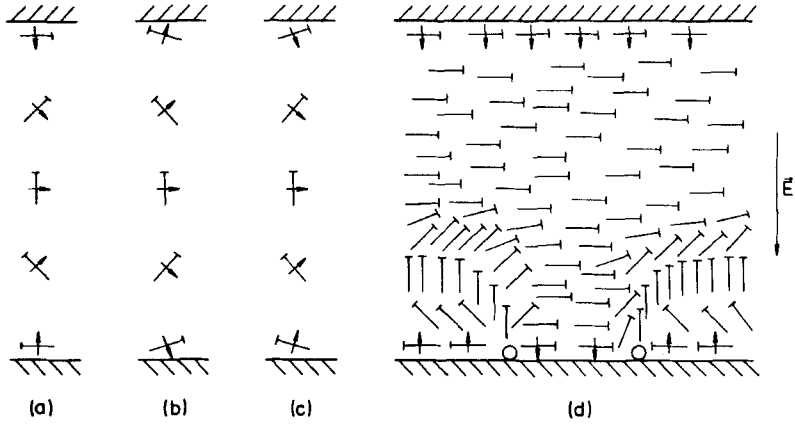

FIGURE 1. The director fields of twisted samples projected to the smectic layer. The crossbars indicate the ends of director, which project out of the page. The arrows denote the local dipole-moments $\vec{P}$. (a) planar surface anchoring as found in the twisted samples of M-compound.[6] (b), (c) tilted surface anchoring with different polarities of the surface layers. (d) electric field deformation of the TW structure (a) and its switching to the PU structure. The PU area is limited by the 2π disclination loop shown in a crossection as the circles.

EXPERIMENTAL RESULTS

The DOBAMBC samples used were confined between parallel glass plates coated with conductive transparent layers. No treatment of the plates to obtain anisotropic anchoring was used.

Temperature transition between the helical and the twisted samples

For 6 μm thick samples transitions between the helical (denoted PH_2 in Ref. 7) and the TW structures are observed (Figure 2) at the tempe-

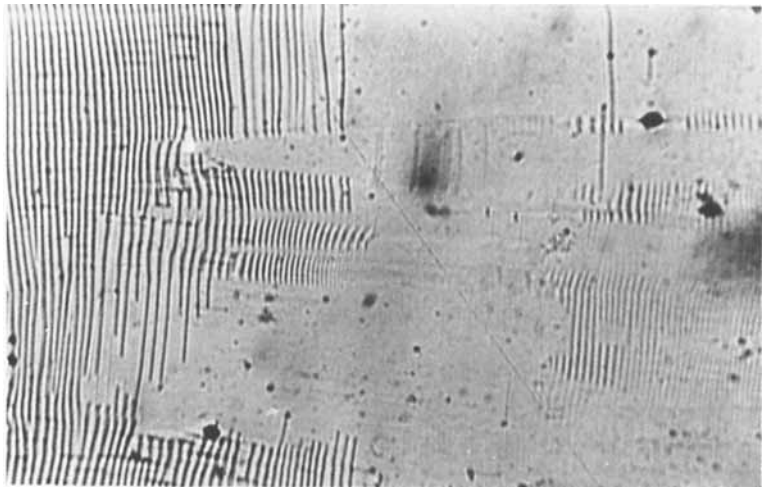

FIGURE 2. The transition of PH_2 structure, characterized by a linear texture of 2π disclinations, to a twisted structure. Observed at cooling the DOBAMBC sample of t = 6 μm at $T_1 = T_c - 0.5$ k.

ratures T_1, T_2 about 0.5 and 1 deg., resp., below the phase transition temperature T_c from Sm A to Sm C* phase ($T_c \approx 95^{\circ}C$). At cooling, first a transition $PH_2 \rightarrow TW$ at T_1, then a transition $TW \rightarrow PH_2$ at T_2 is observed. At heating the same sequence of transitions $PH_2 \rightarrow TW \rightarrow PH_2$ occurs.

With DOBAMBC, the value of p is about 2 μm just below T_c, during the cooling p reaches its maximum $p_m \approx 6 \div 10$ μm and again decreases.[11]

Such a p(T) dependence can be obtained with thick and well aligned samples, where the equilibrium value p is reached. In our samples, which are rather thin, the helical structure is strongly pinned to the system of the 2π disclinations, so that the p(T) dependence is very weak. Nevertheless, in the temperature interval T_1T_2 the helical structure becomes unstable and unwinds. The twist, which is fixed by surfaces, remains.

Response to a d.c. electric field

For DOBAMBC samples of $t \approx 1 \div 2$ μm the TW structure is stable in the whole temperature interval of the Sm C^* phase existence. With a d.c. electric field of about $E_c \approx \pm 3$ kV/cm a transition to a uniform structure (denoted PU in Ref. 7) takes place. The PU structure appears in a form of islets, which show an optical extinction between crossed polarizers. The switching mechanism can be assumed to be similar to that reported in Ref. 6 (Figure 1d). For $\vec{E}$ pointing down (up), the PU area boundaries are focused near the lower (upper) sample surface. This fact implies (cf. Figure 1d) that the $\vec{P}$ in the surface layers of TW structure has a component pointing to the sample bulk. Determination of the director in the surface layers (if planar, Figure 1a, or tilted, Figure 1c), is impeded by the small thickness of the sample and will require a more detailed optical study.

Low field dielectric permittivity

A typical temperature dependence of ε for the TW sample measured during the cooling run is shown

in the Figure 3. In the TW samples the phase

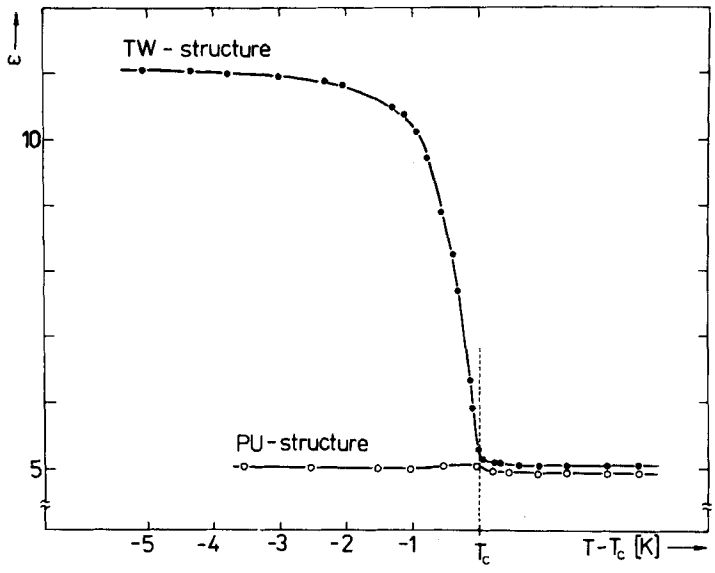

FIGURE 3. Typical ε vs. temperature dependence of DOBAMBC measured at 26 Hz, 30 V/cm for the twisted structure and the unwound structure by a d.c. electric field.

transition from Sm A to Sm C* phase could not be optically distinguished, so as T_c was not determined exactly. However, from our previous $\varepsilon(T)$ results[12] obtained for DOBAMBC helical samples, where the phase front was easily seen, we know that in Sm A ε remains constant down to T_c. Then, we can suppose that the increase in ε is connected with the appearance of the Sm C* phase.

When a d.c. bias field of about 10 kV/cm is applied the phase transition to the PU structure takes place at T_c and no ε anomaly below T_c

appears (Figure 3).

From the Landau expression for the free energy pertaining to the Sm A → Sm C* phase transition an increase in ε at the T_c region can be calculated.[13] It consists of a soft-mode contribution in both the Sm A and Sm C* phases and a Goldstone mode contribution existing in the Sm C* only. The experiments show no soft mode contribution, because $\varepsilon(T)$ in Sm A phase is constant. The Goldstone mode is connected with the existence of the helical structure. For this reason it does not exist in the unwound PU structure.

On the other hand the ε increase observed can be explained by the deformation of the twisted structure by the electric field (see Figure 1d), which is accomplished by a polarization change.

CONCLUSIONS

The observation of the transition between the helical and the twisted structures supports the concept that the critical thickness for the onset of the TW structure is comparable to the pitch p of the helical structure. A similar result has been obtained with M-compound where p was controlled by the concentration of the components[6] and with DOBAMBC in a wedge-shaped sample[10] of varying thickness. The experiment described above, where the p-value is controlled by the temperature change, shows in addition that the structures change reversibly following the changes of p.

The unwinding of the TW structure in a d.c. electric field, which can be explained by the same mechanism as described in Ref. 6 for M-compound, showed the polarity of the unwound surface layers.

The dielectric permittivity observed does not reflect bulk properties of the Sm C^* phase. The permittivity increase occuring below T_c is a consequence of the twisted structure which is fixed by boundary conditions.

The tilt angle of the surface molecules and its behaviour in the electric field which is decisive for the optical and electrooptical properties of the twisted samples has not been known up to now and will be a subject of our further study.

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