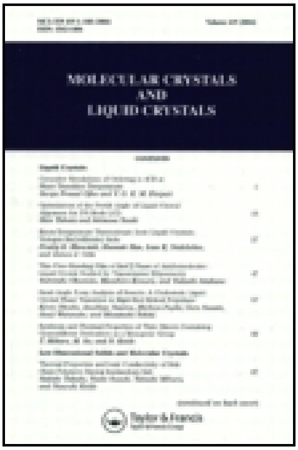

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Garry Lester [a] & Harry Coles [b]

[a] School of Engineering, University of Exeter, Exeter, EX4 4QF, U.K

[b] Liquid Crystal Institute, Department of Physics, University of Southampton, Southampton, SO17 1BJ, U.K

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Surface Uniformity and Induced Surface Pretilt for PTFE Alignment Layers

GARRY LESTER[a,]* and HARRY COLES[b]

[a]*School of Engineering, University of Exeter, Exeter EX4 4QF, U.K;*
[b]*Liquid Crystal Institute, Department of Physics, University of Southampton, Southampton SO17 1BJ, U.K*

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Suitably deposited thin films of poly (tetrafluoroethylene) (PTFE) will induce alignment in a liquid crystal [1]. These films are deposited in a one step dry process which offers advantages over polyimide or SiO_2 alignment layer application [2]. Previous studies of such films [3, 4] have shown the quality of liquid crystal alignment to be good and to exhibit an induced surface pretilt of the order of 1°. The relationship between the conditions under which the films are deposited, the uniformity of the deposited film and the induced surface pretilt induced by these surfaces has been investigated further. The uniformity has been studied by observation of the surface tension and the pretilt studied using a modified version of the crystal rotation method. There would appear to be a relationship between the observed uniformity of the surface, the alignment quality and the induced pretilt observed. The data are consistent with the hypothesis that the induced surface pretilt observed is due to irregularities in the structure of the surface.

Keywords: PTFE films; surface treatment; pretilt angle; liquid crystal alignment

INTRODUCTION

The quality of surface alignment is of utmost importance in the production of good quality liquid crystal devices. In most devices produced at present this is achieved through rubbed polymer coatings or evaporated SiO_2 [1]. A technique for applying surface coatings has been investigated, in which the substrate is heated and passed at a constant velocity under a bar of PTFE which is held against the substrate with a constant force. The technique is

*Corresponding author.

based on the formation by friction of quasi monocrystalline substrates of PTFE [5, 6]. It is found that the long axes of the PTFE molecular chains align in a highly ordered manner along the direction of rubbing, which will induce alignment in a liquid crystal in contact with the substrate. Wittman and Smith [2] have reported having successfully aligned nematic liquid crystal materials using PTFE films produced in this way.

One of the most important factors in determining the performance of a liquid crystal device is the angle that the molecular axis makes to the substrates. This is known as the surface pretilt angle and it is important to determine this angle for any alignment method.

DEPOSITION METHOD AND EQUIPMENT

The essential elements of the equipment used to deposit the PTFE films are shown in Figure 1. The two main components are a thermostatically controlled heated stage that carries the substrate in steps of ~1 μm at velocities of up to 5 mm/s and a gantry holding a piston arrangement which is used to hold a bar of PTFE against the substrate as it is moved.

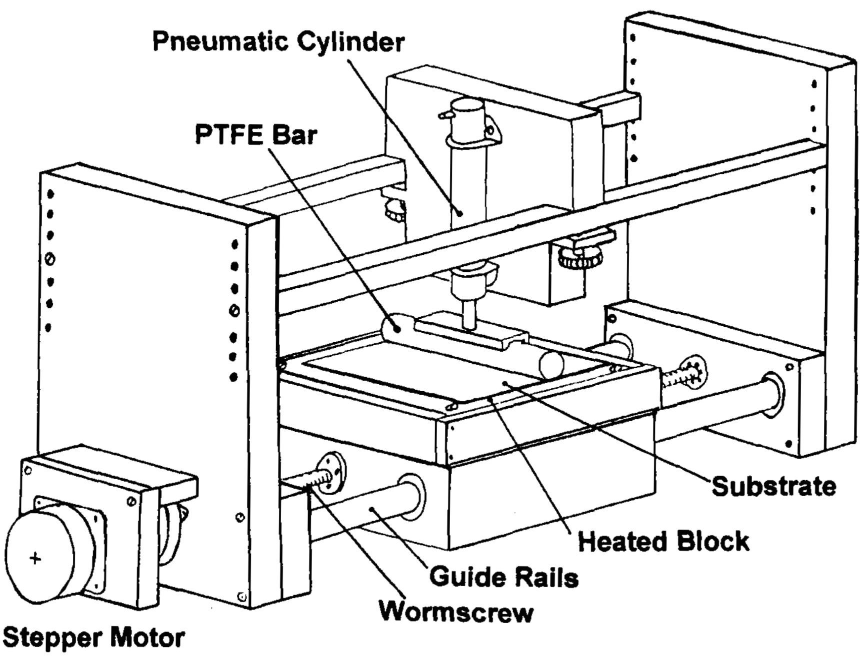

FIGURE 1 Schematic diagram of the PTFE deposition system.

Design of the Deposition Apparatus

The heated block carrying the substrate runs on two high strength steel rails of circular cross-section. The table has four linear ball bushings set into it, and these run along the rails. In between these two rails runs a steel wormscrew. A nut is set into the table so that the block moves along the two rails as the screw is driven by a computer controlled stepper motor via a gearbox. This arrangement allows the table to be translated at speeds of up to 5 mms^{-1}.

The heated block was made from brass, since this has a high thermal conductivity ensuring an even temperature across the substrate. The block could be heated at a rate of up to 10°C/min and the maximum temperature obtainable was in excess of 200°C. The temperature of the block was stable to 0.2°C over the time taken to coat a typical substrate (a few tens of seconds) and to 1°C in the long term.

The PTFE bar was attached to the piston shaft of a double-acting pneumatic cylinder with a cross sectional area of 2×10^{-4} m^2. The piston was driven by nitrogen at pressures of up to 520 N/m^2 allowing the PTFE bar to be rapidly applied to and removed from the surface of the glass, with a force dependant upon the gas pressure used.

In use the substrate to be coated is placed along one edge of a recess in the heated block, such that the relative motion of the PTFE bar maintains the position of the substrate against the recess. The substrate is moved at the desired rate, set by the stepping rate of the motor, and the pitch of the worm drive. Gas pressure is applied to the cylinder after 1 – 2 mm of the substrate have passed under the edge of the PTFE bar. Gas pressure is applied to lift the piston before the edge of the substrate has been reached.

PTFE Bar

The first PTFE bar used for deposition was made by .turning in a lathe, producing ridges in the bar which led to uneven deposition of PTFE and therefore poor alignment quality. To reduce this effect a PTFE bar was machined by taking cuts along its length to give the cross section shown in Figure 2a, this bar gave good alignment quality. The cross section in Figure 2a has a small apex in order to allow any machining marks to be 'worn' smooth with use. Though only a very small amount of material is taken from the bar on each deposition cycle the combination of heat and force deforms the bar to conform to the substrate and gradually removes any residual structure in the surface of the PTFE due to machining. With

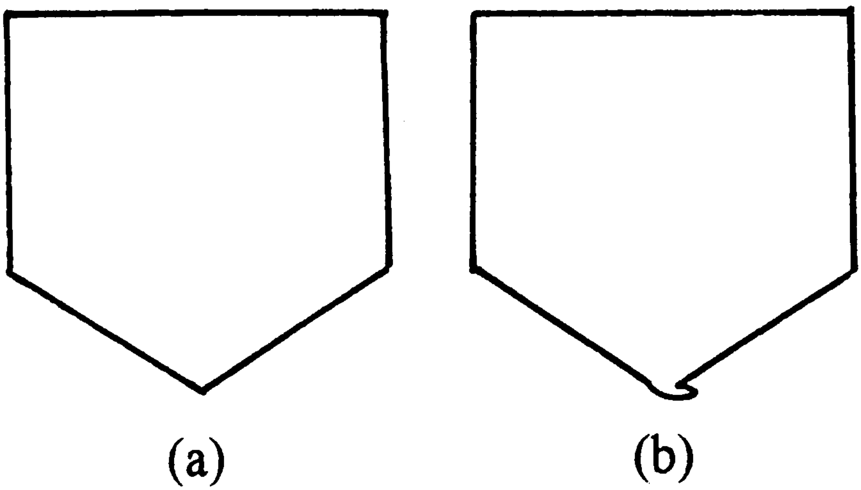

FIGURE 2 Cross section of the PTFE bar used for deposition (see text).

repeated use the bar gradually acquires a more uniform surface and takes the cross section shown in Figure 2b, this gives improved alignment quality compared to use of a recently machined PTFE bar. The width of the PTFE in contact with the substrate during deposition was estimated to be 2 mm.

As yet it is unclear how many deposition cycles at which temperatures and pressures, are required in order to 'run in' a new PTFE bar and investigation of the effect of other deposition conditions (temperature, pressure, velocity) could not practically be carried out during this running in period. In order to maintain consistency all of the data presented are for substrates coated using a PTFE bar of the shape shown in Figure 2b following a prolonged period of running in.

Test Sample Preparation

In order to determine the effects of deposition conditions on the PTFE alignment layer and the induced pretilt cells were made up with deposition conditions in the following ranges, temperatures between 75°C and 175°C, substrate velocities between 0.25 mms^{-1} and 2 mms^{-1} and cylinder pressures between 172×10^3 and 520×10^3 N/m^2, corresponding to contact pressures of approximately 9–27 atm.

All substrates were subject to a standard cleaning procedure. Initially they were placed in a solution of Decon 90 in grade 1 ultra-pure water for 2 hours. To assist cleaning the solution was agitated mechanically. They were then rinsed using three changes of grade 1 ultra-pure water followed by a rinse with analar grade solvent. Following cleaning the substrates were rubbed once with the PTFE bar at the required conditions before being tested experimentally. Multiple rubbing was not used in order to evaluate the film deposited on one deposition stroke.

SURFACE CHARACTERISATION

Uniformity Assessment by Surface Tension

The technique probes the variation of surface tension across the material under investigation through the variation of droplet size of condensation formed on the surface. The size of the droplets is strongly dependant upon, and therefore reflects the variation in, the surface tension of the solid material. This technique was used to investigate the uniformity of the applied film as a function of deposition conditions.

Condensation is formed on the substrate by first cooling the substrate and then exposing this to warm moist air, the relative humidity of the air in the laboratory is normally sufficient to produce useful patterns of condensation. The substrates were cooled in a freezer compartment to $-10°C$ and then photographed through a $\times 10$ microscope objective within approximately 10–15 seconds of removal from the freezer to record the droplet pattern over an area of 2 mm$\times$2 mm.

Surface Pretilt Measurement Method

The surface pretilt was measured using a modified version of the crystal rotation method [7, 8]. In the crystal rotation method the liquid crystal is contained in a cell which is assembled such that the deposition directions of the film are anti-parallel. The liquid crystal is assumed to uniformly align with the director $\hat{n}$ at an angle to the substrates, the surface pretilt angle α. Rotation of such a cell between crossed polarisers oriented at 45° to the rubbing plane will show a variation in the transmission with rotation angle ψ. The pretilt angle will give rise to an asymmetry in the transmission ψ_x and this may be used to calculate the pretilt angle. The modified technique includes an offset of the centre of rotation in order to reduce the effect of the thickness variations of the test cell on the measured pretilt angle [9]. Figure 3 shows the essential geometry of the experiment and Figure 4 the experimental arrangement used to carry out the experiments, a Helium-Neon laser with a beam diameter of 1.2 mm was used.

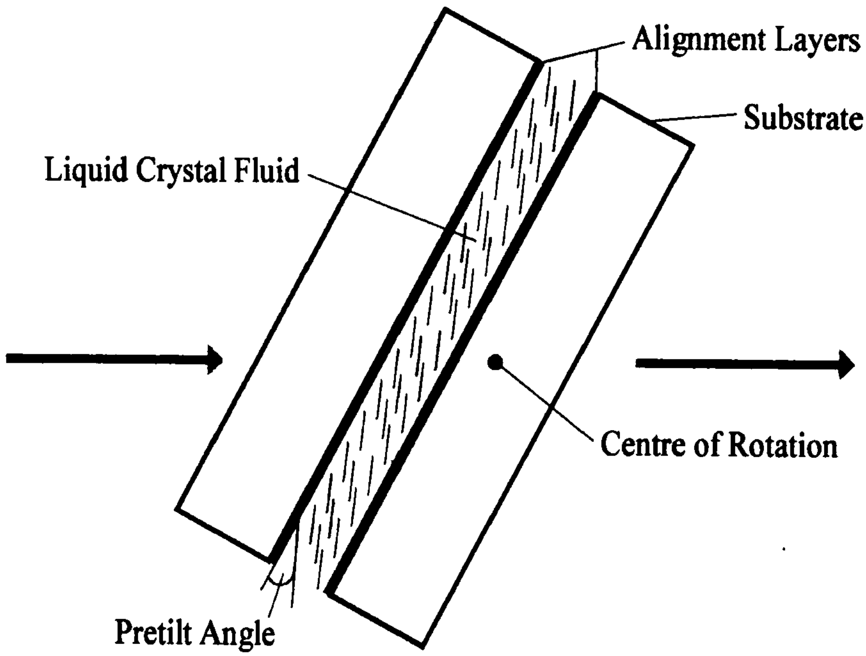

FIGURE 3 Geometry of the crystal rotation technique.

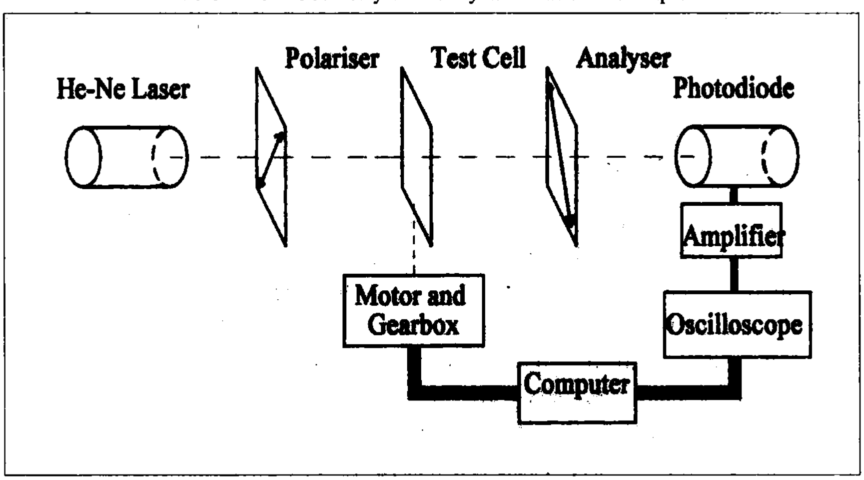

FIGURE 4 Surface pretilt measurement equipment.

Substrates were of 1.1 mm thick glass with a standard ITO (Indium Tin Oxide) coating of resistance 100Ω/square supplied by Balzers. Once coated with a PTFE film these were assembled such that the deposition directions were anti-parallel. In order to provide a significant change in the optical retardation with rotation angle for the test cells used in the pretilt test rig cell thicknesses of the order of 40 μm were used. Cells were constructed using two glass fibres as spacers, one each along the long edges of the 2 cm×3 cm test cell. This technique consistently produced cells flat to better than 1 μm over most of the area of the test cell with very few failed cells. The test cells were filled with the commercial liquid crystal material K15 which has a nematic phase at the temperature at which the experiments were carried out (≈ 25°C) and refractive indices $n_e = 1.715$ and $n_o = 1.53$. Figure 5 shows a typical graph of transmission vs rotation angle ψ for a cell of this construction. The symmetry angle ψ_x and the pretilt angle α are related by

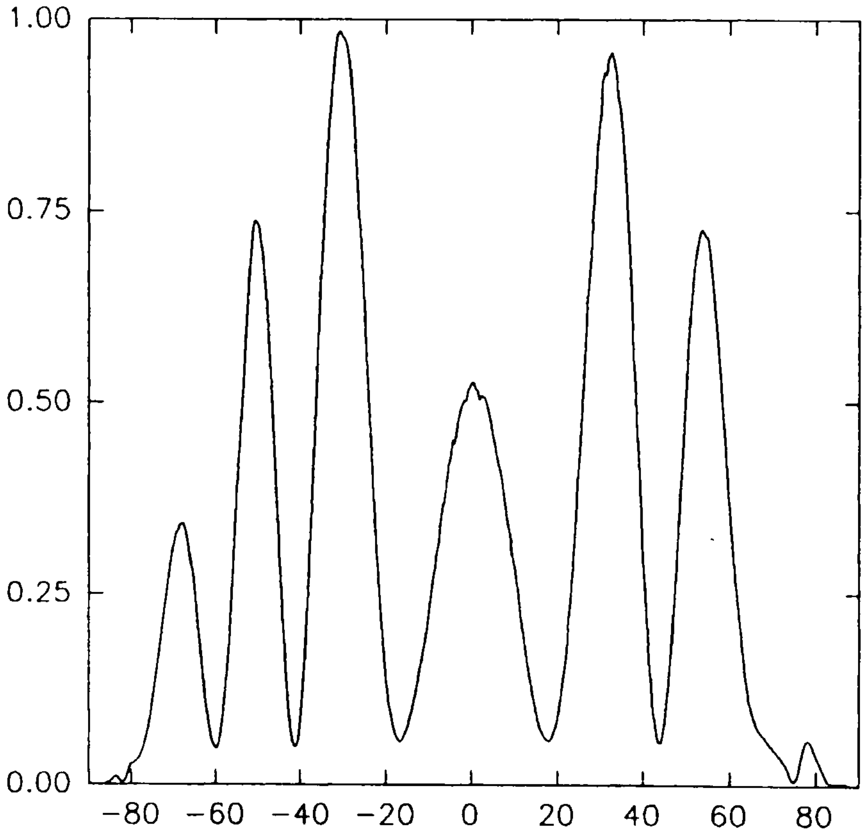

FIGURE 5 Typical Transmission vs Rotation angle characteristics obtained using the pretilt apparatus.

the following equation

$$\frac{1}{c^2}(a^2 - b^2)\sin\alpha\cos\alpha - \frac{a^2b^2}{c^3}\left(1 - \frac{a^2b^2}{c^2}\sin^2\psi_x\right)^{-1/2}\sin\psi_x + b(1 - b^2\sin^2\psi_x)^{-1/2}\sin\psi_x = 0$$

where $a = 1/n_e$, $b = 1/n_o$ and $c^2 = a^2\cos^2\alpha + b^2\sin^2\alpha$.

ψ_x may be determined from the measured transmission vs rotation angle and n_e and n_o are the refractive indices of the liquid crystal allowing α to be calculated.

DISCUSSION

It is believed that deposition of the PTFE alignment layers at lower temperatures may be more prone to tearing and roughening of the film giving some surface pretilt due to roughness. It is to be expected that this effect wold be reduced at higher temperatures through softening of the PTFE bar, giving a more uniform but lower surface pretilt. The results shown in Table I would certainly be consistent with this hypothesis. The deposition conditions which tend to produce surface non-uniformities also generally show larger observed pretilt angles. The better the quality of the alignment the lower the observed pretilt and the lower the variation in the

TABLE I Comparison of surface pretilt angle, uniformity and alignment quality

Temperature		*Velocity* →			
75°C	↓**Pressure**	0.25	0.5	1.0	mm/s
	9	n×	×	N×	
	18	×	N×	N×	
	27	N×	n0°	N×	
125°C					
	9	0°	n1.1°×	n1.4°×	
	18	0.8°×	n1.8°×	n2.2°×	
	27	0.4°	n1.6°	n0.9°	
175°C					
	9	n×	×	×	
	18	0.7°	0.3°	×	
	27	0°	0°	n1.7°	
	Atms.				

× – a tendency for cells to show inconsistent alignment.
n – slight non-uniformity over the observed area.
N – gross non-uniformity over the observed area.

pretilt angle. The variation in the observed pretilt for the 125°C cells is of the order of ±1° and for the 175°C cells less than ±0.5°. PTFE layers deposited at 125°C have a greater tendency to induce some pretilt than those deposited at 175°C. This is particularly true at higher velocities and would be consistent with the pretilt being induced by surface roughness.

These pretilt angles for PTFE films are consistent with other reported values for comparable film deposition conditions [4]. The pretilt angles are consistent for repeated measurements on the same area of a cell but vary from point to point across a cell. Similar variation in observed pretilt angle has also been reported elsewhere [4,10].

Very few of the cells with alignment layers deposited at 75°C show good transmission characteristic. These departures from the ideal are due to variations in the direction and quality of alignment of the liquid crystal. This behaviour is consistent with the observation of significant non-uniformity of these films possibly even with regions where PTFE may not have been deposited.

Alignment layers deposited at the lower surface pressure of 9 atmospheres also show poor alignment, though this does not appear to be reflected in the uniformity studies. It is probable that the force on the piston is insufficient to maintain good contact between the bar and the substrate at this pressure resulting in uneven film deposition, even at higher temperatures.

CONCLUSIONS

PTFE films have been shown to produce good quality alignment in liquid crystal materials. Previous studies have shown that such alignment exhibits some surface pretilt, this work has shown that this surface pretilt is influenced by the deposition conditions of the alignment layer.

By observing the uniformity of the aligning surface over the same range of deposition conditions as pretilt measurements were taken it has been shown that conditions which produce a rough, non-uniform surface also give some surface pretilt.

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