Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Alignment of Liquid Crystals on Surfaces with Films Deposited Obliquely at low and High Rates

T. Wilson [a] , G. D. Boyd [a] , E. H. Westerwick [a] & F. G. Storz [a]
[a] Bell Laboratories, Holmdel, NJ, 07733
Version of record first published: 21 Mar 2007.

Mol. Cryst. Liq. Cryst., 1983, Vol. 94, pp. 359–366
0026-8941/83/9403–0359$18.50/0

Alignment of Liquid Crystals on Surfaces with Films Deposited Obliquely at Low and High Rates

T. WILSON, G. D. BOYD, E. H. WESTERWICK, and F. G. STORZ
Bell Laboratories, Holmdel, NJ 07733

(Received December 16, 1982)

We report observations on the alignment of nematic liquid crystals on obliquely deposited oxide and flouride films at low and high deposition rates. The effects of mixing a pleochroic dye with the liquid crystal and coating the evaporated columns with surfactant are also discussed.

1. INTRODUCTION

The successful operation of many liquid crystal devices depends upon the correct boundary angles being defined on the sides of the cell. In many cases homogeneous or homeotropic alignment is required and this may be readily established by rubbing or coating the surface with some suitable surfactant.[1] However in certain applications tilted boundary conditions are required and in these cases we must grow an anisotropic grating.[2,3] A complete understanding of the alignment process does not seem to exist at present but the essence is shown in Figure 1 where we assume that the liquid crystal wets the sides of the columns which form the anisotropic grating;[4] it also wets the rounded tops of the columns, and thus the final tilt angle of the director lines in the bulk of the cell is a weighted average of these two effects and will in general, be less, measured from the surface, then the tilt angle of the columns themselves.

The anisotropic columnar structure may be grown by a grazing angle (typically 5°–8° from the surface) evaporation.[5] It is important that the angle of evaporation is not too high as otherwise the grating shape becomes

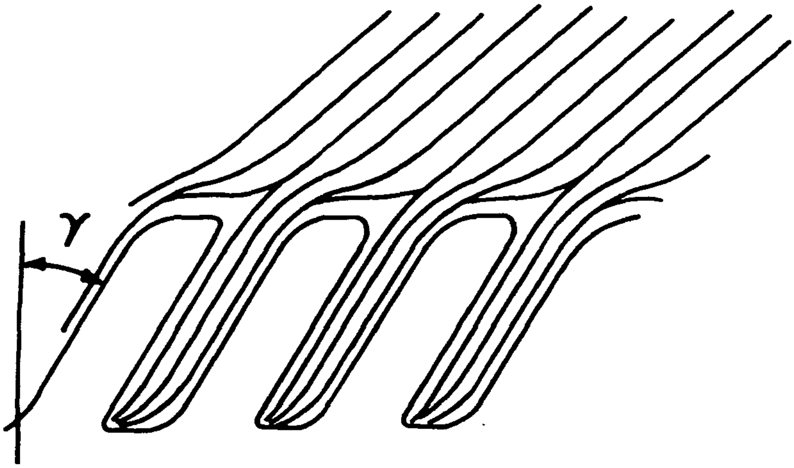

FIGURE 1 Model predicting the bulk nematic director tilt angle due to a combination of the aligning effects of the voids inclined at an angle γ and the column tops parallel to the substrate.

such that it is energetically more favorable for the liquid crystal to lie down rather than point upwards and homogeneous alignment is obtained.[6]

The actual director tilt angle which one obtains is governed by a host of phenomena including the material to be evaporated, the angle, rate and thickness evaporated, the substrate material, its temperature during evaporation and the particular liquid crystal to be aligned. In this paper we shall present results for the alignment of the nematic liquid crystal E-7 under various evaporation conditions with several materials.

2. EXPERIMENTAL

The alignment test cells consisted of two indium tin oxide coated glass substrates on which an alignment-producing material was evaporated. The substrates were separated from each other by mylar spacers nominally 25 μm thick. The source of substrate distance in the electron beam or thermal evaporator used was ~18 in. and hence there is a small angular spread across the substrates. Thus care must be taken in assembling the test cells to orient the substrates so as to minimize the effect of this spread such that a cell with uniform tilt results rather than one with a slight twist. This is particularly important as we use the conoscopy technique[7] to measure the tilt angles. After assembly the cells were placed on a hot plate and filled by capillary action with the liquid crystal in the unordered isotropic phase. They were subsequently allowed to cool into the ordered nematic phase in the presence of a magnetic field.

TABLE I

A summary of the tilt angles measured.
All the evaporations were made with an electron beam evaporator except for SiO where a thermal evaporator was used

Material	θ_N	θ_S	Rate Å/s
SiO_2	50°	40°	5
TiO_2	61°	29°	1
MgF_2	62°	28°	1
Al_2O_3	64°	26°	1
SiO	70°	20°	10–15

Table I is a summary of the tilt angles that we have measured. Each value is the average of many evaporation runs; the value for each run also being an average of many readings. The spread in readings was typically no more than two or three degrees. The evaporated film thickness in each case was 2000 Å as measured by a quartz crystal monitor for a uniform film at normal incidence. This thickness was not found to be critical.

Evidence for the columnar alignment is provided by the scanning electron photomicrograph of an SiO_2 evaporation on Figure 2(a). The columns have grown at an angle of ~50° from the surface whereas the nematic

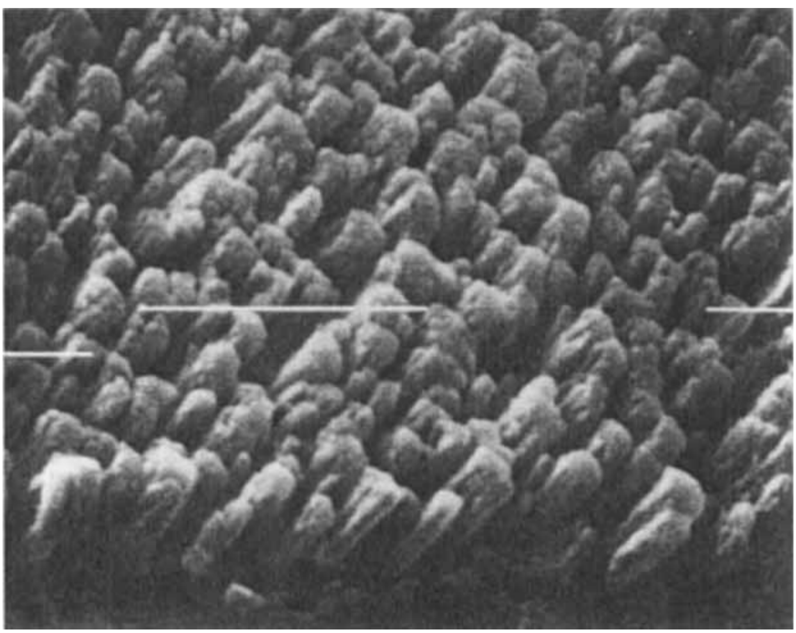

FIGURE 2(a) Edge profile of an SiO_2 grating incidence (5° from surface) deposition at 5 Å/s showing the tilted columnar aligning structure.

director has aligned at 40° from the surface due to the rounded ends of the columns. Further evidence is shown in Figure 2(b) where distinct chaining of the columns can be seen. This value is slightly less than those reported by Armitage[11] for some of the constituents of E-7. A similar image of a typical TiO_2 evaporation reveals a similar texture but with much more closely spaced columns.[8]

In the case of SiO however the evidence in support of the columns alignment has not been conclusive, especially for growth on glass substrates at high evaporation rates. Goodman *et al.*[9] revealed the existence of surface inhomogeneities by transmission electron microscopy which showed anisotropic chainlike features suggestive of columnar growth. Cheng *et al.*[8] studied the phenomena at low evaporation rates (1 Å/s) and observed a columnar structure on fused silica substrates. In Figure 3 we present scanning electron microscope evidence for columnar growth at high rates of evaporation (15 Å/s). The chaining is quite evident. The columns shown here were grown on indium tin oxide coated glass but we may also grow columns on columns. This is indicated in Figure 3(c) where we have masked part of the substrate and performed a second evaporation to give a

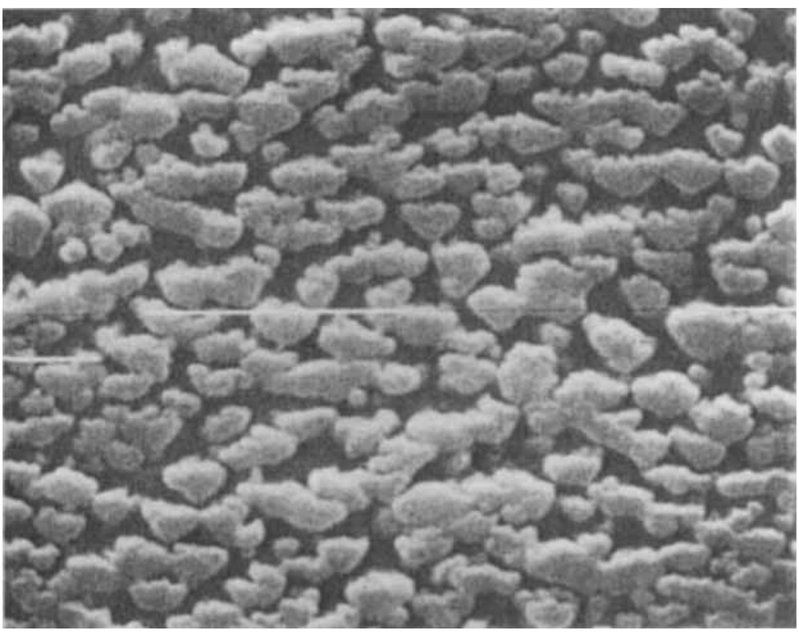

FIGURE 2(b) View at 35° from the surface showing substantial chaining into elongated islands. The calibration bars are 1 μm long.

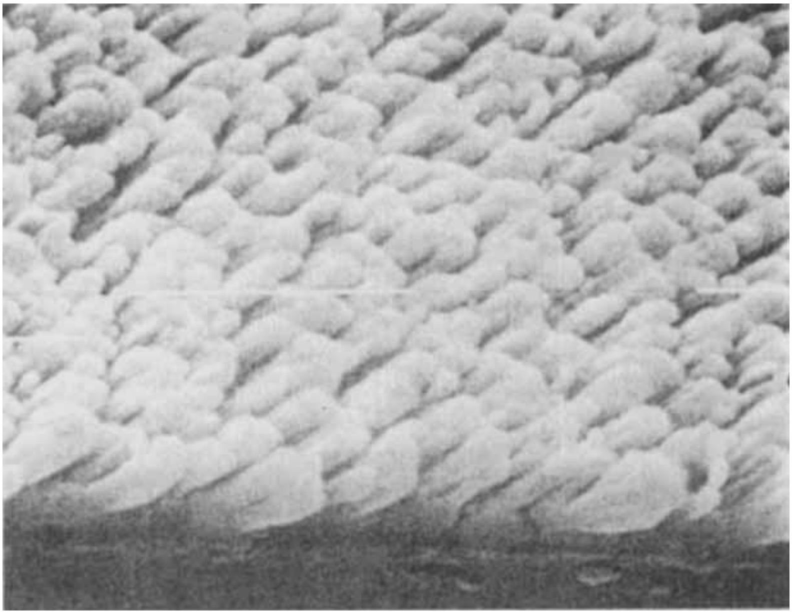

FIGURE 3(a) Edge profile of an SiO grating incidence (5° from surface) deposition at 15 Å/s showing the existence of a tilted columnar aligning structure.

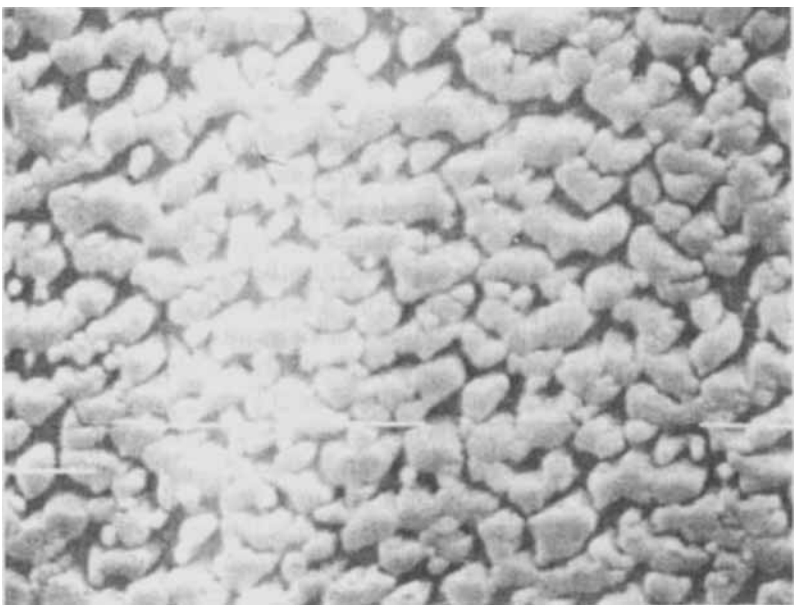

FIGURE 3(b) View at 35° from the surface. In this case the chaining into elongated islands is not as pronounced as in Figure 2(b) for SiO_2.

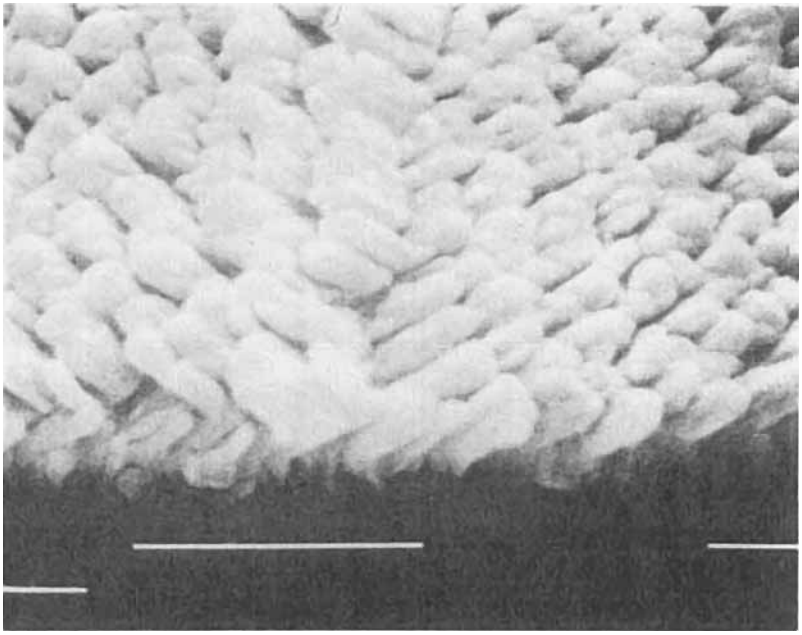

FIGURE 3(c) Edge profile showing the results of a second evaporation in the opposite direction to the first indicating that a second correctly angled layer will grow on a previously deposited rough layer.

region of reversed tilt. The columnar structure in both regions is quite evident. The evaporation rate was not found to be critical; the tilt angle did not vary significantly between evaporations carried out at 2 Å/s and 15 Å/s. The micrographs for the MgF_2 evaporation which are not shown are similar to those for SiO and a comparable packing density of columns is observed. The rate was also found uncritical between 0.5 Å/s and 2 Å/s.

We provide further evidence in Figure 4 suggesting that the roughness of the surface may not be a critical factor in the growth of columns. Figure 4 indicates the quality of the columnar growth that resulted from an evaporation of TiO_2 at 1 Å/s on the rough surface of a non-glare glass substrate.

Some care must be taken with the cleanliness of the cell and purity of the liquid crystal used in these experiments. Heffner *et al.*[4] have shown that if the liquid crystal is not pure then one may obtain a surprisingly high nematic director tilt angle which is found to be the complement of the one desired, that is the liquid crystal points *away* from the evaporation source rather than toward it.

This is presumably caused by one component of the liquid crystal mix-

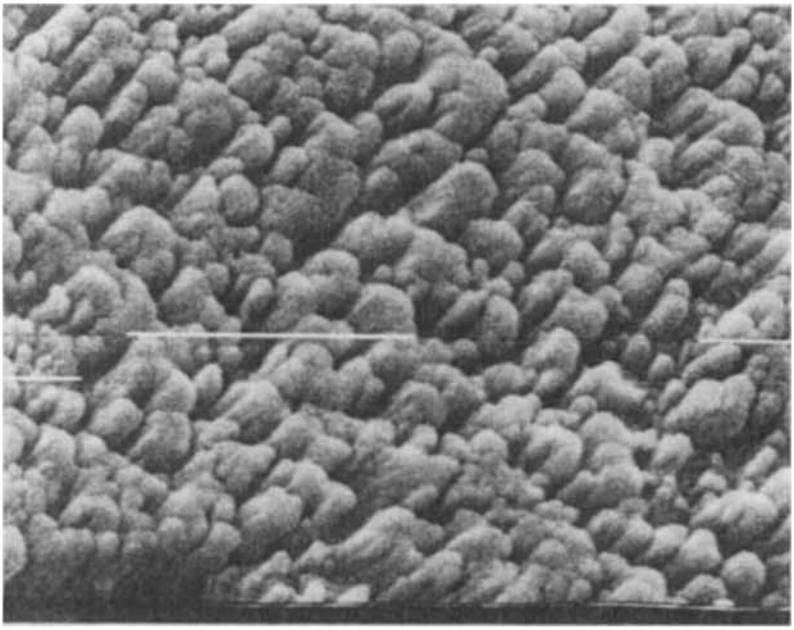

FIGURE 4 Edge profile showing the growth of tilted columns on a rough substrate of non-glare glass. The calibration bars are 1 μm long.

ture, or surface adsorption of some impurity, causing alignment to be locally perpendicular to the aligning columnar structure. It is possible to obtain tilts toward the evaporation source by repurifying the liquid crystal.[4] In this context our results for the Al_2O_3 evaporation are of interest in that we measure a surface tilt angle of 25° which is the complement of the angle measured by Morrissy *et al.*[9] We are therefore tempted to suggest[4] that in their case the liquid crystal may have been directed away from the evaporation source.

We should also note that in many applications a pleochroic dye is added to the liquid crystal and thus we filled some of our cells with a 2% solution of the blue dye D5 mixed with E-7 and in none of the cases saw any change in director tilt compared with a similar cell filled without the dye. Similarly, coating the evaporated columns with a homogeneously aligning surfactant had no effect on the final tilt angle. It is important in this case to use a surfactant which only deposits a monolayer on the columns such that the interstitial regions are not filled in thereby preventing the desired tilted alignment. We used a 1% solution by weight of Methyltrichlorosilane in dry tetrahydrofuran.

3. CONCLUSION

In conclusion we have presented a series of data for the alignment tilt angles which one may expect to obtain by grazing incidence evaporation of oxides and fluorides with the nematic E-7. We have presented definite evidence for the columnar growth structure with SiO at high rates and also demonstrated that reverse tilted columns may also be grown on previously deposited columns at a similarly high rate. We have also shown that the presence of a small amount of pleochroic dye or the coating of the columns with a homogeneous surfactant does not affect the tilt angle obtained.

Acknowledgment

We thank M. Biazzo for his assistance and T. M. Leslie for selecting and providing the surfactant.

References

1. L. A. Goodman in "Introduction to Liquid Crystals," edited by E. B. Priestley, P. J. Wojtowicz and Ping Sheng, Plenum (1975).
2. G. D. Boyd, T. Wilson, R. N. Thurston, J. Cheng, F. G. Storz, and E. H. Westerwick, "A 20 × 40 Matrix Addressed Bistable Nematic Liquid Crystal Display Using Thermal Erasure," 1982 International Display Research Conference, Cherry Hill, N. J.
3. "A Matrix Addressable Bistable Nematic Liquid Crystal Display with Electric Field Writing and Thermal Erasure," to be published.
4. W. Heffner, D. W. Berreman, M. Sammon, and S. Meiboomm "Liquid crystal alignment on surfactant treated obliquely evaporated surfaces," *Appl. Phys. Lett.*, **36**, 144 (1980).
5. J. L. Janning, "Thin film surface orientation for liquid crystals," *Appl. Phys. Lett.*, **21**, 173 (1972).
6. J. Cognard, "Alignment of nematic liquid crystals and their mixtures," *Molecular Crystals and Liquid Crystals;* Supplement 1, (1982).
7. W. A. Grossland, J. H. Morrissey, and B. Needham, "Tilt angle measurement of nematic phases of cyano-biphenyls aligned by obliquely evaporated films," *J. Phys. D: Appl. Phys.*, **9**, 2001–2014 (1976) and **10**, L175–L178 (1977).
8. J. Cheng, G. D. Boyd, and F. G. Storz, "A scanning electron microscope study of columnar topography and liquid crystal alignment on obliquely deposited oxide surfaces at low rates," *Appl. Phys. Lett.*, **37**, 716, (1980).
9. L. A. Goodman, J. T. McGinn, C. H. Anderson, and F. Digeronomo, "Topography of obliquely evaporated silicon oxide films and its effects on liquid orientation," *IEEE Trans. Electron Devices*, **ED-24**, 795 (1977).
10. J. H. Morrissy, B. Needham, and W. A. Crossland, "Nematic Tilt Angles Over SiO Alignment Layers," presented at the 1978 Bordeaux Conference, Bordeaux, France.
11. D. Armitage, "Alignment of liquid crystals on obliquely evaporated silicon oxide films," *J. Appl. Phys.* (1980).