Anchoring Energy Measurements: a Practical Approach

[a]C. J. P. NEWTON, [b]M. IOVANE, [c]O. DUHEM, [b]R. BARBERI, [d]G. LOMBARDO and [a]T.P. SPILLER
[a]Hewlett-Packard Laboratories, Bristol, Filton Road, Stoke Gifford, Bristol BS34 8QZ, U.K.; [b]Dipartimento di Fisica, Università della Calabria, I-80736, Rende(CS), Italy; [c]INFM Research Unit of Calabria, c/o Dipartimento di Fisica, Università della Calabria, I-80736, Rende(CS), Italy. [d]Dipartimento di Meccanica e Materiali, Facolta' di Ingegneria, Universita' degli Studi di Reggio Calabria, Localita' Feo di Vito, 89060 Reggio Calabria.

We describe a simple method for determining anchoring energies from the measured optical response of liquid crystal cells. The method is quick and easy to use and can therefore be used to check a range of possible treatments, or for process control in an industrial environment.

Keywords Liquid crystals; Surface anchoring; Computer modelling

INTRODUCTION

Liquid crystal displays need reliable anchoring (such as planar, or homeotropic). To test a range of treatments applied under various conditions, or in an industrial environment, we need a quick and reliable method to measure the zenithal anchoring energy.

The method described uses a simple experimental set-up that can be easily automated. Furthermore, because of the simple model used the data analysis is also straightforward, unlike other methods previously published. The experimental set-up is shown in Figure 1. The

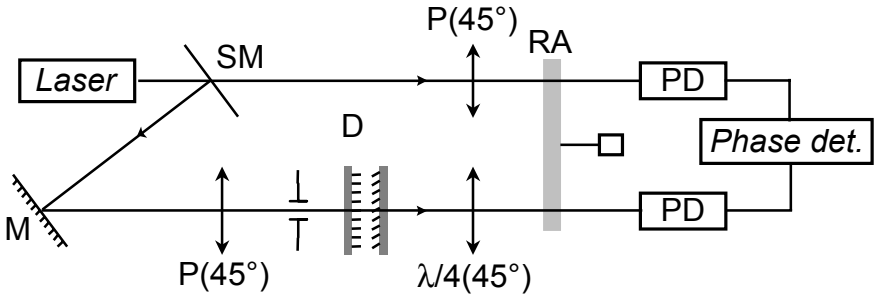

FIGURE 1 The experimental set-up [1,2]. Key: D – diaphragm, M – mirror, P – polariser, PD – photo-diode, RA – rotating analyser, SM – semi-silvered mirror.

set-up measures the retardation as a function of applied voltage (an AC voltage is applied and the RMS voltage is recorded). A typical set of experimental data, for the planar anchoring case, is shown in Figure 2.

We first model how the director profile varies across the cell. This model is used to calculate the cell's retardation. By varying the model parameters to get a good fit to the experimental data we can obtain the anchoring strength. The experiments use a hybrid cell (Figure 3) aligned with the planar rubbing direction horizontal.

A hybrid cell is used because it allows a number of simplifying assumptions to be made in the model we use to fit the data. We first describe this model for the planar anchoring case and then show how it is used to fit the data shown in Figure 2.

THE PLANAR ANCHORING MODEL

The anchoring energy at the planar surface can be measured for liquid crystals with a positive dielectric anisotropy. It is assumed that the voltage applied is sufficient to ensure that at the homeotropic surface we have $\theta = 0$ and $d\theta / dz = 0$. Variations in the cell depend upon z only, and in this case the total energy, per unit area in the xy-plane, is given by [3,4]

$$U = \int \left(F_n + F_s + F_d \right) dz \qquad (1)$$

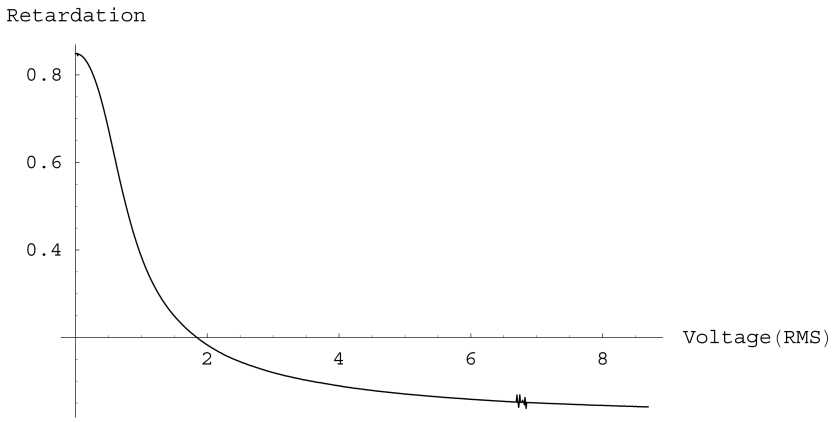

FIGURE 2 Retardation (μm) against applied voltage for a hybrid cell filled with 5CB.

with contributions from nematic distortion, the planar anchoring energy and from the applied electric field.

- The nematic energy density is given by

$$F_n = \frac{1}{2} K_{11} \left(1 + Q \cos^2 \theta\right) \left(\frac{d\theta}{dz}\right)^2 \tag{2}$$

where K_{11} is the splay elastic constant and Q is defined as

$$Q = \frac{K_{33} - K_{11}}{K_{11}}$$

with K_{33} the bend elastic constant (There is no twist in this hybrid configuration).

- The planar anchoring energy is given in the usual Rapini-Papoular form [5].

$$F_s = \frac{1}{2} A_1 \sin^2 (\frac{\pi}{2} - \theta) \delta \left(z + \frac{t}{2}\right) \tag{3}$$

where the δ-function ensures that this term only contributes to the total energy at the surface.

- The dielectric contribution to the free energy density is given by

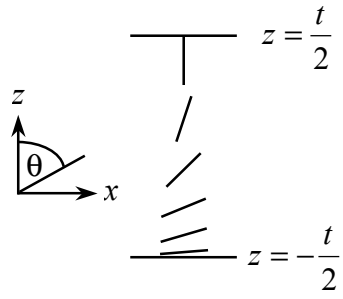

FIGURE 3 The hybrid cell.

$$F_d = -\frac{1}{2}\varepsilon_0\varepsilon_\perp\left(1 + R\cos^2\theta\right)E_z^2 \tag{4}$$

with $R = \varepsilon_a/\varepsilon_\perp$ and $\varepsilon_a = \varepsilon_{//} - \varepsilon_\perp$. $\varepsilon_{//}$ and $\varepsilon_\perp$ are the dielectric constants parallel and perpendicular to the nematic director. In addition we have for the dielectric terms

$$D_z = \varepsilon_0\varepsilon_\perp\left(1 + R\cos^2\theta\right)E_z \tag{5}$$

and

$$D_z = const = D_0 \text{ (say)}$$

subject to the condition that

$$-\frac{D_0}{\varepsilon_0\varepsilon_\perp}\int_{-t/2}^{t/2}\frac{1}{\left(1 + R\cos^2\theta\right)}dz = V_0 \tag{6}$$

the applied voltage.

The Euler-Lagrange equation

$$\frac{d}{dz}\left(\frac{\partial F_{total}}{\partial\theta_z}\right) - \frac{\partial F_{total}}{\partial\theta} = 0$$

can be used to give

$$\frac{1}{2}K_{11}\left(1 + Q\cos^2\theta\right)\left(\frac{d\theta}{dz}\right)^2 - \frac{D_0^2}{2\varepsilon_0\varepsilon_\perp}\frac{1}{\left(1 + R\cos^2\theta\right)} = const \tag{7}$$

and the torque balance equation

$$l\left(1 + Q\cos^2\theta_1\right)\left.\frac{d\theta}{dz}\right|_{z=-t/2} = \cos\theta_1\sin\theta_1 \tag{8}$$

with $l = K_{11}/A_1$, the anchoring extrapolation length.

The integration constant in (7) can be obtained by using the boundary conditions at the homeotropic surface ($\theta = 0$ and $d\theta / dz = 0$). This gives

$$K_{11}\left(1+Q\cos^2\theta\right)\left(\frac{d\theta}{dz}\right)^2 = \frac{D_0^2}{\varepsilon_0\varepsilon_\perp}\frac{R\sin^2\theta}{\left(1+R\right)\left(1+R\cos^2\theta\right)} \tag{9}$$

Eliminating $d\theta / dz$ in (8) gives a new equation for the surface angle θ_1

$$\cos^2\theta_1 = \frac{l^2 D_0^2 R}{K_{11}\varepsilon_0\varepsilon_\perp\left(1+R\right)}\frac{1+Q\cos^2\theta_1}{1+R\cos^2\theta_1} \tag{10}$$

These equations together with the condition placed on D_0 (6) are the basic equations of the model.

We now make a number of further assumptions to simplify the analysis and data fitting.

Simplifying the model

We assume that

- The director profile can be modelled using the function

$$\theta(z) = \theta_1 \exp\left[-\frac{z+t/2}{\xi}\right] \tag{11}$$

  where
  - θ_1 is the angle at the planar boundary and can be obtained from the torque balance equation, and
  - ξ is a characteristic length. To (approximately) satisfy the BCs at the homeotropic surface $\xi <<$ t, the cell thickness.

and

- The field in the cell can be considered uniform. In this case we have

$$D_0 = \frac{\varepsilon_0\varepsilon_{//}V_0}{t} \tag{12}$$

With the uniform field assumption, the bulk director equation is satisfied (for small angles) by the ansatz for $\theta(z)$ with

$$\xi = \frac{t}{V_0}\left(\frac{K_{33}}{\varepsilon_0\varepsilon_a}\right)^{\frac{1}{2}} \tag{13}$$

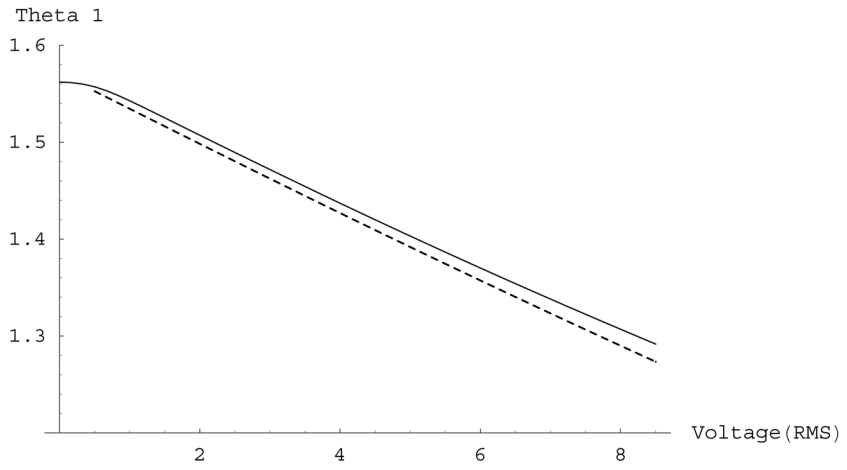

FIGURE 4 Comparison of model results for θ_1 (radians) against applied voltage.

(this is the electrical extrapolation length). The ansatz is thus valid for V_0 well above the characteristic voltage $V_c = \left(K_{33} / \varepsilon_0 \varepsilon_a\right)^{\frac{1}{2}}$.
The torque balance equation (10) becomes

$$\cos^2 \theta_1 = \frac{l^2 (1+R)(1+Q)}{\xi^2} \frac{1+Q\cos^2 \theta_1}{1+R\cos^2 \theta_1} \tag{14}$$

The optical retardation

Once the director profile is obtained it can be used to give the optical retardation [2,6]

$$\Delta l = n_o \int_{-t/2}^{t/2} \left(\frac{1}{\sqrt{1 - R_o \sin^2 \theta(z)}} - 1 \right) dz$$

with

$$R_0 = 1 - \left(n_o / n_e\right)^2$$

where n_o and n_e are the ordinary and extraordinary refractive indices.

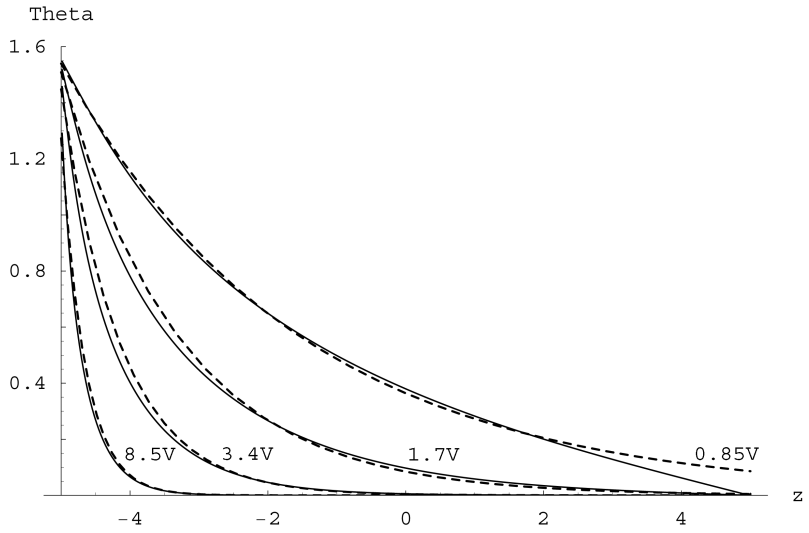

FIGURE 5 Comparison of the model director profiles, θ (radians) vs. z (μm), for a number of different voltages.

Testing the model

We have developed a numerical model that correctly handles the energy terms and applied electric fields [7,8,9]. This has been used to model the system with different voltages applied and to give the angle at the planar surface (θ_1), the director profile and the retardation as a function of applied voltage. These results for an anchoring extrapolation length of 0.05μm in a 10μm cell filled with 5CB are shown in Figures 4, 5 and 6 together with results from the simplified model (In these figures the dotted lines represent results from the simple analytical model and the solid lines results from our numerical model). There is reasonable agreement provided that the voltage is high enough (> 2.0 V, $V_c \approx 0.295$ Volts).

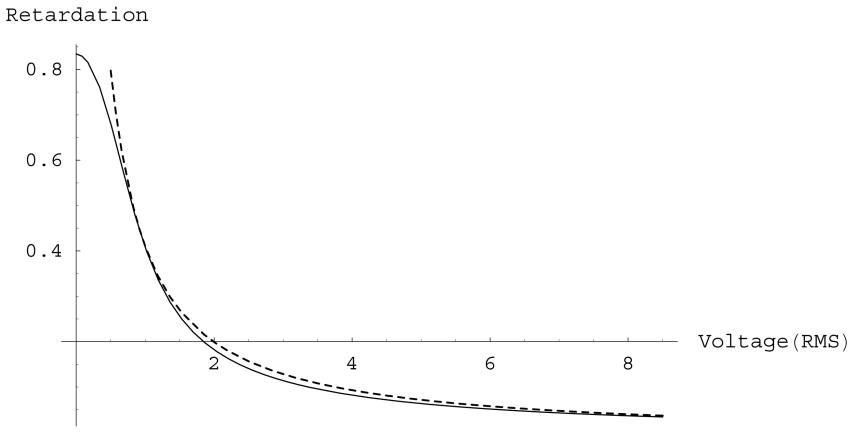

FIGURE 6 Comparison of model results for optical retardation (μm) against applied voltage.

EXPERIMENTAL RESULTS

The results shown in Figure 2 are for a hybrid cell filled with 5CB (5CB was used because data on its elastic constants and refractive indices are available in the literature). The planar anchoring was obtained using a rubbed polyimide (JSR Microelectronics AL1254). The homeotropic alignment was obtained using a proprietary treatment known to give reliable homeotropic alignment when used with 5CB. The cell was measured empty using a spectrophotometer and the transmission data fitted, giving the thickness as 9.78μm. The cell was filled and measured, the model described above was then fitted to the data (for voltages greater than 2.0V) using a least squares fit and this gave the anchoring extrapolation length, l=0.04μm. The measured data and the fitted curve are shown in Figure 7.

Rubbed polyimide is known to give strong planar alignment and this value is certainly consistent with that. To further check the validity of the model we are in the process of testing other treatments, which give weaker planar alignment. A second test using a thinner cell

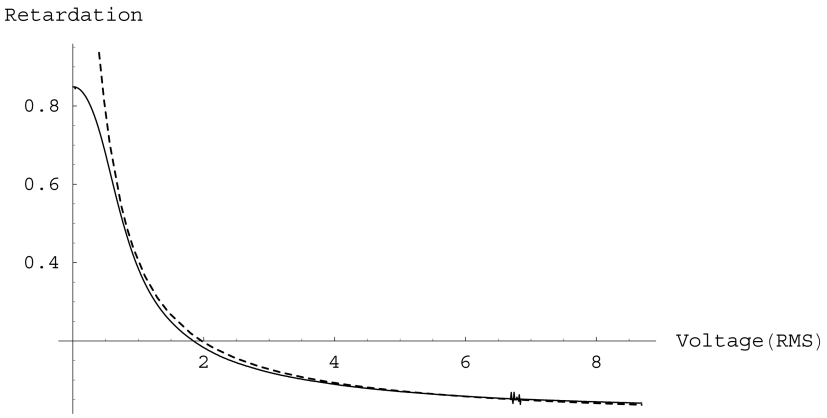

FIGURE 7: The model fit to the experimental data shown in Figure 2. The cell was measured to be 9.78μm thick and the best fit was obtained for l = 0.04μm.

gave an anchoring extrapolation length of 0.025μm. The source of this difference is not clear. It could be due to

- Differences in the polyimide. The cells were made at different times; the thickness of the polyimide and/or the rubbing may be different. Both of these factors are known to have an effect on the anchoring strength.
- The cell thickness is measured with the cell empty, it may change when the cell is filled and this will affect the results.
- Failure of the Rapini-Papoular function to adequately represent the anchoring energy function.
- Limitations in the current model. The assumptions may be too severe.

We are currently working to clarify the situation by systematically measuring a range of cells. This is made feasible because of the simplicity of the model and of the data fitting procedure. At the same time we are investigating other methods that will allow us to obtain independent confirmation of our results.

CONCLUSIONS

The method described above allows the planar anchoring strength to be quickly assessed. As such it should be useful for process checking and, if used consistently, for relative measurements of a variety of different surface treatments. With simple modifications the model could also be used to measure the homeotropic anchoring energy (for liquid crystals with a negative dielectric anisotropy and using a voltage regime where the electrodynamic instabilities are absent).

The model makes strong assumptions, which have been validated by comparison with our numerical model. It needs the liquid crystal parameters and cell thickness to be known beforehand. If necessary, the liquid crystal parameters can be independently measured. The real problem, as with other published methods [2,6,10], is knowing the actual thickness of the cell being measured.

Acknowledgements
This work has been partially supported by the European Scientific Network SILC - (Surface and Interfaces of Liquid Crystals), contract no. FMRX CT98 0209.

References

[1] A. H. van Sprang, Mol. Cryst. Liq. Cryst, **199**, 19 (1991).
[2] S. Palto, R. Barberi, M. Iovane, V.V. Lazarev and L.Blinov, Mol. Materials, **11**, 277 (1999).
[3] P. G. de Gennes and J. Prost, The Physics of Liquid Crystals, Clarendon Press, Oxford (1993).
[4] S. Chandrasekhar, Liquid Crystals, (Second edition), Cambridge University Press (1992).
[5] A. Rapini and M. Papoular, J. Phys. (Paris) Colloq., **30**, C4-54 (1969).
[6] P. R. Maheswara, V. A. Murthy, V. A. Raghunathan and N. V. Mahadusana, Liquid Crystals, **14**, 1107 (1993).
[7] C. J. P. Newton and T. P. Spiller , Proc. IDRC (SID), 13 (1997).

[8] C.J.P. Newton and T.P. Spiller, Mol. Cryst. Liq. Cryst, Proc. SICL 2000 (2000).
[9] C. J. P. Newton and T. P. Spiller in preparation.
[10] K. H. Yang and C. Rosenblatt, Appl. Phys. Lett., **43**, 62 (1983).