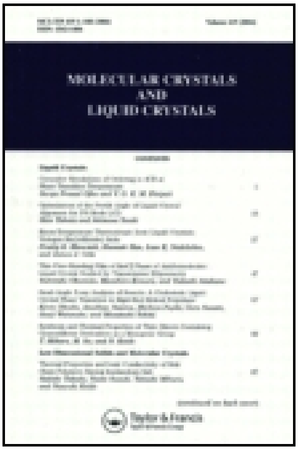

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Measurement of the Sum ($e_1 + e_3$) of the Flexoelectric Coefficients e_1 and e_3 of Nematic Liquid Crystals using a Hybrid Aligned Nematic (HAN) cell

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A hybrid aligned nematic cell (HAN) is often used to measure the sum ($e_1 + e_3$) *of the flexoelectric coefficients* e_1 *and* e_3*. However, a HAN cell has the difficulty of an internal offset voltage (internal bias) caused by the homeotropic alignment. We present a method to determine the internal bias and then take it into account in the flexoelectric measurement.*

Keywords: flexoelectric coefficient; flexoelectricity; HAN; hybrid aligned nematic; offset voltage; sum

1. INTRODUCTION

It is generally thought that the flexoelectric effect [1,2], particularly the sum $(e_1 + e_3)$ of the flexoelectric coefficients e_1 and e_3, plays a major roll in the switching behaviour of zenithally bistable nematic devices (e.g., ZBD) [3–6]. Therefore it is important to measure the sum $(e_1 + e_3)$ so that the device and material performance can be optimized.

A hybrid aligned nematic cell (HAN) was first used by Madhusudana [7,8] to measure the sum $(e_1 + e_3)$ and shows a strong flexoelectric response when an electric field E is applied across the device, because of the asymmetric structure due to the homeotropic alignment on one side and the planar alignment on the other side. Due to flexoelectricity, an applied dc voltage distorts the director,

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differently for positive voltages compared to negative voltages. This distortion can be measured and used to determine the sum $(e_1 + e_3)$. However, there is a surface polarisation associated with the homeotropic alignment [9,10]. This may be caused by the polarity of the surface aligning material together with ordering of the liquid crystal molecules at the surface. This surface polarisation acts like an offset voltage and is in the range of a few hundreds millivolts. To avoid confusion between an external applied offset voltage and the offset voltage created by the surface polarisation, we refer to it here as the "internal bias". This internal bias influences strongly the measurement of the sum $(e_1 + e_3)$ and it is therefore very important to determine the internal bias and include it in the flexoelectric measurement.

2. DETERMINATION OF INTERNAL BIAS

It has been found that the commercial material TL216 (Merck) has negligible flexoelectricity [11] and is non-ionic. Both criteria are important and necessary to determine the internal bias. Negligible flexoelectricity is important because the HAN structure has a strong splay-bend distortion from one substrate to the other substrate, due to the different alignment structures. This strong splay-bend distortion would lead in a material with flexoelectricity to a net flexoelectric polarisation, which shows electro-optic behaviour similar to that caused by an offset voltage. It would be not possible to differentiate between the apparent offset voltage caused by the flexoelectric polarisation and the internal bias, and therefore impossible to measure the internal bias. Applying a dc voltage to a liquid crystal device leads to ionic migration which cancels out the electric field. However using a non-ionic material allows us to use dc voltages to determine the internal bias. Applying a dc voltage and measuring the transmission through the device at normal incidence, shows an asymmetry in the form of a voltage shift, as presented in Figure 1. This voltage shift can be identified as internal bias but can not be measured accurately using this data. The accurate internal bias is measured using the experiment described below.

3. THEORY

Liquid crystal continuum theory [12–15] together with Jones optics [16] is used to simulate the effect of 2 ms pulses which are 50 ms apart and have a magnitude of 1 V (Fig. 2 thin line). Results show (Fig. 2a) that without flexoelectricity and symmetric pulses (e.g, no offset in positive pulse), the magnitude of the optical response (thick line) is

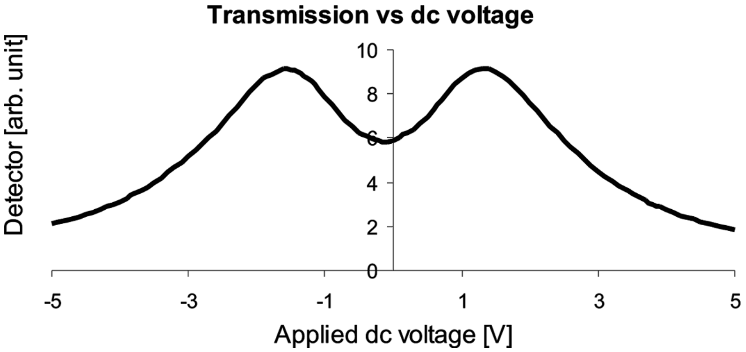
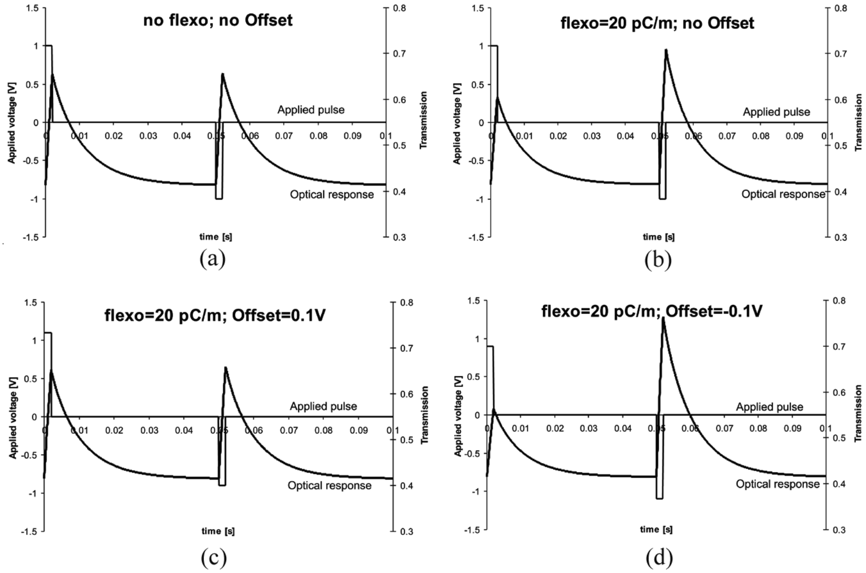


FIGURE 1 The effect of the internal bias can be seen by applying dc voltage and measuring optical response for the material TL216 with negligible flexoelectricity.

the same for a positive and negative pulses. This is not the case if flexoelectricity is included in the theory [1] (Fig. 2b). The magnitude of the optical response is different for a positive and negative pulse. Increasing only the positive pulse by +100 mV decreases the



(a) (b)

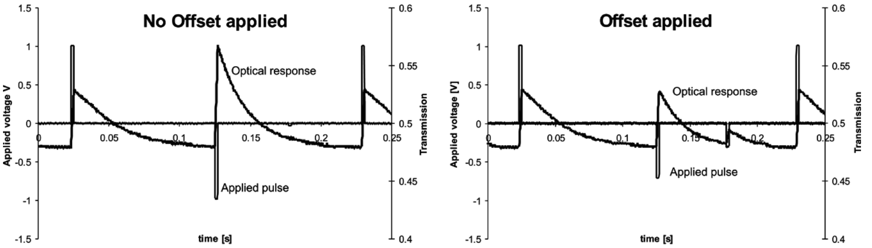
(c) (d)

FIGURE 2 Simulation for the flexoelectric sum $(e_1 + e_3)$ and offset: (a) No flexo and no offset, (b) flexo = 20 pC/m and offset = 0 V, (c) flexo = 20 pC/m and offset = 0.1 V, (d) flexo = 20 pC/m and offset = −0.1 V.

asymmetry in the optical response and decreasing only the positive pulse by $-100\,\mathrm{mV}$ increases the asymmetry (Figs. 2c and d). With an increase (offset) of $+100\,\mathrm{mV}$ in the positive pulses only, the influence of flexoelectricity can be cancelled out (Fig. 2c). Further, it is possible to calculate the flexo-offset correlation using the simulation e.g., $(e_1 + e_3) = 20\,\mathrm{pC/m}$ corresponds to 100 mV. This correlation allows us to calculate the flexoelectricity once the offset is measured. Further, the flexo-offset correlation depends on the elastic, dielectric and refractive properties and has to be calculated for each material.

4. EXPERIMENT

In the experiment 2 ms pulses, which are 100 ms apart and have a magnitude of 1 V or -1V, are applied to the HAN cell. The dynamical optical response is measured at normal incidence using a red laser (632.8 nm), crossed polarisers, detector and oscilloscope. The experimental data with symmetric pulses (no offset in one of the pulses), show an asymmetrical pulse response (Fig. 3a), as expected and predicted by the theory. The asymmetrical pulse response is cased by a combination of flexoelectricity and internal bias. Changing the magnitude of the negative pulse only until the asymmetric optical response disappears (Fig. 3b), allows us to measure the offset voltage necessary to cancel out the combination of the flexoelectric effect and internal bias. The experimental results shown are for E7 at room temperature (22°C) and a offset of $+105\,\mathrm{mV}$ is measured, which means that the magnitude of the negative pulse was changed from -1V to -0.895 V while keeping the magnitude of the positive pulse at 1 V. The same result can be obtained varing the positive pulse and keeping the



(a) (b)

FIGURE 3 Experimental data for E7 at room temperature (22°C): (a) Pulses are symmetric (no offset) and optical response asymmetric, (b) Offset of $-105\,\mathrm{mV}$ is applied to negative pulse which gives a pulse magnitude of -0.895 V and a symmetrical optical response.

negative pulse constant. To determine the internal bias, TL216 is used which is non-ionic and has negligible flexoelectricity, and a value of $-135\,\text{mV}$ is measured. Assuming that the measured internal bias of $-135\,\text{mV}$ just depends on the homeotropic alignment and not on the liquid crystal material or ions, and that it is constant and the same in the batch of HAN cells used, it can be treated like a constant offset and taken into account in the flexoelectric measurement of the other materials. For E7, it is now possible to calculate the offset which corresponds to flexoelectricity by $105\,\text{mV} - (-135\,\text{mV}) = 240\,\text{mV}$. Using the simulated flexo-offset correlation for E7 where $20\,\text{pC/m}$ correspondent to $106\,\text{mV}$, the sum $(e_1 + e_3)$ can be calculated by $20\,\text{pC/m} \cdot 240/106 = 45\,\text{pC/m}$. To avoid problems with ions the pulse length is 2 ms which should be short enough so that ions are not able to move to the edge of the device and cancel out the electric field. However applying asymmetric pulses e.g., 1 V and $-0.895\,\text{V}$, leads to a net dc voltage which causes ionic drift. This problem is avoided in the experiment by applying a third pulse which is also 2 ms long and appears 50 ms after the negative pulse. The magnitude of this third pulse is equal to the offset but the sign is opposite to compensate for the offset e.g., $-105\,\text{mV}$.

5. RESULTS

Using our new method, the eight materials E7, CB, PCH, DE, E70A, MDA-02-2419, Material B [17], and MLC-7029 were measured at room temperature (22°C) and investigated, as shown in Table 1. TL216, as mentioned before, is non-ionic and has a very small flexoelectricity

TABLE 1 Overview of measured offset at room temperature (22°C) and simulated flexo-offset correlation. Results are shown for the sum $(e_1 + e_3)$ of the flexoelectric coefficients

Material	Offset measured	Simulated Flexo-Offset correlation	Flexo sum $(e_1 + e_3)$
TL216	−0.135 V	–	–
E7	0.105 V	0.106 V per 20pC/m	45 pC/m ± 50%
CB	0.080 V	0.096 V per 20pC/m	45 pC/m ± 50%
PCH	0.145 V	0.116 V per 20pC/m	48 pC/m ± 50%
DE	0.135 V	0.117 V per 20pC/m	46 pC/m ± 50%
E70A	0.065 V	0.117 V per 20pC/m	34 pC/m ± 50%
MDA-02-2419	0.125 V	0.051 V per 20pC/m	102 pC/m ± 50%
Material B [17]	0.145 V	0.049 V per 20pC/m	114 pC/m ± 50%
MLC-7029	−0.210 V	0.217 V per 20pC/m	−7 pC/m ± 50%

TABLE 2 Comparing dielectric permittivity $\Delta\epsilon$ and the sum $(e_1 + e_3)$, which indicates a correlation. The data were taken at room temperature (22°C)

Material	Dielectric permittivity $\Delta\epsilon$	Flexo sum $(e_1 + e_3)$
TL216	5.1	1pC/m
E7	13.7	45 pC/m ± 50%
CB	13.2	45 pC/m ± 50%
PCH	12.2	48 pC/m ± 50%
DE	9	46 pC/m ± 50%
E70A	10.4	34 pC/m ± 50%
MDA-02-2419	38.5	102 pC/m ± 50%
Material B [17]	42.1	114 pC/m ± 50%
MLC-7029	−3.7	−7 pC/m ± 50%

[11], which can be neglected. It was used to determine the internal bias of $-0.135\,\text{V}$ for the batch of HAN cells. The "Offset measured" in the table presents the change in magnitude required in one of the pulses, to cancel out flexoelectricity and internal bias. Subtracting from this "Offset measured" the internal bias of $-0.135\,\text{V}$ gives the offset which correlates to flexoelectricity, which is not shown in the table. Using the calculated "flexo-offset correlation factor", which depends on the material and has to be simulated for each material, the sum $(e_1 + e_3)$ can be calculated. The materials E7, CB, PCH, DE, and E70A show a medium flexoelectric value compared to MDA-02-2419 and Material B [17], which show a high value, and MLC-7029 a negative and low value. The errors (50%) are somewhat arbitrary estimates and are very high because of the assumptions made about the internal bias.

Comparing now the dielectric permittivity $\Delta\epsilon$ values with the sum $(e_1 + e_3)$, as shown in Table 2, the two materials MDA-02-2419 and Material B [17] have large dielectric permittivity $\Delta\epsilon$ values and also the highest sum $(e_1 + e_3)$ values here measured. The other materials have typical dielectric permittivity $\Delta\epsilon$ values and show medium sum $(e_1 + e_3)$ values. MLC-7029 has a small negative dielectric permittivity $\Delta\epsilon$ value with also a small negative sum $(e_1 + e_3)$ value. This indicates a correlation between dielectric permittivity $\Delta\epsilon$ values and the sum $(e_1 + e_3)$.

6. CONCLUSION

The new experiment described is a fast, simple and easy approach to measure the sum $(e_1 + e_3)$ of the flexoelectric coefficients and one material takes less than 10 min. Also the calculation of the flexo-offset correlation is quick as well and has to be done just once for each material. However, the assumption that the internal bias is constant and just depends on the homeotropic alignment material and not on the liquid crystal material or ions, leads to a big error margin. This means that it is not possible yet to measure accuratly the sum (e_1+e_3). The results are only estimations but take the internal bias into account. Our method, allows us to measure different materials quickly and classify the sum (e_1+e_3) of the flexoelectric coefficients as high, middle, low, and negative. We are interested in improving the accuracy of measurement. If it would be possible to determine the internal bias for each material and cell individually, it would improve the accuracy and lead to a fast, simple, and accurate experiment to determine the sum (e_1+e_3) of the flexoelectric coefficients.

The results show an interesting trend. E7, CB, PCH, DE, and E70A are materials with a dielectric permittivity $\Delta\epsilon$ between 9 and 14 and show a middle value of the flexoelectric sum. MDA-02-2419 and Material B [17] have a dielectric permittivity $\Delta\epsilon$ of around 40 and shows a high sum. MLC-7029 dielectric permittivity $\Delta\epsilon$ is -3.5 with a small and negative sum. This indicates a correlation between dielectric permittivity $\Delta\epsilon$ and the sum (e_1+e_3), as shown in Table 2. A similar correlation was found between dielectric permittivity $\Delta\epsilon$ and the difference (e_1-e_3) [18].

The materials CB, PCH, and DE are mixtures made of the homologues 3/5/7 with a ratio of 30/40/30% [19]. These three materials are similar except that one of the ring structures and the link between the two rings varies. The results indicate that the ring structure and link between the rings has some influence on the elastic, dielectric and refractive properties [19–21] but only a small influence on the flexoelectric coefficients. The measured sum (e_1+e_3) for all three materials is in the region of 46 pC/m.

REFERENCES

[1] Meyer, R. B. (1969). *Phys. Rev. Lett.*, *22*, 918.

[2] Patel, J. S. & Meyer, R. B. (1987). *Phys. Rev. Lett.*, *58*, 1538.

[3] Bryan-Brown, G. P., Wood, E. L., Brown, C. V., Jones, J. C., Sage, I. C., & Brett, P. (1997). *Proc. IDW '97* PLC2-1, 261.

[4] Bryan-Brown, G. P., Brown, C. V., Jones, J. C., Wood, E. L., Sage, I. C., Brett, P., & Rudin, J. (1997). *SID Digest XXVIII*, *5.3*, 37.

[5] Parry-Jones, L. A., Edwards, E. G., Elston, S. J., & Brown, C. V. (2003). *Appl. Phys. Lett.*, *82*, 1476.

[6] Brown, C. V., Parry-Jones, L. A., Elston, S. J., & Wilkins, S. J. (2004). *Molec. Crys. Liq. Crys.*, *410*, 417.

[7] Madhusudana, N. V. & Durand, G. (1985). *J. de Phys. Lett.*, *46*, L195.
[8] Warrier, S. R. & Madhusudana, N. V. (1997). *J. de Phys. II*, *7*, 1789.
[9] Mazzulla, A., Ciuchi, F., & Sambles, J. R. (2001). *Phys. Rev. E*, *64*, 021708.
[10] Jewell, S. A. & Sambles, J. R. (2002). *J. Appl. Phys.*, *92*, 19.
[11] Kischka, C., Elston, S. J., & Raynes, E. P. (2007). *BLCS conference 2007 in Sheffield (UK)*, [Determined using a symmetric Pi cell in the bend tate].
[12] Frank, F. C. (1958). *Discussions of the Faraday Soc.*, *25*, 19.
[13] Eriksen, J. L. (1961). *Trans. Soc. Rheol*, *5*, 23.
[14] Leslie, F. M. (1968). *Archive for Rational Mechanics and Analysis*, *28*, 265.
[15] Parodi, O. (1970). *J. de Phys.*, *31*, 581.
[16] Jones, J. C. (1941). *J. Opt. Soc. Amer.*, *31*, 488.
[17] Jones, J. C., Beldon, S. M., Brett, P., Francis, M., & Goulding, M. (2003). *SID Digest XXXIV*, *26.3*, 954.
[18] Kischka, C., Parry-Jones, L. A., Elston, S. J., & Raynes, E. P. (2007). *Journal of Applied Physics*, unpublished result.
[19] Bradshaw, M. J., McDonnell, D. G., & Raynes, E. P. (1981). *Molecu. Crys. Liq. Crys.*, *70*, 289.
[20] Bradshaw, M. J., Constant, J., McDonnell, D. G., & Raynes, E. P. (1983). *Mole. Crys. Liq. Crys.*, *97*, 177.
[21] Bradshaw, M. J. & Raynes, E. P. (1983). *Mole. Crys. Liq. Crys.*, *91*, 145.