Romanian Reports in Physics, Volume 55, Number 1, P. 124 - 129, 2003

ON AN ULTRASONIC METHOD FOR LIQUID CRYSTAL ELASTIC CONSTANTS DETERMINATION

M. TINTARU, R. MOLDOVAN, A. IUGA, T. BEICA, I. ENACHE

National Institute for Materials Physics, R-76900, Bucharest-Magurele, P.O. Box MG 7, Romania

(Received July 30, 2002)

Abstract. The paper presents a new ultrasonic method for the elastic constants determination of liquid crystals, using small quantities of material. The results for the nematic liquid crystal ZLI 1132 (Merck) are compared with those obtained by the well-known optical method. The new method is best adequate for the splay elastic constant determination.

Key words: liquid crystal, elastic constant, ultrasonic spectroscopy

1. INTRODUCTION

The most important application of liquid crystals is in the field of display devices. The performances of these devices depend among other things, on the elastic properties of the liquid crystal. There are three so-called Frank elastic constants associated with each type of bulk deformation of liquid crystals, namely, splay (k_{11}), twist (k_{22}) and bend (k_{33}) elastic constant. Therefore, precise measurement of the Frank constants represents an important subject both for the display design and for a better knowledge of the liquid crystal physical properties.

There are a large variety of experiments that provide data on the elastic properties of nematics. However, the most frequently, to measure elastic constants one chooses director deformations generated either by external electromagnetic fields in a suitable simple geometry (Fréedericksz transition) [1-4], or director deformations imposed by the surface anchoring conditions in nontrivial geometries such as droplets, cylindrical cavities or hybrid aligned films [5-8].

Usually, the detection of the director field deformations by an external field action is done by optic or by capacitance measurements [9, 10], but there are also other detection methods such as ultrasonic ones [11 - 13].

Using the electric field, the most straightforward method to determine the elastic constants is via the observation of the threshold voltage, at which the Fréedericksz transition is obtained (Fréedericksz threshold). For a nematic liquid crystal with positive dielectric anisotropy ($\Delta\varepsilon>0$), the determination of the elastic constants by threshold measurements requires a homogeneous planar cell (P) or a 90° twisted planar one (TN). The threshold voltages are given by:

$$U_{th}^{P} = \pi\sqrt{\frac{k_{11}}{\varepsilon_0 \Delta\varepsilon}}\,, \qquad (1)$$

for the homogeneous planar geometry, and

$$U_{th}^{TN} = \pi\sqrt{\frac{1}{\varepsilon_0 \Delta\varepsilon}\left[k_{11} + \frac{k_{33} - 2k_{22}}{4}\right]} \qquad (2)$$

for the twisted planar one. ε_0 is dielectric constant of vacuum.

Using the results of the threshold measurements for the two geometries, one can determine k_{11} and the constant k, defined as the relation between bend and twist elastic constants:

$$k = k_{33} - 2k_{22}. \qquad (3)$$

In this paper we present the results of the elastic constants measurements for a nematic liquid crystal, using a new ultrasonic detection method that allows the using of small quantities of liquid crystal. Our purpose is to find a more simple and direct way to measure the liquid crystal elastic properties. Therefore we compare the proposed method with the well-known optical detection.

Our paper is organized as follows: the experimental part is described in Section II; in this section, the experimental results for a nematic liquid crystal are also presented using both optical and ultrasonic detection; Section III is devoted to the discussion of the experimental results and to the conclusions.

2. EXPERIMENTAL

2.1. Sample preparation

The samples used in the experimental investigations were prepared from planar glass plates, 1.5mm thick, covered with a transparent conductive layer of indium-tin oxide. The planar alignment was assured by a vacuum deposition of SiO at an incidence angle of 60°. The two glasses forming a cell were mounted so that either a homogeneous planar cell, or a 90°- twisted planar cell were obtained. The cell gap was assured by use of Mylar spacers, 75μm thick. The cells were filled with the nematic commercial mixture ZLI 1132 (Merck) having the nematic range -6° ÷ +70°C.

2.2. Experimental method

The liquid crystal samples were introduced into a homemade acoustical cell (Figure 1).

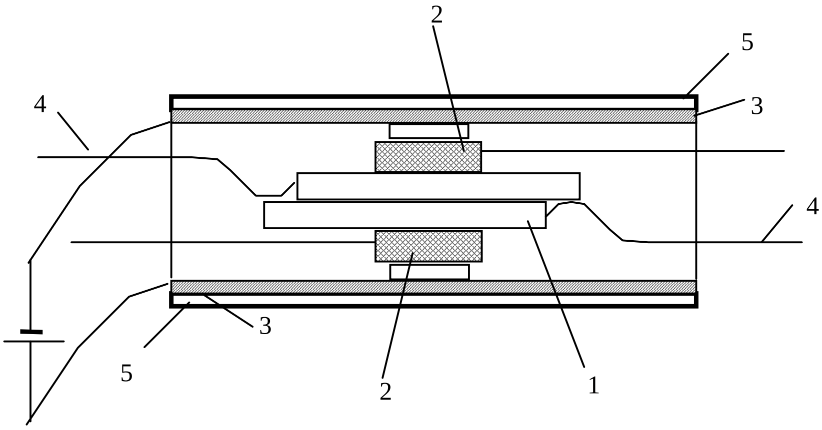


Fig. 1

The acoustical cell
1-liquid crystal sample; 2-piezo-ceramics transducer; 3-heater resistance; 4-elastic electric contact; 5-thermic insulator

The cell ensured the acoustical coupling between the transducers (2) and the liquid crystal sample (1), and, also, the temperature control. The temperature control was performed using an electric heater (3) commanded by a computational program. In this way, the temperature could be maintained at any desired value to an accuracy of 0.02°C. The acoustical cell was provided also with elastic electric contacts (4) for applying the a.c. electric field.

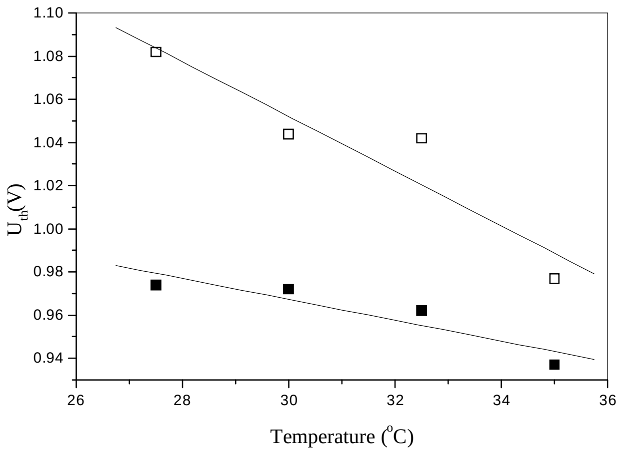
As ultrasonic measurement method, we used the Fabry-Perot type spectroscopy. The ultrasonic investigation was carried out through the combined use of a HP 4194A Impedance/Gain-Phase Analyser and a pair of ultrasonic longitudinal wave transducers. When a planar sample is submitted to a sweeping frequency sound, interference between incident and reflected waves takes place, and thus, a Fabry-Perot interference spectrum is generated. The used ultrasound intensity value was of 1mW/cm^2. The determinations were performed both on the homogeneous planar sample, and the 90°- twisted one. For each case, we followed the variation (ΔI) of a chosen interference maximum in the presence and the absence of the electric field, respectively. By extrapolating to zero the linear part of ΔI vs. applied voltage, the threshold for Fréedericksz transition was obtained. The measurements were made at several temperatures in the nematic range.

In order to verify our method, the elastic constants k_{11} and k were determined using optical detection by measuring the change in birefringence of a liquid crystal sample with applied electric field.

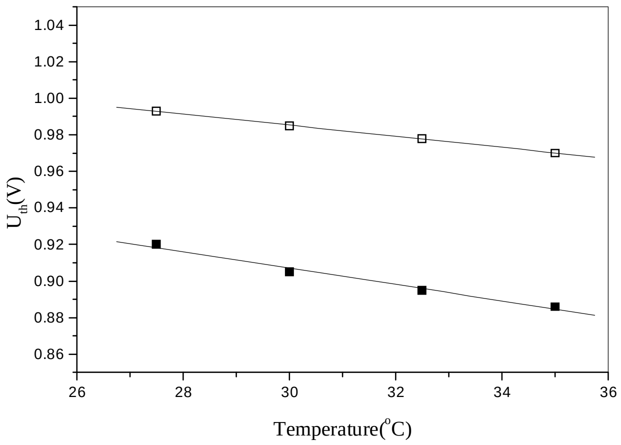
Experimentally, one records the transmission of the light as function of applied field. Above the Fréedericksz threshold, successive minima and maxima occur. The transmission of the light as a function of the applied voltage, both for homogeneous and twisted planar cells was recorded. The measurements were performed at the same temperatures as for the ultrasonic detection. With the aid of a computational program carried out by us, the voltage values corresponding to the extrema of the transmitted light intensity, were identified. Then, the phase difference (until a constant factor) vs. applied voltage was plotted. By extrapolating to zero the linear part of the curve, one obtained the Fréedericksz threshold value.

2.3. Experimental results

In Figure 2, the experimental results for Fréedericksz threshold obtained by using the two detection methods, for both studied geometries, are presented. It can be seen that the threshold for the twisted planar cell remains greater than that for the homogeneous one in the whole investigated temperature range. One can also remark the diminution of the threshold voltage with the temperature increasing, for both studied geometries. From both detection methods for the homogeneous geometry, a quasi-linear threshold variation in function of temperature is observed. In the case of the twisted sample, the ultrasonic results present a greater dispersion.



(a)



(b)

Fig. 2 - The threshold voltage of Fréedericksz transition, U_{th}, vs. temperature determined from: a) ultrasonic detection; b) optical detection
■ - homogeneous planar geometry; ☐ - 90° - twisted planar geometry
Continuous curves are obtained by fitting with linear functions.

The experimental data for Fréedericksz threshold in the two geometries were fitted with linear functions. The fitting functions are given by:

$$U_{th}^{p} = 1.1125 - 0.00484 \cdot t \qquad (4)$$

for the planar geometry, and

$$U_{th}^{TN} = 1.4325 - 0.01268 \cdot t \qquad (5)$$

for the twisted one. t is the temperature in Celsius degrees.

Using the fitting functions (4), (5) and eqs. (1) and (2), the temperature dependencies of elastic constants, k_{11} and k, were established. The results are given in Table 1.

Table 1
Comparison of elastic constant values determined by ultrasonic and optical methods

Method / Temperature (°C)	$10^{6}\cdot k_{11}$ (dyne)		$10^{6}\cdot k$ (dyne)	
	Ultrasonic	Optical	Ultrasonic	Optical
27.7	0.88	0.78	0.20	0.13
30.0	0.86	0.76	0.16	0.14
32.5	0.84	0.74	0.12	0.14
35.0	0.82	0.72	0.08	0.14

3. DISCUSSION AND CONCLUSIONS

The ultrasonic Fabry-Perot type spectrum for liquid crystal samples proved to be sensitive to the action of an electric field, allowing the elastic constants determination from the Fréedericksz threshold value. Our results showed that for the studied liquid crystal (ZLI 1132) the splay elastic constant k_{11} has a value comparable with that known for most thermotropic liquid crystals, $k_{11} \cong 1 \cdot 10^{-6}\,\mathrm{dyne}$. The elastic constant k_{11} slowly decreases with temperature in the studied range (with about 5%). These results are in accordance with those obtained by the optical detection. We also observe that in the ultrasonic measurements, the values of k_{11} are systematically greater with about 10% than those obtained from the optic measurements. Taking into account the low intensity of the ultrasonic field used in our experiment (about 10^2 times lower than acousto-optical thresholds known from literature [14]), a disturbing effect on the liquid crystal homogeneous planar structure is unlikely. Therefore, we believe that the disagreement between the results obtained by the two methods is due to the insufficient sensitivity of the used transducers.

As it is shown in Table 1, the value of k obtained by the optical method remains constant on all the temperature range, and equal to about $0.14 \cdot 10^{-6}$dyne. In the ultrasonic determination of this constant, we obtained a relative great dispersion of results due to the dispersion threshold values in the planar twisted cell geometry. This could be explained by a possible untwisting effect of the acoustical field on this structure [15]. To limit the effects of this dispersion, we used in the k determination the values found by fitting the experimental data with a linear function. In this way, we obtained in the ultrasonic method the decreasing trend with temperature shown in Table 1. Although in the ultrasonic method k has a different behavior with temperature, its mean value coincides with that determined by the optical method.

In conclusion, taking into account the results of the comparative analysis, the ultrasonic detection, can be successfully used for elastic constant determination in homogeneous geometries for which the disturbing effect of the ultrasonic field is weaker. The precision of this method can be improved by using more sensitive transducers.

More, unlike the most ultrasonic methods, the interferential method, proposed in this paper, uses small quantities of liquid crystal. Comparing with the optical method, the ultrasonic detection is a more direct and rapid. Thus, the last method allows the direct determination of the Fréedericksz threshold by extrapolating the variation curve of the chosen interference maximum from ultrasonic spectrum, while, the optical method involves the additional processing of the experimental data.

Acknowledgements: The authors thank the Romanian Ministry of Education and Research for the financial support under the Grant No.5077/1999.

References

[1] P.G. DE GENNES, J. PROST, *The Physics of Liquid Crystals*, Oxford University Press (1993)

[2] *Handbook of Liquid Crystals*, ed. by D. DEMUS, J. GOODBY, G.W. GRAY, H.W. SPIESS, V. VILL, (Wiley-VCH), 1998

[3] H. GRULER, T.J. SCHEFFER, G. MEIER, "Elastic constants of nematic liquid crystals", Z. Natruforsch. **27a**, 966 (1972)

[4] H. DEULING, "Deformation of nematic liquid crystals in an electric field", Mol.Cryst.Liq.Cryst. **19**, 123 (1972)

[5] G.P. CRAWFORD, J.A. MITCHELTREE, E.P. BOYKO, W. FRITZ, S. ZUMER, J.W. DOANE, "k_{33}/k_{11} determination in nematic liquid crystals: An optical birefringence technique", Appl.Phys.Lett. **60**, 3226 (1992)

[6] A. SAUPE, "Disclinations and properties of the director field in nematic and cholesteric liquid crystals", Mol.Cryst.Liq.Cryst. **21**, 211 (1973)

[7] S. CHEN, B.J. LIANG, "Stability of a hedgehog nematic configuration in a small cylindrical cavity", Appl.Phys.Lett. **59**, 1173 (1991)

[8] S. FAETTI, "The effects of curvature on nematic liquid crystals confined in a cylindrical cavity", Phys.Lett. A **237**, 264 (1998)

[9] A. SCHARKOWSKI, H. SCHMIEDEL, R. STANNARIUS, E. WEISSHUHN, "Elastic constants of nematic

phenylpyrimidines determined by two different methods", Z. Naturforsch. Teil a **45**, 37 (1990)

[10] A. SCHARKOWSKI, H. SCHMIEDEL, R. STANNARIUS, E. WEISSHUHN, "Elastic constants and diamagnetic susceptibility of nematic liquid crystals determined by a combined electro-magneto-optical methods", Mol.Cryst.Liq.Cryst. **191**, 419 (1990)

[11] J.C. BACRI, "Magnetic field effects on the attenuation and velocity of ultrasonic waves in a nematic liquid crystal", J.Phys. (Paris) **35**, 601 (1974)

[12] J.C. BACRI, "Divergence de la constante de Frank K_{33} et de l'atténuation ultrasonore au-dessus d'une transition smectique à nématique", J.Phys. (Paris) **36**, C1-123 (1975)

[13] T.HATAKEYAMA, Y. KAGAWA, "Effects of electric fields on the ultrasonic attenuation in liquid crystals", J.Chem.Phys. **65**, 4128 (1976)

[14] M. WITOWSKA-BORYSEWICZ, A. SLIWINSKI, "Optically detected variation of nematic liquid crystal orientation induced by ultrasound", J.Phys. (Paris) **44**, 411 (1983)

[15] O.A. KAPUSTINA, *Acoustical Phenomena in Liquid Crystals* (ed. M.M. Labes), Gordon & Breach, London, pp.1-164 (1984)