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

Apparatus for High-Resolution Birefringence Measurement in Liquid Crystals

Khoon-Cheng Lim [a] & John T. Ho [a]
[a] Department of Physics and Astronomy, State University of New York at Buffalo, Amherst, New York, 14260
Version of record first published: 28 Mar 2007.

To cite this article: Khoon-Cheng Lim & John T. Ho (1978): Apparatus for High-Resolution Birefringence Measurement in Liquid Crystals, Molecular Crystals and Liquid Crystals, 47:3-4, 173-177

To link to this article: http://dx.doi.org/10.1080/00268947808083741

Mol. Cryst. Liq. Cryst., 1978, Vol. 47, pp. 173–177

Printed in Holland

Apparatus for High-Resolution Birefringence Measurement in Liquid Crystals

KHOON-CHENG LIM and JOHN T. HO

Department of Physics and Astronomy, State University of New York at Buffalo, Amherst, New York 14260

(*Received March 6, 1978; in final form April 29, 1978*)

A rotating-analyzer technique for measuring the optical birefringence in liquid crystals is described. This apparatus is continuously readable and has excellent sensitivity. For a sample 50 μm thick, the apparatus has a resolution in the change of birefringence of 4×10^{-6}, corresponding to a temperature change of 1 mK in the sample tested.

I INTRODUCTION

The common liquid crystal phases, such as the nematic and the smectic A, are uniaxial. The optical birefringence $\Delta n = n_{\parallel} - n_{\perp}$ is a useful measure of the degree of orientational order, where $n_{\parallel}$ and $n_{\perp}$ are the refractive indices parallel and normal to the director, respectively.[1] Many interesting studies on the properties of liquid crystals involve measuring small changes in Δn as a function of temperature or external fields. Several methods of measuring Δn have been used. They include the Chatelain prism method,[2] the temperature scan method,[3] the wedged sample method,[4] the spectrophotometer method,[5] and the synchronous detection method.[6] Most of these techniques are not particularly suitable in studies where a high resolution in changes in Δn is required. We have constructed an apparatus for measuring Δn which is continuously readable and has a high sensitivity.

II APPARATUS

Our apparatus is inspired by the rotating-analyzer technique used in ellipsometry.[7] The experimental setup is shown in Figure 1. Polarized light at wavelength $\lambda = 633$ nm from a He–Ne laser is divided into two beams with a

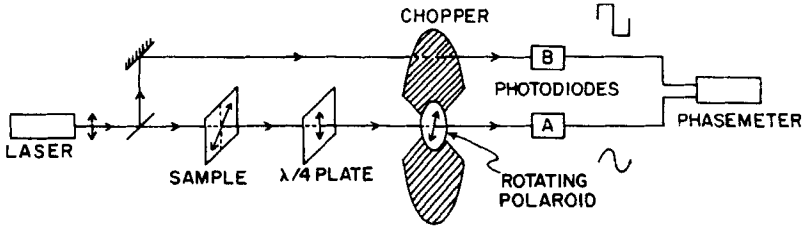

FIGURE 1 Experimental setup.

beamsplitter. The main beam passes through successively the sample, a quarter-wave plate and a rotating polaroid before reaching the photodiode *A*. The liquid crystal sample is sandwiched between glass slides with the director aligned in a direction parallel to the slides. The alignment axis is oriented at an angle of 45° to the laser polarization direction. The axis of the quarter-wave plate is adjusted to be along the laser polarization direction. The polaroid is mounted at the end of the hollow shaft of a synchronous motor running at 1800 rpm. The light intensity at photodiode *A* has a sinusoidal time dependence. The frequency of the signal is twice that of the motor and its phase depends on the birefringence of the sample. The shaft of the motor also carries a light chopper, which intercepts the second beam twice in each revolution before the light reaches the second photodiode *B*. The signal at photodiode *B* is therefore a square wave with the same frequency as the signal at photodiode *A* but with a constant phase. The relative phase difference between the two signals is measured with a sensitive phasemeter and digitally displayed or logged.

If d is the thickness and Δn is the birefringence of the sample, the phase difference δ between light polarized parallel and perpendicular to the sample alignment axis has the value

$$\delta = \frac{2\pi d\Delta n}{\lambda}. \tag{1}$$

The light emerging from the sample is elliptically polarized. The quarter-wave plate renders the light plane-polarized again, but with its polarization direction rotated at an angle θ from the original direction, where

$$\theta = \frac{\delta}{2}. \tag{2}$$

If ω is the frequency of the motor, the light intensity I after the rotating polaroid varies with time t as

$$\begin{aligned} I &= 2I_0 \cos^2(\omega t + \theta) \\ &= I_0[1 + \cos(2\omega t + 2\theta)]. \end{aligned} \tag{3}$$

Thus the ac signal at photodiode A has a frequency of 2ω and a relative phase ϕ equal to

$$\phi = 2\theta = \delta. \tag{4}$$

In practice, the thickness d is such that

$$\delta = \delta' + 2\pi N, \tag{5}$$

where N is an integer and δ' is the reading on the phasemeter. The birefringence Δn is given by

$$\Delta n = \frac{\lambda \delta'}{2\pi d} + \frac{\lambda N}{d}. \tag{6}$$

A change in the phasemeter reading δ' is therefore proportional to the change in Δn. The actual change in Δn can be readily calculated knowing λ and d. To obtain the value of Δn, the integer N is required. If the material has positive diamagnetic anisotropy, N can be obtained by applying a magnetic field normal to the sample and noting the number of 2π variations in the phasemeter reading between the Freedericksz critical field[1] and a field large enough to result in a saturated homeotropic alignment of the sample. Alternatively, one can measure Δn at a given temperature with any conventional method, such as using a Pulfrich refractometer. The integer N can then be obtained by measuring δ' at the same temperature and using Equation (6). It should be noted that either procedure of obtaining N has to be done only once during an experiment. In many applications, one is interested only in the relative value of Δn. In that case, the phasemeter provides a readout which is directly proportional to the change in Δn.

It can be seen from Equation (6) that the absolute calibration of the apparatus depends on the knowledge of the sample thickness d. An uncertainty in d, such as due to the compressibility and non-uniformity of the spacer, can affect the absolute value of the Δn measured. However, this does not change the accuracy of the apparatus in measuring relative changes in Δn.

III PERFORMANCE

Under ideal conditions, phase measurements can be made with an accuracy of 10^{-4} rad, usually with the help of lock-in detection. In practice, major limitations on the accuracy arise from the mechanical rigidity of the setup and the thermal stability of the sample. In our prototype apparatus, a sensitivity in δ of 2×10^{-3} rad is achieved. For a sample 50 μm thick, this implies a sensitivity in Δn of 4×10^{-6}, which is more than adequate for most applications.

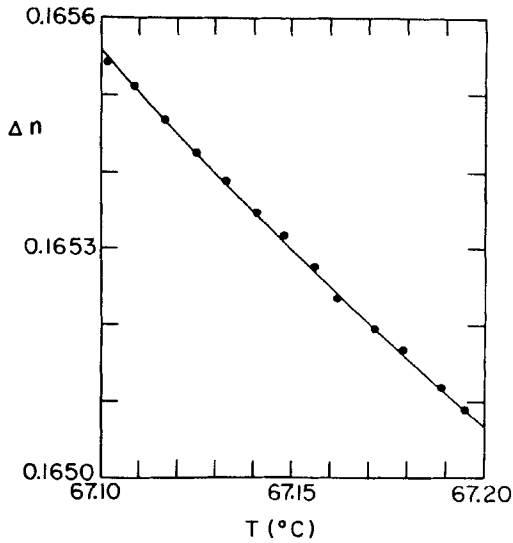

FIGURE 2 Variation in birefringence Δn of nematic 4-cyano-4′-octyloxybiphenyl in a temperature interval of 100 mK. The scale in Δn is meant to show the changes as a function of temperature. Its absolute value depends on the accuracy of the sample thickness.

We have used the apparatus to measure in detail the temperature dependence of the birefringence in 4-cyano-4′-octyloxybiphenyl.[8] A planar sample is formed between two glass slides coated with obliquely deposited SiO thin film,[9] separated by a Teflon spacer. The sample temperature is controlled to a stability of 1 mK and measured with a platinum resistance thermometer. To illustrate the resolution of the technique, Figure 2 shows a small portion of the data in a temperature interval of 100 mK in the nematic phase near the smectic A transition at 66.8°C. Clearly, the change in Δn of 4.9×10^{-4} in that temperature interval can be followed smoothly and accurately. The average temperature coefficient in Δn of $-4.9 \times 10^{-3}\ K^{-1}$ implies that the apparatus is capable of measuring a change in Δn corresponding to a temperature change of 1 mK.

This apparatus should be useful in high-resolution measurement of changes in liquid crystal birefringence occurring as a result of phase transitions, near a Freedericksz deformation, or due to large longitudinal fields. The same apparatus without the quarter-wave plate can also be used to measure optical rotatory power.[10]

Acknowledgement

This work is supported by National Institutes of Health, Research Corporation, and State University of New York University Awards Committee.

References

1. P. G. de Gennes, *The Physics of Liquid Crystals*, Oxford University Press, London (1974).
2. M. Brunet-Germain, *C. R. Acad. Sci.*, **271B**, 1095 (1970).
3. D. A. Balzarini, *Phys. Rev. Lett.*, **25**, 914 (1970).
4. I. Haller, H. A. Higgins, and M. J. Freiser, *Mol. Cryst. Liq. Cryst.*, **16**, 53 (1972).
5. R. Chang, *Mat. Res. Bull.*, **7**, 267 (1972).
6. Y. Poggi and J. C. Filippini, *Phys. Rev. Lett.*, **39**, 150 (1977).
7. J. C. Suits, *Rev. Sci. Instrum.*, **42**, 19 (1971).
8. K. C. Lim and J. T. Ho, *Phys. Rev. Lett.*, **40**, 944 (1978).
9. J. C. Janning, *Appl. Phys. Lett.*, **21**, 173 (1972).
10. P. S. Sokol and J. T. Ho, *Appl. Phys. Lett.*, **31**, 487 (1977).