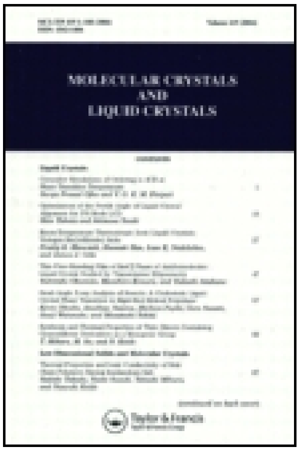


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Coherent Light Interferometry of Liquid Crystal Distortions

David Peri [a] & Dan Igner [b]

[a] Electrical Engineering Department, Technion-Israel Institute of Technology, Haifa, 32000, Israel

[b] Solid Slate Institute, Technion-Israel Institute of Technology, Haifa, 32000, Israel

Version of record first published: 20 Apr 2011.

To cite this article: David Peri & Dan Igner (1984): Coherent Light Interferometry of Liquid Crystal Distortions, Molecular Crystals and Liquid Crystals, 102:4, 87-94

To link to this article: http://dx.doi.org/10.1080/01406568408070517

Mol. Cryst. Liq. Cryst. Volume 102 (Letters), pp. 87-94
0140-6566/84/1024-0087$18.50/0

COHERENT LIGHT INTERFEROMETRY OF LIQUID CRYSTAL DISTORTIONS

DAVID PERI
Electrical Engineering Department, Technion-Israel Institute of Technology, Haifa 32000, Israel.

and

DAN IGNER
Solid State Institute, Technion-Israel Institute of Technology, Haifa 32000, Israel.

(Received for Publication April 25, 1984)

Abstract: Attention is drawn to the fact that coherent light interferometry can provide a systematic method for finding director distributions at liquid crystal distortions. Exploratory experiments are described and discussed.

There is no need to stress the interest in knowing the director orientation at liquid crystal distortions caused by defects, boundary conditions and/or by magnetic, electric, gravitation and flow fields. One would like to have systematic quantitative methods for study of these orientation distortions. The purpose of this letter is to draw the attention to the fact that coherent light interferometry could provide such a method.

In the past, interferometry has been used for study of liquid crystal distortions[1]. The probing rays passed through the sample give information on the refractive index field of the extraordinary ray $\nu_e(x,y,z)$. $\nu_e(x,y,z)$ is a function of the mutual orientation between the ray and the local director $n(x,y,z)$, and one can get $n(x,y,z)$ out of it. However, the past applications were based on the information given by rays passing the sample on a straight path, thus limiting the methods to special cases since most distortions deflect rays. Surprisingly, it seems that no attention has been given to the fact that use of coherent light can bring to the retrieval of the information carried by deflected rays. We will try to clarify this point later in this letter.

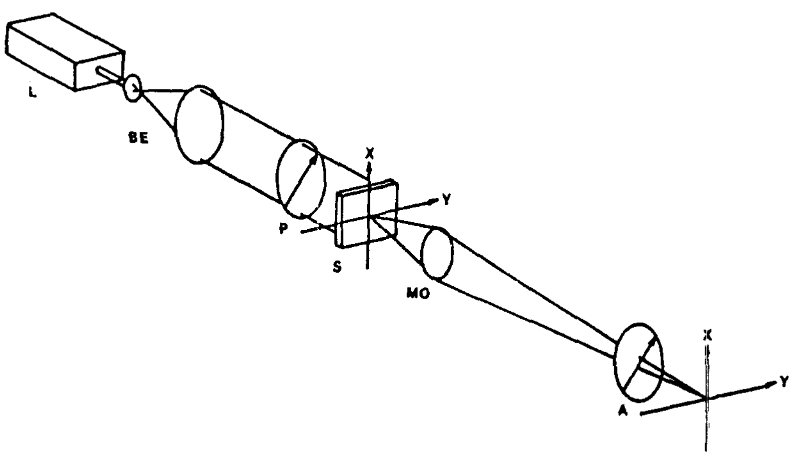


Fig. 1: On-line viewing system.
L - laser, BE - beam expander, P - polarizer, S - sample, MO - microscope objective, A - analyzer.

In order to explore possible applications, two interferometric set-ups using coherent light were tried.

The first set-up is shown schematically in Fig. 1. It is simply a polarizing microscope set-up with coherent parallel light illumination. Photograph 1, taken with this set-up, is of a Williams Domains (W.D.) pattern[2] formed in a $125\mu m$ MBBA planar sample viewed between crossed polarizers. The polarizers were oriented at 45° in respect to the initial director orientation. The plane in focus is somewhere between the plane in which divergently focused W.D. lines and the planes in which convergently focused lines appear when the sample is viewed in ordinary noncoherent light[2].
When the position of the plane in focus is changed, the fringe pattern changes too. No fringe pattern is seen when monochromatic "noncoherent" light is used. The fringe pattern formation in coherent light can be explained as follows. The linearly polarized rays normally incident on the sample divide into extraordinary (e.o.) and ordinary (o.) rays. While the o. rays propagate without changing direction, the e.o. rays are deflected (refracted) by regions in which the distortions in the sample produce nonzero $\partial \nu_\theta / \partial x$ and $\partial \nu_\theta / \partial y$ gradient components (coordinates defined in Fig. 1). The o. ray and the deflected e.o. ray which originate from the same ray incident on the sample will usually not intersect at the image plane. No interference between e.o. and o. rays is observed in W.D. patterns when viewed in ordinary "noncoherent" light because

the o. and e.o. rays which intersect at the image plane originate at different places in the object plane and therefore are not coherent. When coherent plane wave illumination is used, the phase of all o. rays is the same at any z = const. plane in the sample. Because of the long range transverse coherence, the deflected e.o. rays interfere with whatever o. rays they meet in the image plane and interference fringes are formed. Since the polarization vectors of e.o. and o. rays are mutually perpendicular and their interference brings to creation of elliptically polarized light, one must use an analyzer in order to translate phase information into intensity information[3]. This example shows that the set-up of coherent light microscope of Fig. 1 is an interferometer in which o. waves serve as reference and the e.o. waves as probing waves.

In fact, we need to precise that ordinary "noncoherent" microscope illumination possesses a transverse coherence of the order of a few wave lengths. Use of single spectral line (e.g. from a low pressure gas discharge lamp), careful collimation starting from a small size source can increase the transverse coherence to hundreds of μm while the transverse coherence from a common single mode He-Ne laser is as its output beam cross section and can easily expanded to the transverse size of a typical sample. Remarkable photographs of interference fringes created by distortions associated with point disclinations of strength ±2 in nematics have been produced in the past when care was taken in using well collimated monochromatic light[1a,b]. One may remark that increasing monochromaticity of light and collimation is equivalent to improving temporal and spatial coherence respectively. Much of the fringe pattern presented in Ref. (1b) could probably be attributed to interference with participation of deflected e.o. rays. This interference, we believe, was made possible by increased coherence due to improved monochromaticity and collimation. While calculations could decide if this is true for the specific distortions of Ref. (1b), we have no doubt that in the case of W.D. with proven strong lateral deflection of rays[2], the fringe patterns are made possible because of coherence of the laser beam used in set-up of Fig. 1. Interference fringes produced by distortions associated with $s = \pm 2$ singular points (as in Ref. 1b), singular lines and walls in nematics were easily obtained with this set-up (see photos 1-4).

Methods of calculation of $\nu(x,y,z)$ which can apply to the data yielded by the set-up of Fig. 1 are available. Some of these methods are explained and reviewed in Ch. 6 of Ref. 4. For practical purposes one distinguishes three main cases (criteria given in Ref. 4). In the simplest one, νe is not dependent on z (the coordinate along the direction of the input ray), and lateral deflection is negligible. Retrieving $\nu_e(x,y)$ is trivial since the bright fringes are formed in this case at places where

$$N\cdot\lambda = \int_0^d (\nu_e(x,y) - \nu_o)dz = d\cdot(\nu_e(x,y)-\nu_o) \tag{1}$$

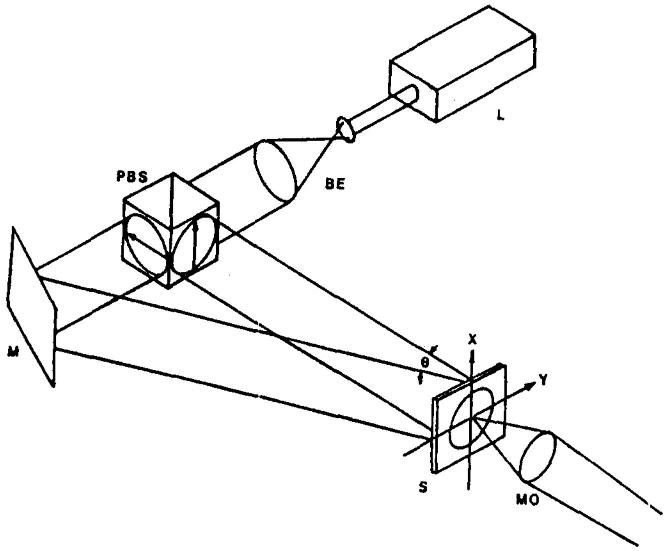


Fig. 2: Off-line viewing system.
L - laser, BE - beam expander, PBS - polarizing beam splitter, M - mirror, S - sample, MO - microscope objective.

N - integer; λ - wavelength; d - sample width.

In case there is transverse deflection but still no z dependence of ν, there are methods to calculate deflection error terms even for strongly refracted rays[5a], or else iterative schemes can be used[5a,b]. Also in this case, depending on the specific properties of the sample, there might exist a particular plane in the sample so that if the microscope is focused on this particular plane, the deflection effects on the fringes are minimized to the point that no correction is necessary, and one might use eq. (1) as though the fringes were formed by rays traveling only in the z-direction (Ch. 6 of Ref. 4).

In case ν_θ has z dependence, probing of the sample with light traveling in a few different directions is necessary. For this case schemes using Fourier Transforms, Radon Transforms and other methods[5a] were applied or proposed.

In the second set-up we tried (Fig. 2), the laser beam is divided by a polarizing beam-splitter into two linearly polarized beams with mutually perpendicular polarization directions. The two beams are made to meet at an angle ϑ in the plane where the W.D. sample is to be inserted. In the absence of the sample, interference fringes can be viewed if an analyzer is used (inset photo 5). The distance between the fringes is given by $\delta=\lambda/\sin\vartheta$. Care is taken to have the direction of the fringes parallel to the polarization of one of the beams. This beam serves as e.o. beam and should be normal to the sample plane. If the W.D. sample is then inserted with the W.D. perpendicular to the fringes, transverse modulation of the fringes is observed. This happens because of modulation of the optical paths of the e.o. rays passing through the W.D. distortions.

A particularly simple-to-analyze pattern is obtained if the plane in focus is a plane where the field is seen uniformly illuminated when only e.o. rays are passed through the sample. In this case only the phase modulation effects are contributing and intensity effects (caused by refractions) are canceled. Such a plane exists in a W.D. sample and is situated somewhere between the plane where the W.D. lines are divergently focused and the planes of convergently focused W.D. lines. The resulting modulated fringes for a $50\mu m$ sample of MBBA at $\approx 1V$ over the threshold is seen in photo 5. These fringes can be analyzed and information on the director angle with the x-axis extracted.

$$\int_0^d (\nu_{eff}(x,y_{oi},z)-\nu_o)dz = N_i(x,y_{oi}) \cdot \lambda \qquad (2)$$

where $N_i(x,y_{oi}) = \dfrac{y_i(x) - y_{oi}}{\delta}$.

$y_i(x)$ - local y coordinate on fringe i. (y is oriented horizontally in photo 5); y_{oi} - y coordinate of fringe i at zero E field; d - sample width.

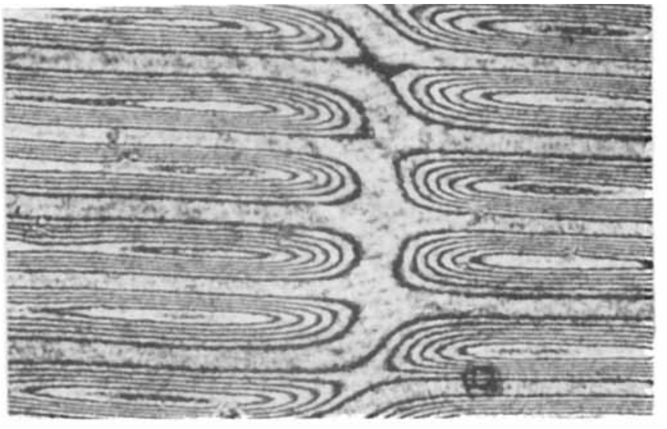
$$\nu_{eff} = \nu_e \cdot \nu_o(\nu_e^2\sin^2\psi(z) + \nu_o^2\cos^2\psi(z))^{-1/2}. \qquad (3)$$

ψ - angle between director and x-axis. Eq. 2 is valid under the assumption that the fringe spacing δ is set small enough such that $|\nu_{eff}(x,y+\delta,z)-\nu_{eff}(x,y,z)| < \dfrac{\lambda}{d}$.

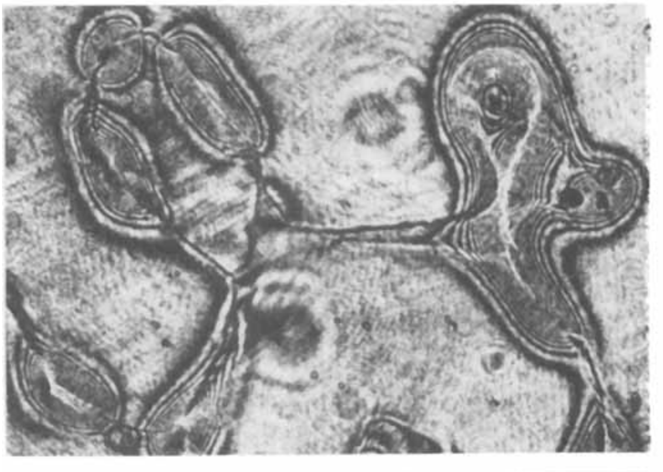
If no oblique probings of the sample are done, in order to calculate the integral of eq. (2), one must model on z dependence of ψ (e.g. as in Ref. 2).

Comparing the experiments of set-ups of Figs. 1 and 2, we note: (1) The former gives interference patterns which are easier to grasp qualitatively, being more related to the picture we see with white light illumination. (2) The latter removes ambiguities in the sign of the change of the phase between fringes. It also produces information in the form of positions which are usually easier to process than light intensities which is the product of set-up of Fig. 1.

We would also like to suggest an explanation of another interference observed in W.D. samples and apparently not dealt with in literature. When convergently focused W.D. lines are taken out of focus by moving the focal plane of the microscope away from the

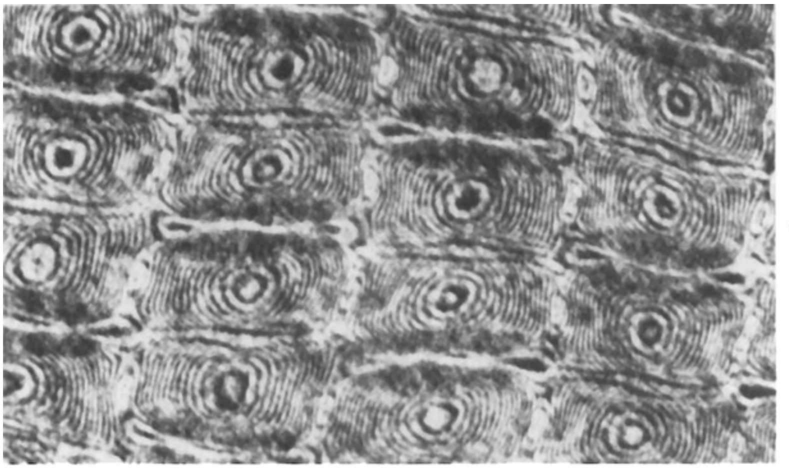


1

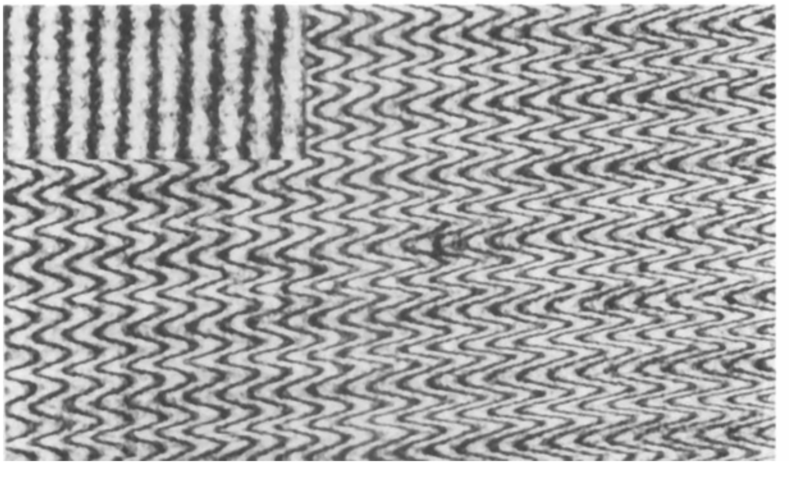


2

3



4



5

Photographs 1,2,4. Interference patterns produced by nematic distortions with set-up of Fig. 1. 1. Williams Domains with double edge dislocation .125μ, MBBA sample. 2. Distortions associated with closed surface and bulk disclination lines. 4. Grid pattern formed in homogeneously aligned 50μ, MBBA sample at 1.6 times the threshold voltage for Williams Domains.

Photo 3. As 2 but with white light illumination, no interference is seen.

Photo 5. Fringe modulation produced by 50μ, MBBA sample of Williams Domains with the set-up of Fig. 2. Inset: The fringes when no field is applied to the sample.

sample, the images of these lines enlarge laterally in both directions and split longitudinally into interference lines. This can be observed to some extent even with ordinary "noncoherent" light. The explanation we offer is that this happens because W.D. are behaving as imperfect cylindrical lenses. Because imperfection, rays incident at different distances from the yz-plane of symmetry of a Williams Domain converge into different z = *const.* focal lines in this plane (x coordinate along director alignment at zero excitation field, y along W.D., z along sample width). The cylindrical wavelets propagating out of these focus lines interfere in the focal plane of the microscope creating fringes. Similar interference is a well known phenomenon with imperfect lenses. A simple drop of water laid on a microscope slide behaves also as a non-ideal lens. When inspected with the microscope, the same effect is seen.

A gratifying bonus for someone looking at a good W.D. pattern with a microscope equipped with parallel coherent illumination is beautiful self-imaging (Talbot effect). As the distance between the objective and the sample is increased, the W.D. pattern goes out of focus and is focused again and again for as many as tens of times before it degrades.

Acknowledgement

The research was supported by the S. Faust Research Fund.

REFERENCES

1a. R.B. Meyer, *Mol. Cryst. Liq. Cryst.*, *16*, 355 (1972).

1b. R.B. Meyer, *Phil. Mag.*, *27*, 405 (1973).

1c. H. Gruler, T.J. Scheffer, G. Meier, *Z. Naturforsch.*, *27a*, 966 (1972).

2. P.A. Penz, *Mol. Cryst. Liq. Cryst.*, *15*, 147 (1971).

3. See for example G. Bruhat, *Optique* (Masson & Cie., Paris, 1959), p. 304.

4. C.M. Vest, *Holographic Interferometry* (John Wiley & Sons, New York, 1979).

5a. References given in Ch. 6 of Ref. 4.

5b. S. Cha and C.M. Vest, Opt. Lett. *4*, 311 (1979).