

BRITISH LIQUID CRYSTAL SOCIETY

LIQUID CRYSTAL NEWS

August 2005



SID/BLCS Ben Sturgeon Award for 2005

Graham Woodgate



This years Ben Sturgeon prize from the SID UK and BLCS has been awarded to Graham Woodgate (*sorry about the awful picture – ed*). The Ben Sturgeon award is give to a young scientists or engineer (under 40) who has made significant contributions to the displays field over the past 10 years. Ideally the work they are nominated for should be in the liquid crystal display field (this includes all aspects of technology used in LCDs). Under exceptional circumstances nominees from other display areas will be considered. In that case the international value of the work must be clearly demonstrated. The award will be presented at this years EID show in Edinburgh.

Graham read physics at Bristol University achieving a first class honours degree in 1987. From here Graham went on to Reading University where he did an MSc in Applied & Modern Optics gaining a distinction and picking up the Pilkington Prize for top student in 1988.

Graham began his career as an Optical Engineer at Crosfield Electronics Ltd working on the development of a novel high productivity 6000 dpi scanner for the printing industry. After three years he joined the newly set up Sharp Laboratories of Europe (SLE) in Oxford as Principal Researcher within the Imaging Optics Team. This very productive period saw Graham make a major contribution to Sharp's 3D imaging portfolio. This included the invention and

development of several autostereoscopic 3D displays and led to Sharp producing the worlds first switchable 2D/3D display cell phone. Sharp has gone on to sale 3 million units and the technology is now in laptops and LCD monitor products. In 1998 Graham was promoted to Manager of the Novel Projector Technology Group where he led the development of several novel technologies for LCD projectors. He was responsible for around 20 granted US patents during his tenure at SLE.

In 2001 with Jonathan Harrold he founded Ocuity Ltd in Oxford. Originally the company provided high value technical consultancy services in optical and electronic projects for the electronic displays and fibre-optic telecommunications industries. After a short period Graham and Jonathan began their own internal research programme into new types of optical systems. This led to the invention and demonstration of a new class of optical architectures suitable for flat panel displays. This new architecture is called Polarisation Activated Microlens™. This technology may be used for brightness enhancement which is particularly important for OLED and transfective displays as well as to produce very high quality, high efficiency, low cost switchable 2D/3D displays. This technology has been protected by a portfolio of 12 patents, the fundamental one of which is now granted. The technology has recently been licensed to a major manufacturer in Asia for productionisation (*is this a word? – ed*). The work has also been published at the IDW03 and in IDW04 where it was the recipient of the SID Outstanding paper Award.

Sally Day,
University College London.

The BLCS 2005 Committee

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BLCS Young Scientist Lecture 2004

Dual-Frequency HAN Cells: Rapid Switching with a New Twist

SHARON A. JEWELL

Thin Film Photonics Group, School of Physics, University of Exeter, UK,

Introduction

Dual-mode liquid crystal displays offer the potential to operate in either a low-power black and white reflective bistable mode for displaying simple, low resolution data or in a colour high-resolution emissive mode for the display of video-rate images. However, the relatively slow switching speed of current monochrome bistable displays, such as the ZBD¹ and PABN² devices, hinders their application in a dual-mode device. In these bistable devices two optically different states are produced by the director changing alignment at one of the surfaces resulting in two different stable configurations being permitted. The associated switching speed is governed by the mechanical and viscous properties of the liquid crystal material. An alternative way of switching a liquid crystal device between two states is to use a dual-frequency nematic liquid crystal^{3,4}. Such materials have dielectric anisotropies which are highly dependent on the frequency of the applied field; $\Delta\epsilon$ ($= \epsilon_{//} - \epsilon_{\perp}$) can be positive, negative or zero, depending on the frequency chosen. In particular, liquid crystal compounds are available where the dielectric permittivity is highly dispersive, resulting in the dielectric anisotropy actually changing sign at a particular frequency referred to as the cross-over frequency, f_{co} . These materials can therefore be driven into an alignment either parallel or perpendicular to the direction of the applied field by simply modifying the frequency of the field applied. Dispersion in a liquid crystal is dependent on the molecular structure, viscosity and temperature of the material. It arises due to the molecular rotation about the short axis being hindered in the nematic phase, resulting in the value of $\epsilon_{//}$ varying with the frequency of the applied field. Conversely, the rotation about the long axis of the uniaxial molecule is unrestricted and ϵ_{\perp} is almost constant up to GHz frequencies. Dual-frequency liquid crystal materials are mixtures of several highly dispersive positive and negative dielectrically anisotropic materials combined to produce a compound with a dielectric anisotropy ranging from positive at low frequencies to negative at high frequencies.

The variation of $\epsilon_{//}$ with frequency can be described by a single, Debye type relaxation model¹⁰ of the form:

$$\epsilon_{//}(f) = \epsilon_{//}(\infty) + \frac{\epsilon_{//}(0) - \epsilon_{//}(\infty)}{1 + f^2 \tau^2} \quad (1)$$

where $\epsilon_{//}(\infty)$ and $\epsilon_{//}(0)$ are the static and high-frequency values of the parallel permittivity and τ_o is the Debye relaxation time.

Assuming that ϵ_{\perp} is constant over the frequency range used, eq. (1) can be written in terms of the dielectric anisotropy of the material in the form:

$$\Delta\epsilon(f) = \Delta\epsilon(\infty) + \frac{\Delta\epsilon(0) - \Delta\epsilon(\infty)}{1 + f^2 \tau^2} \quad (2)$$

From these expressions, the cross-over frequency, f_{co} can be determined by using $\Delta\epsilon(f_{co}) = 0$ in eq. (2) to give the expression:

$$f_{co} = \frac{1}{\tau_o} \left(\frac{\Delta\epsilon(0)}{|\Delta\epsilon(\infty)|} \right)^{\frac{1}{2}} \quad (3)$$

The hybrid aligned nematic (HAN) structure has homogeneous alignment (parallel to the substrate) on one surface, and homeotropic alignment (perpendicular to the surface) on the other. In the absence of any chiral dopant in the liquid crystal, the director will tilt through approximately 90° from one surface to the other, giving a near-linear variation in tilt with distance across the cell⁵. To a first approximation, the HAN structure has an equal bias towards both homogeneous and homeotropic alignment. Combining this structure with a dual-frequency nematic therefore allows the director to be driven either parallel or perpendicular to an applied field depending on the frequency used. Furthermore, the HAN structure has no threshold voltage and can respond to the relatively small changes in the dielectric free-energy of the system which occur when a voltage is applied at a frequency where the dielectric anisotropy is very small.

Optical Characterisation

By measuring the director profile in a dual-frequency HAN cell when voltages are applied at different frequencies, it is possible to quantify the dielectric permittivity at each frequency by comparing the measured profile with theoretical profiles generated by minimising the free-energy of the system⁶. To enable the subtle changes in the director profile to be characterised as the

applied frequency is changed, the director profile must be determined with a high degree of accuracy. The well-established fully-leaky guided-mode technique^{7,8} is well-suited to such an application, and has previously been used to determine the director structure in a range of liquid crystal cells. The process involves collecting optical intensity versus angle-of-incidence data from a cell and comparing it to model data generated using a multi-layer optics model. This method has an excellent sensitivity to subtle changes in the optical properties of the liquid crystal layer, produced by the reorientation of the liquid crystal director. It is therefore ideal for studying the frequency dependent director profile in a dual-frequency HAN cell.

The optical fully-leaky waveguide technique used previously for static liquid crystal cell studies has recently been modified to allow the synchronisation of voltage application and data-collection. This allows the director orientation during dynamic reorientation to be recorded on an unprecedented 0.5 μs time-scale whilst maintaining the extreme sensitivity to subtle director changes associated with the original optical characterisation process.

Static dual-frequency HAN properties

For a dual-frequency HAN cell, the result of varying the frequency of an applied field (of fixed voltage) over a frequency range is analogous to varying the voltage applied across a conventional HAN cell. Furthermore, if the frequency range encompasses the crossover frequency, the director will change from being predominantly homeotropic to homogeneous as the frequency increases. Figure 1 shows the result of measuring the static director profile in a 5 μm HAN cell filled with MDA-00-3969 (Merck, Kga), using the static fully-leaky guided-mode technique with various applied frequencies, each of amplitude 4V rms.

The dielectric anisotropy of the material obtained from a free-energy minimisation model used to produce the director profile in the optical fitting routine are shown as symbols in Figure 2. By interpolation, the crossover frequency at this temperature (19.5°C) is determined as 13.0 (± 0.2) kHz. Fitting to the optical data revealed that the director profile was relatively insensitive to the absolute values of the parallel and perpendicular permittivities with the dielectric anisotropy being the most significant fitting parameter. As a result the value of the perpendicular anisotropy (believed to be frequency independent over the frequency range used) was held at $\epsilon_{\perp}=6$, which tended to give the best fits during the preliminary fitting stages. The result of fitting equation (2) to the measured variation of dielectric anisotropy with frequency is shown as a solid line in figure 2 using $\Delta\epsilon(\infty) = -1.15 (\pm 0.03)$, $\Delta\epsilon(0) = +1.85 (\pm 0.03)$ and the Debye relaxation time $\tau_o = 93 (\pm 3) \mu\text{s}$. Using the values for $\Delta\epsilon(\infty)$, $\Delta\epsilon(0)$ and τ_o obtained from the fitting procedure

gives the cross-over frequency as 13.7 (± 0.4) kHz which agrees well with the value suggested direct from the dielectric anisotropy measurements.

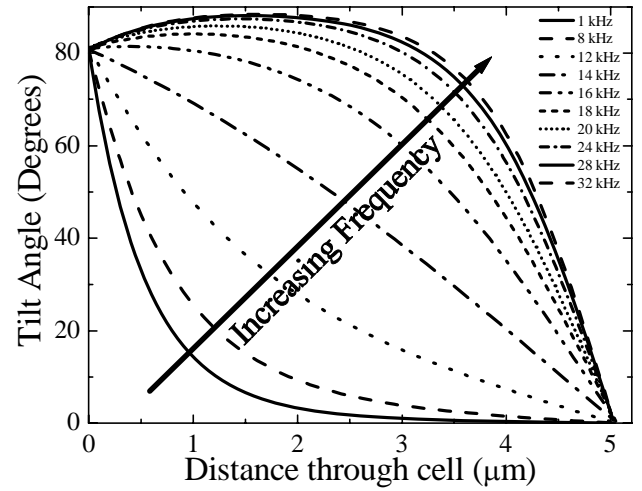


Figure 1. Measured static director profiles at a selection of applied frequencies (shown in kHz) for the variation in the tilt angle of the director (measured from the normal to the substrate) with distance through a non-twisted dual-frequency HAN cell.

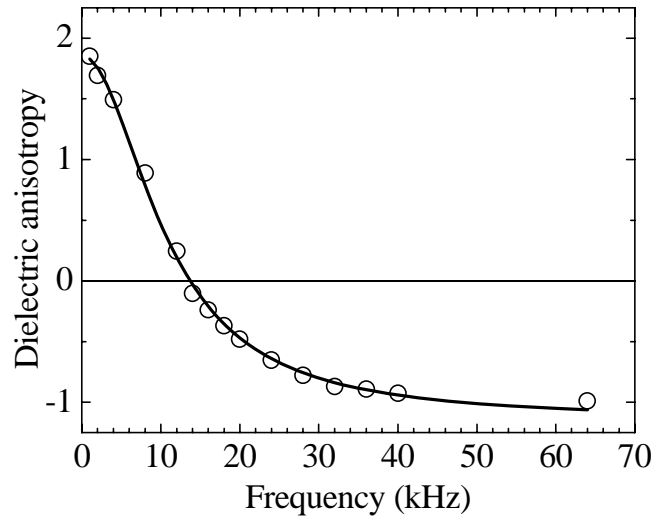


Figure 2. The variation of the measured dielectric anisotropies (symbols) with frequency determined by fitting to the static optical data collected at a range of frequencies. The line shows the fit to a single Debye-type relaxation model.

Dual-frequency HAN cell dynamics

Previous studies of the dynamics of HAN cells filled with conventional liquid crystals with a positive dielectric anisotropy have shown a switch-on time of a few milliseconds¹¹. As mentioned earlier such structures show a great potential for fast-switching applications, and by combining this structure with a dual-frequency material, the director can be rapidly driven into either homogeneous

or homeotropic alignments by applying an electric-field at a frequency either above or below f_{co} . This provides a relatively straightforward means of switching the cell between the birefringent homogeneous alignment and the uniaxial homeotropic alignment, which are both optically very different to the relaxed 0V state.

A multiple frequency pulse can be used to switch a dual-frequency HAN cell from 0V to homeotropic alignment and then drive it back to the 0V state. In the case of the $5\mu\text{m}$ HAN cell described in the static case, to achieve this complete process in the minimal amount of time using a sinusoidal $20V_{pp}$ voltage, the optimal pulse consists of an initial burst of 2 kHz for 6.0 ms, immediately followed by 64 kHz for 4.8 ms (to drive it back towards its initial configuration), and then applying 0V (short-circuit) for the remainder of the data collection.

The form of the director profile during the dynamic switching process, measured using the time-resolved fully-leaky guided-mode technique is shown in figure 3. In all cases, the twist orientation of the director through the cell was held constant at an angle equal to the azimuthal orientation of the rubbing direction of the homogeneous surface. The initial 6 ms of the cell response, where the 2 kHz voltage is applied (figure 3(a)) is similar in form to the switch-on profile associated with a HAN cell filled with a standard positive dielectric anisotropy liquid crystal¹¹. The total response time for the cell to reach homeotropic equilibrium is adversely affected by the relatively small value of the dielectric permittivity of the material at that frequency ($\Delta\epsilon(2\text{ kHz}) \approx 2.0$) resulting in a small torque on the director. This also reduces any influence of a coupling between rotation and flow of the molecules and so backflow at the homeotropic surface is not seen. The application of the high-frequency section of the pulse ($\Delta\epsilon(64\text{ kHz}) \approx -1.0$) produces an immediate response corresponding to the change in the sign of the dielectric permittivity of the liquid crystal. This highlights the extreme sensitivity of the material to the leading edge of the pulse rather than a response to the net field. As a result, when analysing the dynamic response of the material the Fourier components of the applied field should be included in the frequency dependent dynamic model.

The high-frequency section data shows that initially the main bulk of the cell responds by becoming increasingly homogeneously aligned (figure 3(b)). However, at the homeotropic surface backflow can clearly be seen during the initial 2 ms of the 4.8 ms high frequency pulse. In this region, coupling between the rotation and flow in the liquid crystal causes the director to over-rotate in the opposite direction to the main bulk of the cell before reversing direction and being driven towards homogeneous alignment. After this time the whole cell is uniformly driven towards homogeneous alignment for the remainder of the pulse duration. At the point at which the voltage is removed completely, the director is close to the near-linear profile of the 0V state,

although the director is clearly asymmetric about a point $2\mu\text{m}$ into the cell. On removal of the voltage the director relaxes to the 0 V equilibrium state over a further 6 ms (figure 3(c)).

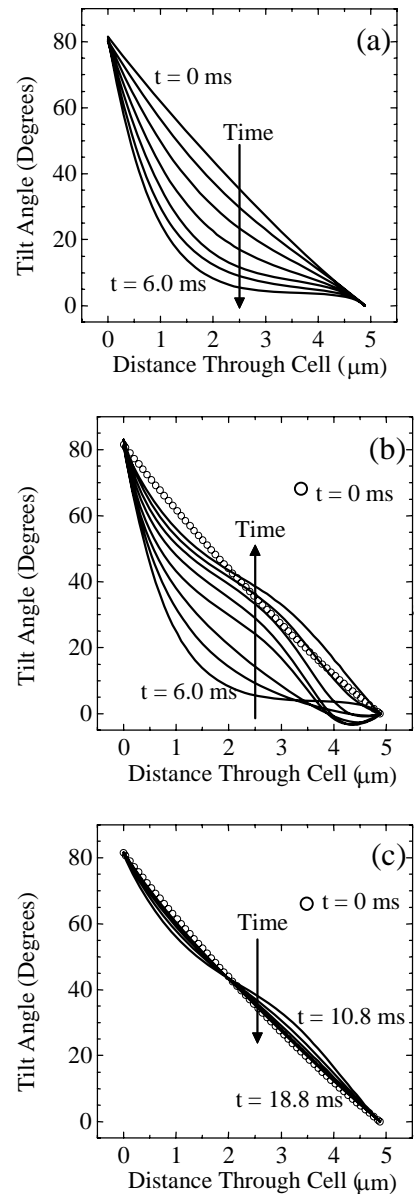


Figure 3. The dynamic response of the director tilt in a HAN cell on application of a multiple frequency pulse composed of (a) 2 kHz for 6 ms (in 1 ms steps); (b) 64 kHz for 4.8 ms (in 0.4 ms steps) and (c) 0V for 8 ms (in 1 ms steps)

In this study of the potential for driving a dual-frequency HAN cell both on and off no optimisation of either the material, the shape of the voltage pulse or the cell structure has been undertaken. However, the entire on-off switching time ($\approx 19\text{ ms}$) is still much faster than the comparable switching time for a standard nematic HAN cell being switched on and allowed to relax back to its 0V equilibrium state ($\approx 65\text{ ms}$)¹².

Chiral dual-frequency HAN cell dynamics

Although the HAN cells discussed so far have provided an excellent method of exploring the physical properties of a dual-frequency material, their poor optical contrast, dictated by the optical birefringence of the material, limits their usefulness in practical devices. One way to overcome this whilst retaining the fast switching time associated with the HAN geometry is to introduce a chiral dopant into the dual-frequency liquid crystal to produce a pitch equal to four times the cell thickness. The resulting director profile both twists and tilts through approximately 90° across the cell¹³. On application of a low-frequency voltage the director aligns homeotropically, effectively destroying the twist, and the cell appears black under crossed polarisers. Conversely, applying a high frequency voltage causes the director to lie parallel to the substrate forming a twisted structure with a pitch of the order of the natural pitch of the material, allowing the transmission of polarised light.

Doping the dual-frequency material MDA-00-3969 with 1% CB15 produces a chiral compound with a nominal pitch of approximately $13\ \mu\text{m}$. Introducing this into a $5\ \mu\text{m}$ hybrid cell produces a monodomain that distinctly exhibits an enhanced transmission under crossed polarisers at 0V when compared to a similar, non-chiral HAN cell. A 2 kHz pulse applied for 20 ms, immediately followed by an 80 ms pulse at 64 kHz drives the cell from the 0V equilibrium structure into homeotropic and then twisted homogeneous alignment.

The resulting tilt and twist profiles during the application of the pulse to the cell are shown in figure 4. The tilt of the director as it switches to the homeotropic state is shown in figure 4(a) and is similar in form to the case of the non-twisted dual-frequency HAN cell. The corresponding director twist profiles are difficult to quantify during this process due to the low tilt of the director and so have been omitted. As the director approaches the homeotropic state the definition of the twist (in the later half of the cell) becomes meaningless as the projection of the director on the x - z plane is negligible, resulting in the twist effectively being undefined.

On application of the high frequency pulse, the tilt of the director shows an instant response immediately reorientating towards homogeneous alignment throughout the whole cell (figure 4(c)). This is in stark contrast to the response of the non-twisted dual-frequency cell in figure 3(b) which clearly shows backflow occurring at the homeotropic surface. The lack of backflow at the start therefore allows the tilt to reorientate much more uniformly across the cell. However, backflow is seen at the homogeneous surface at around 60 ms as the director appears to “overshoot”

the homogenous alignment condition before settling back to its final equilibrium tilt state (figure 4(b)).

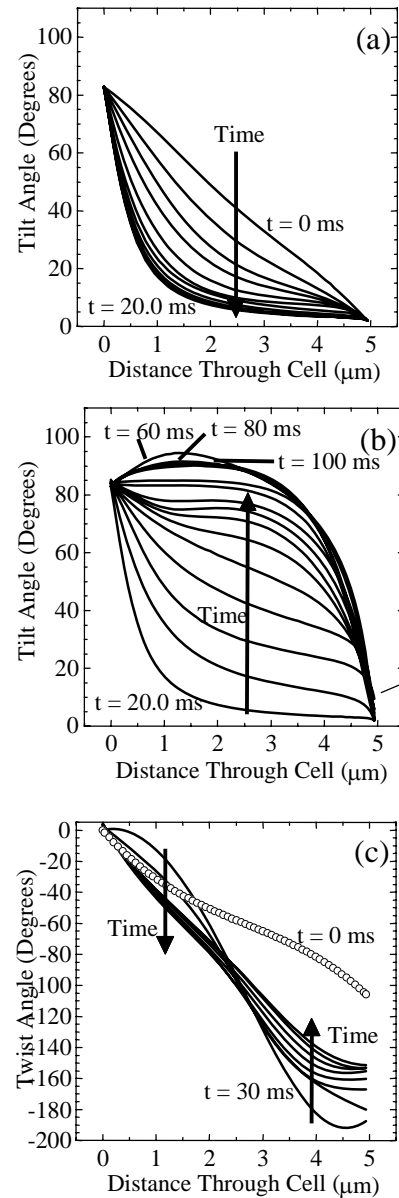


Figure 4. The dynamic response of the director in a dual-frequency chiral HAN cell on application of a multiple frequency pulse composed of 2 kHz for 20 ms followed by 64 kHz for 60 ms (a) the director tilt (in 2 ms steps) during the 2 kHz pulse; (b) the director tilt on application of the high frequency pulse (in 2 ms steps until $t = 40\ \text{ms}$, and then at the times shown) and (c) the director twist from the rubbing direction during the high-frequency pulse from $t = 30\ \text{ms}$ onwards in 10 ms steps.

At the start of the high-frequency section the director is highly homeotropic where ‘twist’ means little, thus the twist profiles have been omitted from the first 10 ms. However, after this point, the twist profiles show a well-defined s -shaped form which gradually relaxes towards a near-linear profile through the cell. The final twist state is reached 60 ms after the initial application of the high-frequency voltage with the final total twist

through the cell being 146° . This twist is comparable to that expected in a naturally twisted structure of this cell thickness for a material of this pitch (140°) and is considerably higher than the original twist through the cell at 0V which was measured as 105° .

Optimisation of the liquid crystal material to produce a 90° twist through the cell when a high frequency field is applied and highly homeotropic alignment at low frequencies would make the dual-frequency chiral HAN cell a suitable candidate for controlling the transmission of polarised light in a display.

Conclusions

An overview of work recently completed on dual-frequency HAN cells has been presented and results from the time-resolved fully-leaky guided-mode technique used to study various static and dynamic properties have been introduced. The static, frequency dependent director profile in a dual-frequency HAN cell for applied fields at frequencies above and below the cross-over frequency have been determined. The resulting variation of the dielectric anisotropy with frequency agrees well with a single Debye-type relaxation model.

The dynamics of the dual-frequency HAN structure has also been considered. Applying a complex pulse containing two regions of different frequency allows the non-twisted structure to be rapidly driven on and off and the complex form of the director profile during the entire reorientation process has been shown in detail.

Finally, a preliminary study of the dynamic response of a long-pitch ($p > d$) chiral dual-frequency HAN cell has been presented. The results suggest a distinctly different dynamic response when compared to a standard dual-frequency HAN cell, and that by optimising the material and pulse sequence this structure has great potential for display devices.

Acknowledgements

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BLCS Annual meeting 2006

11-13th April
University of York.

The BLCS annual meeting (AGM) and conference will be held from April 11th to 13th at the University of York. The main emphasis of the conference is for students to present their latest research work along with invited talks and the Sturgeon lecture. Papers are requested on any topic related to liquid crystal materials and their applications.



THE UNIVERSITY of York

George Gray honoured as a “Hull Pioneer”

George Gray has been the recipient of many scientific awards for his work, including The Kyoto Prize, The Queen’s Award for Technological Achievement and The Rank Prize for Optoelectronics, as well as being a Fellow of the Royal Society and the Royal Society of Edinburgh, a Member of the Royal Irish Academy and a Commander of the British Empire. In recognition of the key role that George has played in the modern history of Hull, he has recently been honoured as a pioneer by Hull Trains.

Hull Trains is naming its new fleet of four Class 222 Pioneer trains after key figures from its home town. In honour of George’s pioneering work in the field of liquid crystals and the reputation he built for the University of Hull, the first train in the fleet has been christened Professor George Gray. The naming ceremony was held on 30th June at the Paragon Station in Hull and was attended by four generations of George’s family, dignitaries from Hull Trains and representatives of the British Liquid Crystal Society.

Mark Leving, Hull Trains’ Managing Director, said: “When we were looking to name our new fleet of Class 222 Pioneers, Professor George Gray was one of the first people that we considered because of the effect that his work has had on the local community as well as the global market. He is a modern pioneer.”

George Gray commented: “I was very touched and surprised when Hull Trains approached me about

naming a train after me. The company is doing great things for the city and I’m delighted and honoured to have one of these splendid trains bearing my name.”



Professor George Gray and the other trains in the fleet, which have yet to be named, will travel daily between Hull and London Kings Cross. The naming of this train will guarantee that George’s place in the history of the Humberside region is remembered by its residents long into the 21st century.

Martin A. Bates,
Department of Chemistry,
University of York.

Dr Cliff Jones honoured at Entrepreneur of the Year awards

founder of ZBD Displays awarded prize for excellence in technology

Competing against 21 of the Central region’s most inspirational and dynamic entrepreneurs, Dr Cliff Jones was presented with the Science & Technology award in recognition of developing a zero-power LCD display that only requires power when the display is changed

Andy Glover, head of Ernst & Young’s Central region entrepreneurial growth markets team, said: “Dr Jones’ focus, determination and drive have made ZBD Displays a company which is about to break into UK and European retail markets”.

He is the co-inventor and founder of ZBD Displays, the developer of a unique “Zero-Power” liquid crystal display technology that has its first use in electronic retail signage where the excellent optical properties and zero power capabilities are vital for the application. Leading retailers are set to trial the

Promotional Electronic Paper labels commencing this summer.

“I was delighted to accept the award as recognition for the innovation of our world class development team and, perhaps more importantly, that we are set to make a huge impact in the retail signage market” said Dr Cliff Jones. “Our future aim is to become the principle provider of electronic displays for the retail signage sector. This is a market of considerable size, and the segment we are targeting represents a \$4.5 billion opportunity.”

Cliff, a physicist who has worked on liquid crystals for over 20 years, is a co-inventor of the ZBD technology and is the Chief Technology Officer and founder of ZBD Displays Limited.

Previously, Cliff was the Technical Leader of the Defence Evaluation and Research Agency (DERA) world renowned Displays Group. His work on bistable

ferroelectric liquid crystal displays led to awards from the Society for Information Display (1992 Sturgeon Award) and the British Liquid Crystal Society (Young Scientist 1994). In 1997 he became the youngest Senior Principal Scientific Officer of Individual Merit in the Civil Service. He received the prestigious Charles Vernon Boys Medal from the Institute of Physics in 2000.

Since forming ZBD Displays Limited, Cliff has led the technical work from material and device physics to display addressing. He is also responsible for managing the Company's intellectual property portfolio. Cliff has over 80 publications and 40 patents in the field of liquid crystals and displays. He is an Honorary QinetiQ Fellow, and a Fellow of the Institute of Physics.

About ZBD Displays Limited:

Established in July 2000, ZBD Displays Limited is the first spin-out from the UK's Defence Evaluation and Research Agency in Malvern (now QinetiQ.)

A venture backed company, ZBD Displays Limited was founded by prize-winning scientists from

QinetiQ's world-renowned Displays Group. ZBD's expertise in LCD technology is unparalleled, covering holographic gratings, liquid crystal materials and physics, optics, electronics and addressing, LCD fabrication and the invention of the revolutionary ZBD technology, which is ideally suited for future portable applications. ZBD's intellectual property portfolio is extensive, including all of the key patents that were assigned to the company by QinetiQ, as well as a number of patents and applications filed since the company's inception.

The combination of zero power between image updates, unlimited image complexity and excellent readability, as well as suitability for flexible or standard plastic substrates, means that ZBD is placed at the heart of future portable electronic devices. The company's initial commercial focus is the retail sector, where the ZBD technology allows electronic shelf edge labels to be upgraded to include promotional and product information.

For further press information or photography please contact Giles Read or Katie Jamieson at LEWIS, the PR agency. gilesr@lewispr.com or katiej@lewispr.com, Web: www.lewispr.com

Liquid crystals expert and his research team move to the University of York

A team of world-leading researchers headed by Professor John Goodby, an authority on liquid crystals, has moved to the University of York's Department of Chemistry.

Professor Goodby and his research team moved to York from the University of Hull, where he had been the Head of the Liquid Crystals and Advanced Organic Materials Group for 15 years and Head of Department for two years. He is an authority on physico-chemical aspects of low molar mass and polymeric liquid crystals and related self-organising systems, and is Past President and Vice President of the International Liquid Crystal Society.

Liquid crystals are a phase of matter whose order is intermediate between that of a liquid and that of a crystal. They are an example of the Fourth State of Matter - neither liquid, solid nor gas - and their molecular orientation can be controlled with applied electric fields, most commonly used in liquid crystal displays (LCDs). A huge number of compounds are liquid crystals, including cell membrane materials, lecithin, DNA, cellulose, cholesterol esters, gangliosids, and paraffins.

Professor Goodby, 52, is Chair of the British Liquid Crystal Society, and is an advisor to the ERATO programme on nano-scale structuring in liquid crystals at Tskuba in Japan.

Educated at Hull University, under the supervision of Professor GW Gray CBE, FRS, he later worked in the University's Chemistry Department as a post-doctoral research assistant before moving to the USA, where he was employed for nine years at AT&T Bell Laboratories, initially in the device materials research department and latterly as supervisor of the Liquid Crystal Materials Research Group. He returned to Hull in 1988 as the STC-Thorn EMI Industrial Reader in Chemistry, becoming Professor of Organic Chemistry two years later.

In 1994 he was the first Amersham Senior Research Fellow of the Royal Society and two years later, he was awarded the GW Gray Medal of the British Liquid Crystal Society. In 2002, he was the Tilden Lecturer of the Royal Society of Chemistry, and in the same year he was awarded an Honorary Doctorate by Trinity College, Dublin.

Professor Goodby said: *"It is a great pleasure to be joining York's growing Chemistry Department, and to develop its activities in Materials Chemistry further. In particular, there is a great opportunity to create internationally leading activities in Nanochemistry and the Fourth State of Matter here in Yorkshire. This can only be achieved through multi-disciplinary interactions, and the University of York uniquely provides fertile ground for this to occur."*

Taken from the York Website

Thermotropic Biaxial Nematics: Frequently Asked Questions

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Introduction

In the past year there has been an upsurge of interest in thermotropic biaxial nematics with the publication in *Physics Review Letters* of four papers claiming to have discovered the elusive biaxial nematic phase [1-4] and another [5] supporting the previous identification for a liquid crystal side-group polymer. But what is a biaxial nematic and why is this phase of such interest? Here we answer these and other frequently asked questions concerning this liquid crystal phase.

What is a biaxial nematic?

The molecules that constitute biaxial nematics, N_B , deviate from the cylindrical symmetry often assumed for those forming the common uniaxial nematic, N_U . For example, in a biaxial nematic of lozenge-shaped molecules all three molecular symmetry axes are orientationally correlated over large distances unlike a uniaxial nematic where just the single molecular symmetry axis exhibits long-range correlations. The molecular organisation in a biaxial nematic phase of lozenges is sketched in Figure 1 which also shows the three directors, \mathbf{l} , \mathbf{m} and \mathbf{n} , defined in terms of the preferred orientations of the three molecular symmetry axes. This molecular definition of the directors is not unambiguous for molecules that normally form liquid crystals because they do not have such high symmetry and are not rigid. For these systems the directors are more satisfactorily defined at a macroscopic level in terms of the principal axes of the dielectric tensor, ϵ , or some similar second rank tensorial quantity, as Frank has suggested [6]. These properties then have three different principal values corresponding to the orientations along the three directors. This contrasts with the behaviour in a uniaxial nematic where the two principal values of the tensor perpendicular to the director, \mathbf{n} , are identical but differ from that parallel to it. This difference in the symmetry of tensorial properties results in significant differences in the optical properties of the two phases; it is this which is the origin of their names, taken from the field of optics. Thus, for a biaxial nematic there are two axes along which plane polarised light can travel without the state of polarisation being changed whereas for a uniaxial nematic there is just one such axis. For a uniaxial nematic this unique axis coincides with the

director, \mathbf{n} , whereas for a biaxial nematic neither of the axes is parallel to any of the three directors.

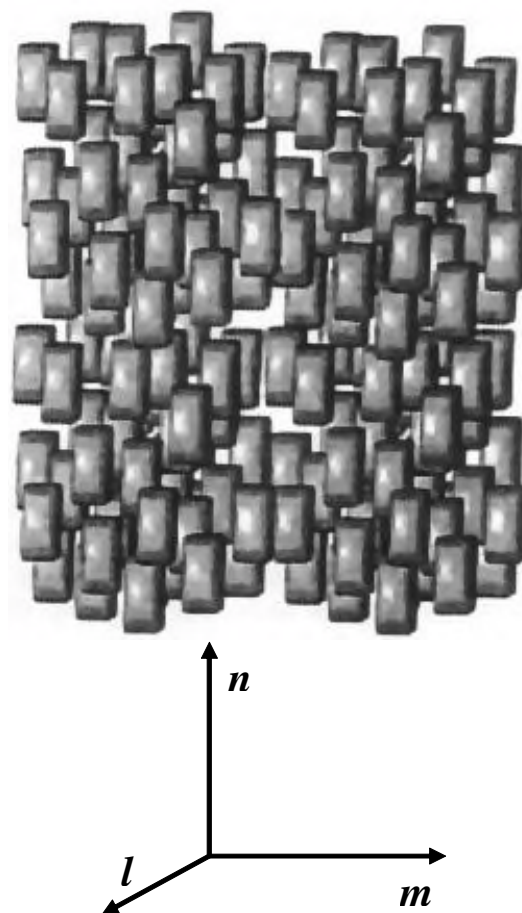


Figure 1. The highly idealised molecular organisation in a biaxial nematic phase composed of lozenge-shaped molecules; the three directors for the phase are denoted by \mathbf{l} , \mathbf{m} and \mathbf{n} .

Are there applications for this phase?

At least three potentially important applications for the biaxial nematic phase have been suggested. One is concerned with the improvement in the response times of liquid crystal display devices. The basic idea is to align the main director, \mathbf{n} , and then to change the orientations of the minor directors, \mathbf{l} and \mathbf{m} , with an electric field. The ability to do this would depend on the dielectric anisotropy associated with these directors, $\delta\epsilon$, ($\equiv\epsilon_{XX} - \epsilon_{YY}$, where X and Y denote the laboratory axes for the minor directors, \mathbf{l} and \mathbf{m} , respectively); $\delta\epsilon$ is known as the biaxiality in ϵ . It is to be expected that the rotational viscosity coefficient,

associated with the major director, will be larger than that associated with the minor directors because of the difference in the molecular dimensions associated with the \mathbf{n} and \mathbf{l} directors. For comparable dielectric anisotropies the response time for switching the minor director will be shorter than that to switch the major director. It remains, however, to see just how large the difference in the rotational viscosities might be. The second possible application is as a precursor in the fabrication of optically biaxial polymer films to be used, for example, in improving the viewing characteristics of liquid crystal displays. This would involve the preparation of a monodomain of the biaxial nematic in which the three directors had been uniformly aligned by complementary external fields prior to polymerisation. At present, such films are produced from uniaxial nematics by creating a non-uniform director distribution which results in the optical biaxiality of the film. The third potential application envisages new types of optical switches that would use the additional long range order of biaxial nematics to modulate light intensity or polarisation.

Why else might this phase be of such interest?

The thermotropic biaxial nematic phase is of special interest partly because of the difficulty in finding it. Thus although Freiser [7] predicted its existence over 34 years ago it is only recently that potentially convincing nematics have been prepared and characterised. Indeed this phase has been likened to a Holy Grail of liquid crystal science and so its design, synthesis and unambiguous characterisation would be a major achievement. In addition, the biaxial nematic would introduce new liquid crystal physics which could be of considerable interest. For example, the elastic theory of this phase with its lower symmetry than that of the uniaxial nematic would introduce extra fundamental deformations each characterised by a new elastic constant. In total, twelve elastic constants are needed to describe the elastic behaviour of the phase which, excluding the surface elastic constants, is nine more than for a uniaxial nematic [8]. Similarly, the number of viscosity coefficients needed to describe the visco-elastic behaviour of a biaxial nematic is twelve, dramatically larger than the five necessary for a uniaxial nematic [8]. The determination of such a large number of viscosity coefficients and indeed elastic constants clearly presents a significant challenge to experimentalists as will their interpretation at the molecular level to the theoreticians.

How is a biaxial nematic recognised?

There have been a number of claims [9] to have discovered the biaxial nematic phase which, in view of the significant biaxiality of the constituent molecules might seem reasonable; however such claims need to be justified by a clear identification of the phase biaxiality.

One of the powerful methods by which liquid crystal phases can be identified is from their optical textures observed under a polarising microscope. It was suggested that in the case of the biaxial nematic phase the Schlieren texture should show just two dark brushes and not the two and four dark brushes usually found for a uniaxial nematic (see Figure 2). This view is supported by the observation that the Schlieren texture exhibited by the lyotropic biaxial nematic phase identified by Yu and Saupe [10] shows only two-fold brushes. However, there is concern that the optical texture does not provide definitive evidence for the biaxiality of the phase and that there are other reasons for the absence of the four-fold brushes, including their higher energy.

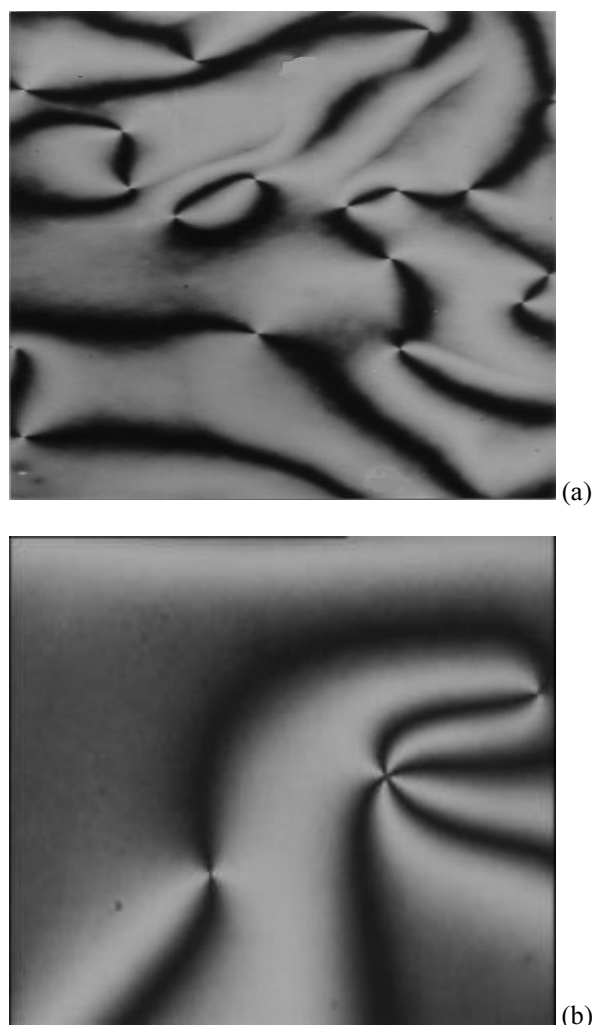


Figure 2. The Schlieren textures observed for a nematic exhibiting (a) only two-fold brushes and (b) two-fold and four-fold brushes normally found for a uniaxial nematic.

A more formal identification of the phase would require the determination of the symmetry of some tensorial property since this is determined by the phase symmetry. One commonly used property in studies of liquid crystals is the refractive index, for the biaxiality in the principal components of this can be determined with conoscopy. In this method a thin film of the nematic is aligned and for a biaxial nematic two constraints are needed to align the three directors, these are usually an

electric field and a surface force. Then using convergent polarised light an interference feature, rather like the Maltese cross sketched in Figure 3(a), is observed for a uniaxial nematic when the director or optic axis is orthogonal to the film. For a biaxial nematic the arms of the cross or isogyres open to an extent that depends on the optical biaxiality; this is sketched in Figure 3(b). Conoscopy is an extremely sensitive technique with which to determine the optical biaxiality of a material. However, paradoxically this proves to be a disadvantage when studying the biaxiality of a nematic phase because, with the thin films necessarily used, surface forces can tilt the director. This will induce a small biaxiality in the director distribution and so result in an image in which the isogyres are open, even for a uniaxial nematic.

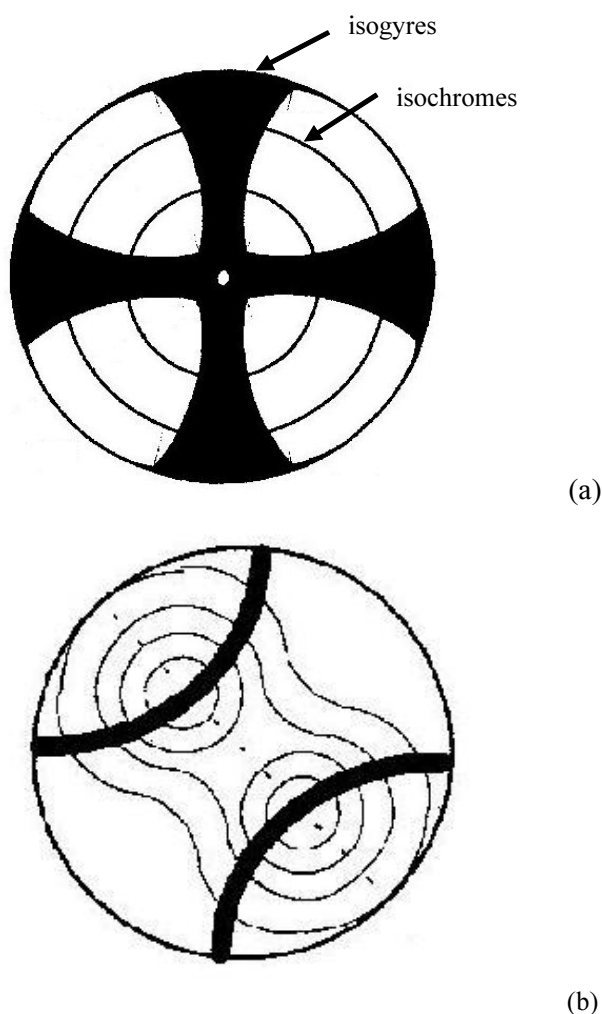


Figure 3. The conoscopic interference images expected for (a) an optically uniaxial and (b) an optically biaxial nematic phase.

As a result of such difficulties NMR spectroscopy has come to be accepted as a powerful, if not the definitive, tool for the determination of the symmetry of the nematic phase. It has the advantage of investigating the bulk sample and so the surface of the container cannot influence the director distribution for the majority of the sample and hence the symmetry of the measured magnetic tensor. For deuterium NMR this tensor is usually the quadrupolar tensor, \mathbf{q} , which is

determined from the spectral doublets associated with each deuteron. The other major advantage is that it is not necessary to prepare a monodomain of the phase because the observed NMR spectrum is a sum of spectra from all director orientations. There are then distinct benefits in studying a disordered sample since a single spectrum will give the three principal components of the quadrupolar tensor. Examples of the spectra expected for uniaxial and biaxial nematics with perfectly random director distributions are shown in Figure 4. There are clear differences between these two spectra, the most striking of which is that the spectrum of the uniaxial phase (see Figure 4(a)) contains two dominant splittings which correspond to the two different principal components of the quadrupolar tensor whereas that from the biaxial nematic (see Figure 4(b)) has three distinct features and the associated separations reflect the three different principal components of \mathbf{q} . The spectra then clearly show the symmetry of the phase and the splittings allow its biaxiality to be quantified.

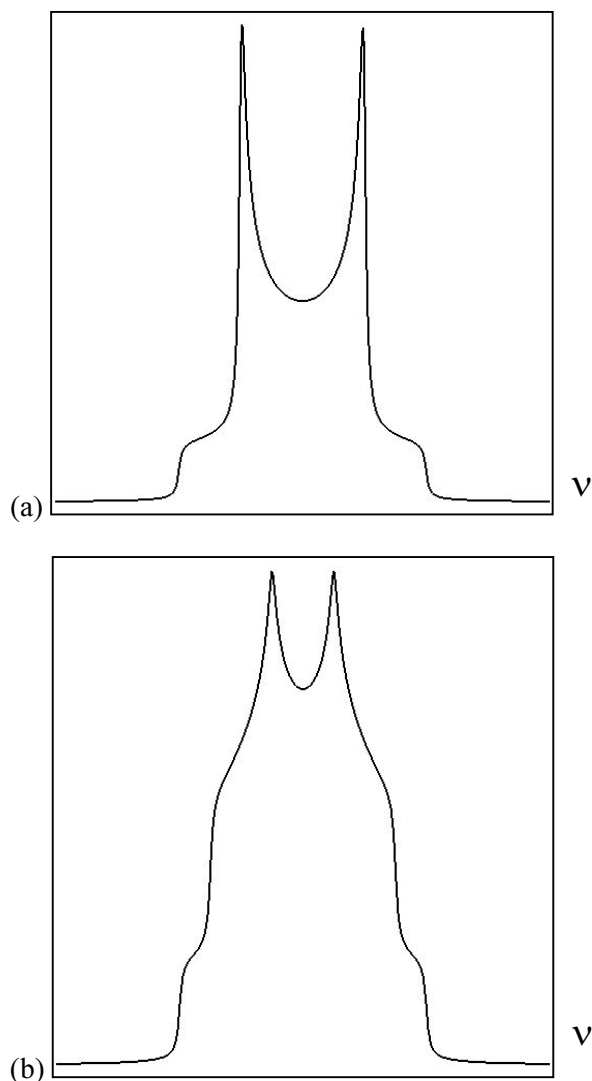


Figure 4. The deuterium NMR spectra expected for (a) a uniaxial nematic and (b) a biaxial nematic; in both cases the directors are randomly distributed and the molecule contains a single deuteron.

How is the phase biaxiality quantified?

The extent of the phase biaxiality can be quantified at both a pragmatic and a fundamental level. It may be helpful, however, to begin with the analogous quantities for a uniaxial nematic since these should be more familiar. Thus, at the pragmatic level the orientational order in a uniaxial nematic may be defined in terms of the anisotropy in quantities such as the dielectric tensor of the phase. Here, the anisotropy, $\Delta\epsilon$ ($\equiv \epsilon_{\parallel} - \epsilon_{\perp}$, where ϵ_{\parallel} is the component parallel to the director and ϵ_{\perp} that perpendicular to the director), provides a measure of the orientational order. It vanishes at the nematic-isotropic transition, as required, but its value in the nematic phase does depend on molecular properties as well as the orientational order. This is usually characterised at a fundamental level in terms of the second rank order parameter, S_{zz}^{ZZ} , which is $\langle 3l_{zz}^2 - 1 \rangle / 2$ [11]. Here l_{zz} is the direction cosine of the molecular symmetry axis, z , with respect to the director, aligned along the Z laboratory axis, and the angular brackets indicate an average. This order parameter has the limiting value of unity for complete orientational order and vanishes in the isotropic phase.

These ideas can be extended to the biaxial nematic. Thus at the pragmatic level the phase biaxiality would be defined in terms of the biaxiality in the dielectric tensor, $\delta\epsilon$. This is, however, often normalised with the major dielectric anisotropy, $\Delta\epsilon$ ($\equiv \epsilon_{ZZ} - (\epsilon_{XX} + \epsilon_{YY})/2$) to give the relative phase biaxiality, η ($\equiv \delta\epsilon/\Delta\epsilon$); like $\delta\epsilon$ this vanishes in the uniaxial nematic phase. However, η also depends on molecular parameters and it is necessary to use orientational order parameters to define the phase biaxiality at a fundamental level. There are two order parameters needed at the second rank level and these are combinations of Saupe-like order parameters [11] but one of them, denoted by S_{22}^2 , is dominant namely $(S_{xx}^{XX} - S_{xx}^{YY}) - (S_{yy}^{XX} - S_{yy}^{YY})$. In this expression x and y are principal molecular axes of the ordering tensor and so S_{22}^2 is the difference in the biaxial ordering of the x and y axes with respect to the X and Y laboratory axes. The biaxial order parameter necessarily vanishes in the uniaxial nematic phase and adopts a limiting value of three for a perfectly ordered biaxial nematic phase. The major orientational order parameter, S_{00}^2 ($\equiv S_{zz}^{ZZ}$), is one in this limit, non-zero in the uniaxial nematic and vanishes in the isotropic phase.

What are the molecular requirements for a biaxial nematic?

The clear requirement for a material to exhibit a biaxial nematic phase is for the constituent molecules to deviate significantly from cylindrical symmetry. Originally Freiser [7] had supposed that the lozenge shape of nematogenic molecules, such as 4,4'-

dimethoxyazoxybenzene, would lead to the biaxial nematic.

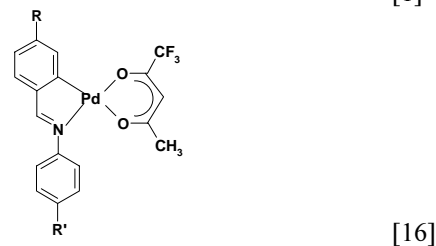
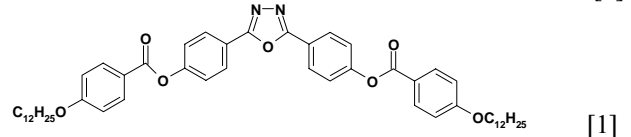
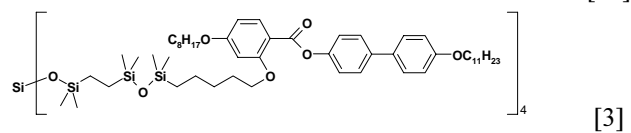
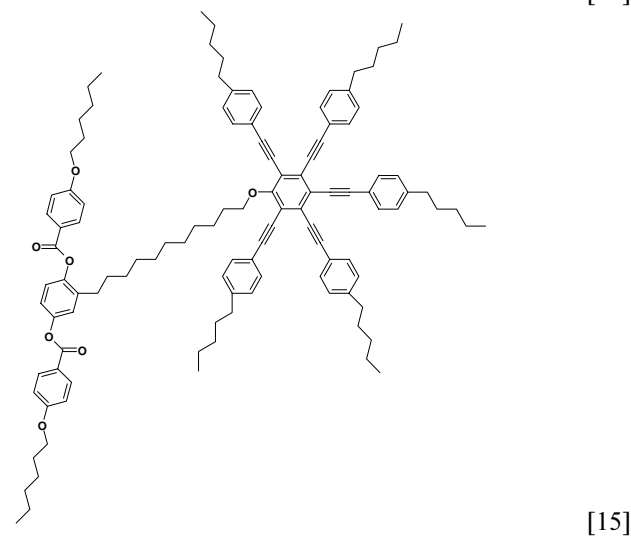
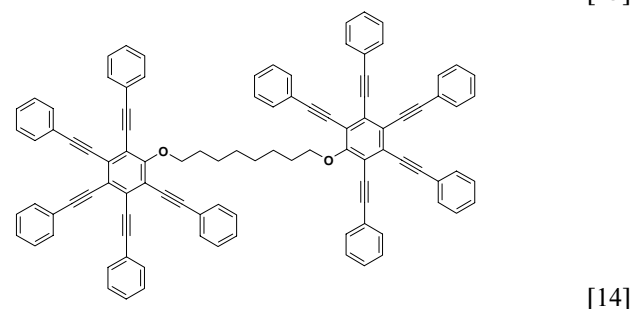
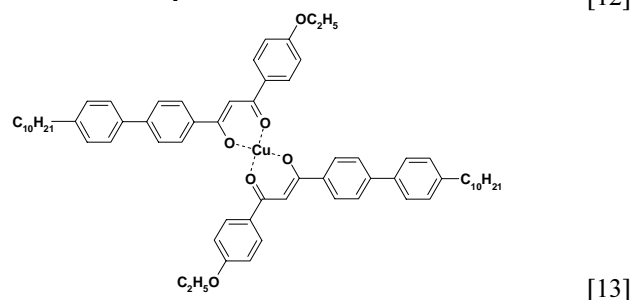
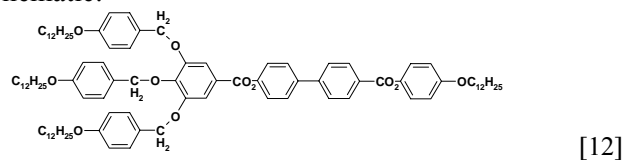


Figure 5. A selection of biaxial molecular structures for which a biaxial nematic phase might be expected or has been claimed. The numbers associated with each structure are to the references where these are described

It was not until much later that more exotic molecules deviating from cylindrical symmetry were prepared. The first of these was made by Malthete *et al.* [12] and was a fusion of a disc-like and a rod-like moiety; this is sketched in Figure 5 where its pronounced biaxiality is apparent. An alternative design strategy was used a few years later by Chandrasekhar *et al.* [13] who prepared a cross-shaped molecule with unequal arms and hence a strong biaxiality (see Figure 5). A detailed generic consideration of the construction of biaxial molecules by linking together rod and disc moieties in rigid structures has been given by Praefcke *et al.* [14]. There are advantages in connecting these units with flexible spacers and a number of such molecules have been prepared; these include structures with two discs [14] as well as a disc and a rod joined together either terminally or laterally [15] (see Figure 5). More recently attention has returned to lozenge-shaped molecules with the creation of a tetrapode [3,4] with four rod-like units linked laterally to a central silicon atom. It is thought that this molecule has a lozenge shape [3] but this will only be true for a selection of conformations of the flexible spacers, for many others the shapes will be quite different. Another structure that has been suggested as having sufficient biaxiality to give the biaxial nematic is a V-shaped or bent core molecule and the structure of one such molecule, developed by Samulski and his colleagues [1], is shown in Figure 5.

In considering the biaxiality of the molecules we have been primarily concerned with the shape of the molecule, which determines the repulsive anisotropic interactions. It might appear, therefore, that the anisotropy in the attractive forces and hence their biaxiality had been ignored. However, provided there are no specific interactions, such as hydrogen bonding, the molecular shape can also reflect the attractive interactions. Accordingly, the biaxiality coming from the attractive and repulsive interactions might be expected to parallel each other. In contrast, if there are specific interactions then it might prove possible to enhance the biaxiality in the molecular interactions and this idea has been used in the design of the palladium complex shown in Figure 5 where the trifluoromethyl group was introduced to provide the specific interaction [16].

How can theory be of benefit?

In principle theory can provide a valuable guide as to how biaxial mesogenic molecules might be designed and, just as importantly, what properties the biaxial nematic phase might be expected to possess. Of course, it might be argued that theories can vary markedly in their reliability but, nonetheless, the generic guidance that they provide should not be lightly ignored. Indeed, the original stimulus alerting the community to the existence of the biaxial nematic phase was provided by

the molecular field theory developed by Freiser [7]. This theory has been extended by Straley [17] and by Boccaro *et al.* [18] to predict how the phase behaviour depends on the molecular biaxiality, λ . This parameter varies from zero for a uniaxial molecule to $1/\sqrt{6}$ for the maximum molecular biaxiality [18]. The variation of the phase behaviour with λ is shown in Figure 6, where the temperature is scaled with T_{Nul} , the transition temperature for the nematogen composed of uniaxial molecules. When λ is zero only the uniaxial nematic is possible but when λ deviates from zero a biaxial nematic appears in the phase diagram. There is a slight increase in T_{Nul} with increasing λ but the growth in the biaxial nematic-uniaxial nematic transition temperature is far more pronounced, especially as λ approaches its maximum limiting value. Indeed, the phase boundaries meet at this maximum value of the molecular biaxiality at which point there is a transition directly from the isotropic to the biaxial nematic phase; this is known as the Landau point. The molecular field theory also predicts that the uniaxial nematic-isotropic transition is first order although the transitional entropy decreases with the molecular biaxiality until it vanishes at the Landau point [11]. In contrast the biaxial nematic-uniaxial nematic transition is predicted to be second order independent of λ , consequently the transition at the Landau point is also second order.

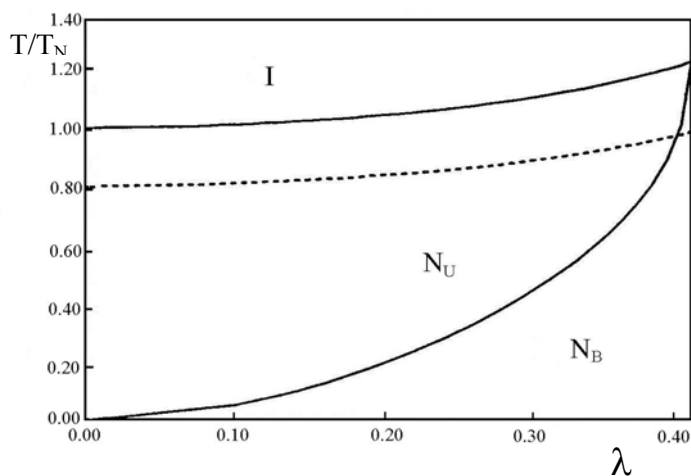


Figure 6. The phase diagram predicted by molecular field theory for the dependence of the transition temperatures, scaled with T_{Nul} for a nematogen composed of uniaxial molecules, on the molecular biaxiality, λ . The dashed line indicates when the nematic phase might be expected to freeze or undergo a transition to a smectic phase.

The theory also predicts the orientational order parameters and, in particular, how they vary with both the molecular biaxiality and temperature. As an example the predicted temperature dependence of the dominant uniaxial and biaxial order parameters, S_{00}^2 and S_{22}^2 , is shown in Figure 7 for λ equal to 0.38. The results show that at the N_U -I transition there is a small jump in S_{00}^2 indicating the weak nature of this first order phase transition expected for the large biaxiality. At the N_B - N_U transition there is just a

small change in the temperature gradient of S_{00}^2 while the biaxiality parameter, S_{22}^2 , increases continuously from zero; these changes are in keeping with the second order nature of the transition.

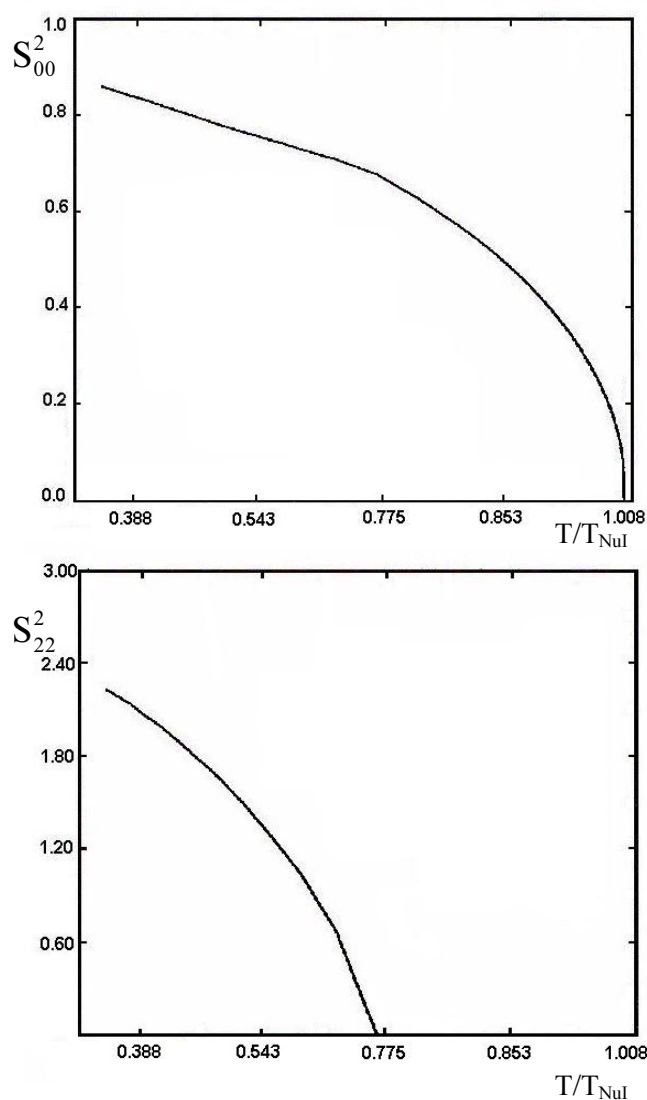


Figure 7. The variation of the dominant (a) uniaxial order parameter, S_{00}^2 , and (b) biaxial order parameter, S_{22}^2 , with the reduced temperature, T/T_{Nul} , predicted for λ of 0.38.

For these predictions to be of particular value it is necessary to be able to relate the biaxiality parameter to the molecular structure. This is a non-trivial task because, in principle, different anisotropic interactions contribute to λ and the nature of this relationship is not understood. However, at a relatively simple level the biaxiality parameter can be related to the molecular shape [19]. For example, for a parallelepiped of length, L , breadth, B , and width, W , the surface tensor model gives λ as $(3/2)^{1/2}L(B-W)/((B+W)L - 2BW)$. Clearly for a square cross-section λ will vanish but when the breadth is the harmonic mean of L and W , that is $1/B = (1/L + 1/W)/2$ the biaxiality parameter adopts its maximum limiting value of $1/\sqrt{6}$. These results provide

some guide to molecular design but their use also requires that account be taken of the large number of conformations that nematogenic molecules can exist in and the different biaxialities that they will have. The same approach can also be employed to gauge the biaxiality of V-shaped molecules; here the biaxiality parameter is given by $(3/2)^{1/2}(1+\cos\theta)/(1-3\cos\theta)$ where θ is the angle between the two cylindrically symmetric mesogenic arms. Clearly when this angle is 180° the molecule is uniaxial and λ is zero. However, as θ decreases the molecular biaxiality increases and reaches its maximum limiting value when the angle is equal to the tetrahedral value [20]; this suggests that the best chance of finding the biaxial nematic phase for V-shaped molecules is to select this particular geometry, at least for rigid molecules.

Do thermotropic biaxial nematics really exist?

Following the original claim by Malthete *et al.* [12] to have discovered the biaxial nematic phase there were a series of such claims [9,13,14,20]. The evidence in support of these claims was based on the biaxial shape of the constituent molecules, the optical textures and the conoscopic images. However, subsequent investigations for certain of these systems using deuterium NMR spectroscopy failed to reveal the necessary biaxiality in the quadrupolar tensor. In addition, other systems for which a biaxial nematic phase might have been expected also failed to reveal the biaxiality in the quadrupolar tensor [15,16,20,21]. It began to seem, therefore, that the design and characterisation of a biaxial nematic phase might not be as straightforward as first imagined. This was certainly the case until Samulski and his colleagues [1,2] reported their studies of V-shaped molecules (see Figure 5). Here, there are two quite different pieces of evidence in support of the phase biaxiality. One of these is provided by NMR spectroscopy using perdeuteriated hexamethylbenzene as a probe; this showed a small phase biaxiality [1]. The other piece of evidence is the significant change in the X-ray scattering pattern when an electric field is applied to a sample with uniform planar alignment for the main director. This evidence, although strong, is not unambiguous. For example, the interarm angle for this nematogenic molecule is 140° which differs significantly from that suggested by theory. This might be because there is another contribution, such as a dipolar interaction, contributing to the stability of the biaxial nematic phase but then, according to molecular field theory, this is expected to yield a polar biaxial nematic, although this seems not to be the case. The change in the X-ray scattering pattern could also be caused by a field-induced biaxiality and not simply by the field-induced alignment of the minor directors.

The other system for which strong evidence of phase biaxiality has been produced is for the tetrapode (see Figure 5) which also exhibits a uniaxial nematic [3] which is more in keeping with theory. Here, there are also two pieces of primary evidence for the phase biaxiality. First,

the second rank orientational order parameters have been determined using IR spectroscopy; this is a valuable technique but for it to be successful a monodomain sample must be investigated. That is all of the three directors must be uniformly aligned and it is not clear how this can be achieved for a biaxial nematic with surface forces alone. However, the biaxiality of the phase seems clear from the order parameters measured although the relative magnitudes of these are not in accord with the predictions of theory. Secondly, the same system has been studied using deuterium NMR with specifically deuteriated 4-heptyl-4'-cyanobiphenyl as a probe and at a relatively high concentration [4]. This rod-like probe does alter the transition temperatures dramatically which indicates that the phase behaviour may also be changed. Nonetheless, the NMR spectra do suggest that the tetrapode exists as both uniaxial and biaxial nematic phases. However, the spectral analysis needed to come to this conclusion is not given in detail and may not be based on entirely reasonable assumptions.

In summary the answer to the original question is an equivocal *maybe*, at least as far as two thermotropic nematics are concerned. In contrast the situation for a lyotropic biaxial nematic phase [10] is far clearer. In particular, the phase biaxiality, determined with deuterium NMR spectroscopy, for this and other lyotropic biaxial nematics is quite clear and seems beyond question.

What is the problem?

It may seem strange that the discovery of thermotropic biaxial nematics is proving to be such a problem since the majority of nematogenic molecules certainly deviate from cylindrical symmetry. One possible explanation of this paradox is that the uniaxial nematic undergoes a transition to a smectic or crystal phase before the transition to the biaxial nematic can occur. Indeed, this possibility was envisaged by Freiser [7] in his seminal paper predicting the existence of the biaxial nematic. In an attempt to quantify the effect of this on the phase behaviour of nematogens, Ferrarini *et al.* [22] suggested that the likely extent of the uniaxial nematic phase prior to its transition to the translationally ordered phase is no larger than 100°C and is normally considerably less. Assuming the larger value, the phase boundary for this blocking transition is shown in Figure 7 as the dashed line. This allows us to see that for much of the permitted range of the molecular biaxiality only the uniaxial nematic is stable. Indeed it is just in the narrow range for λ from 0.39 to 0.4082 ($\equiv 1/\sqrt{6}$) that the biaxial nematic should be found. An equally narrow range of interarm angles is predicted to be necessary if the N_B phase formed by V-shaped molecules is to be stable against the transition to the smectic or crystal phases. This narrow range of molecular biaxialities over which the thermotropic

biaxial nematic is likely to be stable is consistent with the very narrow range of concentration and temperature for which lyotropic biaxial nematics are found to exist [10]. It would seem that to obtain a stable biaxial nematic, as well as enhancing the molecular biaxiality the complementary strategy of inhibiting the formation of a smectic or crystal phase should be invoked. This is certainly the approach Berardi and Zannoni [23] have successfully adopted in the design of a model Gay-Berne biaxial mesogen and its study by computer simulation.

Conclusion

It is clear that several design strategies have produced highly biaxial molecules which, if they do not form a biaxial nematic phase, are certainly close to this goal. This will certainly stimulate the production of other analogous materials, especially as subtle changes in the molecular structure can have dramatic effects on the phase behaviour. This, together with developments in the theory of biaxial nematics and simulations of increasingly realistic models, will continue to aid in the molecular design of likely contenders. In addition, theory will help to understand the properties this phase might have and so guide the development of sound techniques with which to determine the symmetry of the phase. This is certainly an exciting and possibly pivotal moment in the hunt for this Holy Grail of liquid crystal science.

Acknowledgements

I have benefited considerably from enlightening discussions with many colleagues concerning all aspects of biaxial nematic liquid crystals. In particular it is a pleasure to acknowledge those who have contributed to this Article; they are Duncan Bruce, David Dunmur, Christopher Dunn, Louis Madsen, Azizah Mainal and Che Rozid Bin Mamat.

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New directions in liquid crystal science

Monday 5 and Tuesday 6 December 2005

Organised by Professor Duncan Bruce, Professor Harry Coles, Professor John Goodby and Professor Roy Sambles FRS

Synopsis

Liquid crystals are known to all the world in the form of liquid crystal displays, yet it is not widely appreciated that they also have applications as diverse as control of light in optical systems through sensor and artificial muscle to drug delivery and gene therapy. These less well-known aspects of liquid crystals will be addressed in this meeting.

Monday 5 December 2005

Session 1: Chair Professor John Goodby

- 9.50 Welcome by Stephen Cox CVO, Executive Secretary of the Royal Society
- 10.00 Professor Cyrus Safinya
- 10.30 Professor Richard Templar
- 11.00 Discussion
- 11.20 Coffee
- 11.50 Dr Françoise Livolant
- 12.20 Professor John Seddon
- 12.50 Discussion
- 13.10 Lunch

Session 2: Chair Professor Duncan Bruce

- 14.20 Professor Wolfgang Weissflog
- 14.50 Professor Ed Samulski
- 15.20 Discussion
- 15.40 Tea

- 16.10 Dr Andrew Cammidge
- 16.40 Professor Virgil Percec
- 17.10 Discussion
- 17.30 Close

Tuesday 6 December 2005

Session 3: Chair Professor Harry Coles

- 9.20 Dr Tim Wilkinson
- 9.50 Professor Roy Sambles FRS
- 10.20 Discussion
- 10.40 Coffee
- 11.05 Professor Peter Palfy-Muhoray
- 11.35 Professor Heino Finkelmann
- 12.05 Discussion
- 12.25 Lunch

Session 4: Chair Professor Roy Sambles FRS

- 13.25 Dr Iain McCullough
- 13.55 Professor Helen Gleeson
- 14.25 Discussion
- 14.45 Tea
- 15.10 Professor Henk Lekkerkerker
- 15.40 Professor Markus Antonietti
- 16.10 Discussion
- 16.30 Broad discussion
- 17.00 Professor George Gray CBE FRS
- 17.20 Close

To register go to:

https://www.royalsoc.ac.uk/events/forms/dec05_form.htm

BLCS Bursary Award Report

20th International Liquid Crystal Conference, Ljubljana, Slovenia, 4–9 July 2004

The 20th International Liquid Crystal Conference (ILCC) was held in Ljubljana, the capital city of Slovenia, at the Cankarjev dom Cultural and Congress Centre for 5 days between the 4th July and the 9th July 2004. The ILCC is an exciting biennial event attended by around 800 delegates and is a major event for those working in liquid crystal science. The diverse range of topics included the study of liquid crystalline materials in display applications and biological systems, molecular design and both material and dynamic properties.

Of great interest to me was the section on Colloids, Nanostructured Systems and Self Assembly during which I presented a talk on the 'Optical Manipulation of Colloids within a Liquid Crystalline Medium'. This session proved to be extremely interesting since several groups presented work on the optical manipulation of colloids within a liquid crystalline medium, a topic which is new to the ILCC, and this led to fruitful and lively discussions of great relevance to my research. It seems likely that optical trapping will become a useful tool for measuring important physical properties of liquid crystalline materials.

During a poster session, I presented work on the optical trapping of liquid crystalline droplets within an isotropic medium and this also was well received. I enjoyed discussions on work that was relevant to my research and took pleasure in being introduced to topics that were new to me. I found that the one-to-one conversations possible through the poster presentation format were of great value, particularly for making new contacts.

I attended many presentations on topics outside of my research field and was particularly interested in the sections on dynamics and liquid crystal behaviour at surfaces. Invited talks and plenary sessions provided an excellent introduction to important research currently at the forefront of liquid crystal science. These were fascinating and certainly improved my understanding of topics outside of my research area. I left the conference feeling inspired with renewed energy to continue my research.

The conference was held near to the beautiful centre of Ljubljana. At lunch and dinner times there were many opportunities to sample the delicious food and drink at the restaurants lining the Ljubljanica River at the foot of the hill upon which the Ljubljana castle stands. I very much enjoyed attending a concert of classical music in the Franciscan church and a lively conference dinner in the castle grounds, both thoughtfully arranged for the benefit of the conference delegates. A midweek half-day break in the conference agenda allowed a trip to the stunning Lake Bled and a swim in its refreshing (chilly!) waters.

The conference was extremely well organised and the efforts of the organising committee at both the Jožef Stefan Institute and the University of Ljubljana were very much appreciated. I am very grateful that I had the chance to attend this conference and would recommend that other students attend future ILCC events if given the opportunity.

Tiffany Wood
Manchester University

Royal Society fund exchange:

Dr Shengping Ruan of Jilin University, China

Dr Shengping Ruan of Jilin University, Changchun, China is spending a year working with Professor Helen Gleeson at Manchester on a project entitled 'Laser manipulation of mesoscopic liquid crystal systems.' During his time here, Shengping will concentrate on the study of local shear viscosity in nematic liquid crystals using laser tweezing, a technique that has only recently

been demonstrated (T A Wood, PhD thesis, Manchester University (2004)).



Hot LC News

Selling at a Loss?

The last half of 2004 and the beginning of 2005 was a rough time for FPD manufacturers, with only a few (perhaps) managing to stay in the black. The problem was oversupply, combined with relentless pressure from the manufacturers' TV-making customers to keep display module prices low. Large TV displays were being sold at a loss. In the first quarter of this year, DisplayBank reported that the average total cost of a 42-inch PDP panel was \$847, while the average selling price was \$840, resulting in a loss of \$7 per unit. In the same period, 42-inch LCDs lost \$67 a unit, with a cost of \$2167 and a selling price of \$2100. This made TV manufacturers happy and put consumers in a buying mood, but it's no way to run a railroad.

The news from the LCD front is about like the weather outside my office window: partly cloudy with a chance of rain. DisplaySearch Taiwan was predicting that quotes for 32-inch LCD-TV panels - which were \$580 in June - were likely to stay flat for July, while prices of 37-inch panels were likely to fall by 10 to 20 dollars.

The projections for smaller panels were rosier, with prices of 15- and 17-inch LCD-monitor panels projected to increase by two to three dollars, and 15- and 15.4-inch notebook-panel prices projected to rise by three to five dollars. But CPT went further, saying it would raise its prices for 15- and 15.4-inch notebook panels by \$15 as a result of strong demand.

Building larger fabs, localizing the supply chain, and squeezing suppliers, customers, and the distribution channel can take panel makers only so far. But, according to Nikkei Microdevices' Naoki Tanaka, writing in the English-language version of Nikkei Microdevices' Flat Panel Display 2005 Yearbook, LCD executives expect "to cut manufacturing costs to one-third of current levels over the next five years. The seeds for the revolutionary production technology that will be needed to that end have appeared."

Excerpts from SID editorial: www.sid.org

Screen Technology Group Floats on AIM

Screen Technology Group plc has floated on the Alternative Investment Market of the London Stock Exchange with a valuation of more than £20m.



Tony Kellett, CEO at Screen Technology with an 80" ITrans

Peter Smyth, Chairman of Screen Technology said "These funds will enable the Group to maximise the great potential of its novel ITrans® technology. Our next step will be to increase our production capacity and sales and marketing reach within this rapidly growing market place".

ITrans® offers unique performance in the large screen displays market, combining high brightness and high resolution with sizes from one square metre up to tens of square metres.

Tony Kellett, CEO, commented "Designers of large screen displays will have to think again about the range of solutions available to them, no longer limited by the size of a plasma display or the amount of information on a LED screen. ITrans® opens up new opportunities for creativity and powerful communication".

The Group will be launching the ITrans® screens at exhibitions in London, Dubai, Singapore, Brussels and Orlando across the next twelve months.

Information: www.screentechnology.com

LG.Philips LCD Celebrates Beginning of Equipment Installation at Gen 7 Facility

Seoul, Korea, July 7 - LG.Philips LCD Co., Ltd. held a ceremony today to mark the beginning of equipment installation for the first phase of its Gen 7 facility, "P7." P7, which is the centerpiece of LG.Philips LCD's Paju Display Cluster, is expected to begin mass production of LCD panels for 42- and 47-inch HDTVs and large-and-wide PC monitors in the first half of 2006.

Commenting on the progress of construction of the Paju Display Cluster, which broke ground in March 2004, LG.Philips LCD Vice Chairman & CEO Bon Joon Koo said, "The Paju Display Cluster is distinguished by the rapid pace of construction, which was made possible by the active support of the central government, Gyeonggi Province, Paju City, and other authorities. LG.Philips LCD will continue to focus on enhancing its competitiveness with the successful introduction of this new facility."

During the ceremony, Gyeonggi Province Governor Hak-kyu Sohn said, "I am confident that LG.Philips LCD and the Paju Display Cluster will soon emerge as one of the world's largest TFT-LCD production bases. To facilitate this development, Gyeonggi Province and Paju City will continue to support the construction of an industrial complex for parts suppliers and related infrastructure."

The ceremony, which took place at the P7 construction site in the Paju Display Cluster, was attended by Hak-kyu Sohn, the governor of Gyeonggi Province, Jae-hoon Lee, head of the Ministry of Commerce, Industry and Energy's Trade and Investment Policy Office, Jae-chang Lee, and Young-sun Kim, both of whom are National Assembly lawmakers, and other representatives of the central government and Paju City. Michael Brownell (SPIE news)

Source: www.sid.org

LCDs win gold and silver

Boston, Massachusetts, May 24 - For the first time in their 10-year history, the SID/Information Display magazine Display of the Year Awards, the most prestigious awards in the display industry, were announced live today during the Keynote Session at the Society for Information Display (SID) 2005 International Symposium, Seminar and Exhibition at Boston's Hynes Convention Center.

LG.Philips LCD (Korea) won the Display of the Year Gold Award for its LC550W01-A5 LCD Module - the first commercially available thin-film-transistor liquid-crystal-display (TFT-LCD) module for

television sets in the mid-50-inch range, and for addressing the challenges of designing large TFT-LCD modules for television applications with a variety of innovative technologies.

The Display of the Year Silver Award went to Nemoptic (France) for its BiNem® bi-stable LCD, a bi-stable variation on the classic supertwisted nematic (STN) LCD. A black-and-white, VGA version of the display is currently being manufactured and integrated into eBooks by Nemoptic licensee Picvue.

Information: www.sid.org

New HP display 'as clear as a glossy magazine'

The prototype still-image display unveiled at London's National Gallery this week looked far from ready for the high street, but Hewlett-Packard is confident that the revolutionary liquid-crystal display technology it has developed will ultimately lead to ultra high-resolution flat screens ranging in size from a magazine page to an advertising billboard. What is more, they will use far less power than ordinary LCD screens, and can be made using cheap printing technology.

Giant TV screens that hang on the wall have already escaped from the lab, and electronic displays have appeared as small e-book screens, but they cannot match the resolution of the colour printing process used in magazines and books.

Conventional computer screens can only manage 1600 by 1200 pixels, and even high-definition TV displays create their images with an array of 1920 by 1080 pixels at best. Now, HP reckons it can make an A4-sized screen with 7000 by 5000 pixels – matching the quality of a

glossy magazine. HP says it will be able to replicate this quality on screens all the way up to large electronic posters and billboards.

In a standard LCD cell, layers of liquid crystals are sandwiched between two polarising filters. Normally, successive layers of liquid crystals are twisted in a way that rotates the polarised light passing through by 90 degrees.

But apply an electric field across the cell and the crystals line up so that they no longer rotate the light, and the cell switches on. To keep the pixel on or off, a transistor has to supply a "refresh" current 50 or 60 times per second. This transistor is costly, and the refreshing process consumes power.

Information: www.newscientist.com/article.ns?id=dn6557

The ups and downs of LCOS

Intel (Santa Clara, CA) has confirmed the rumors we have been hearing for the last month or so - the company will officially close down its LCOS development efforts. After reviewing the project, Intel management decided that the opportunity for LCOS microdisplays was not large enough to justify the continued investment necessary to fully commercialize the technology. Perhaps two-dozen jobs will be affected in California, Oregon, New Hampshire and Arizona, with most being offered new assignments.

Is this the end of the road for LCOS? We think definitely not. All LCOS approaches are not created equal and the termination of Philips and Intel's LCOS effort is more of an indicator of failed methodology than a failed technology. Sony, JVC and a number of other LCOS players, both public and in stealth mode, have better technical methods that should yield successful products.

However, the fact that Philips and Intel have exited the LCOS arena will cause many to conclude that LCOS cannot be commercialized. This could make it tougher for the remaining LCOS players to gain confidence in the industry and in the minds of consumers.

Management finally added it all up and decided the revenue potential did not outweigh the risk and investments needed to be successful. It decided resources were better spent in other areas of greater potential return - a similar conclusion that Philips' management came to.

We estimate Intel probably spent north of \$50M on LCOS over the last 5-6 years. Plus, it spent tens of millions more in related projection technology and company investments. Some of these investments remain, but Intel is still in the process of deciding if and what it will do with the IP and know how it acquired.

The good news is that the rest of the LCOS manufacturers are making progress as was reported at CES. LCOS 1080p sets are also looking very impressive. Topping the performance list was a 65-inch set from Brillian that has now boosted contrast from 2500:1 to at least twice that level. LG Electronics was

showing an LCOS 1080p set behind closed doors, while Daytek showed a single-panel 52-inch RPTV, featuring a single panel from Microdisplay Corporation, with a four-primary color wheel developed with help from Genoa Color Technologies. We also saw very impressive 1080p demonstrators in the eLCOS suite and in Taiwan engine maker Thintek's booth in the Hilton.



In addition, JVC has introduced two HD-ILA (LCOS) 1080p sets, in 61 and 70 inches. Both will offer integrated ATSC tuners and dual HDMI inputs, and the larger set will include a memory card reader.

In LCD-TVs, Westinghouse Digital is introducing a line of 1080p LCD video monitors, starting with a 37-inch model (LVM-37w1) that will be available at Best Buy for \$2,500 in March. Following in July will be 42- and 47-inch models. Claiming to be the first to introduce a "line" of 1080p models, Westinghouse says it is now a technology leader as well as a price pioneer. However, perhaps the price partially explains the jitter, fuzziness and noise we noticed on the 37-inch demo, despite excellent color saturation and depth. The feed was live football on ABC, so perhaps that's partly to blame.

Information: www.insightmedia.info

Liquid crystal – nanotube dispersions: combining two modern materials.

Ingo Dierking

School of Physics and Astronomy, University of Manchester, Manchester; email: ingo.dierking@manchester.ac.uk

Liquid crystal composites and dispersions of micron- or nano-sized particles in anisotropic fluids are becoming an increasingly popular field of research with a wealth of prospective applications far beyond the well-established liquid crystal display technologies. We have combined the self-organising behaviour of liquid crystals with the anisotropic electrical properties of carbon nanotubes.

Nanotubes basically represent rolled up sheets of mono-molecular carbon into tubes of 1.2 nanometres diameter and lengths in the order of micrometers. They have attracted much interest over the last decade, due to their fascinating physical properties: electric conductivity along the tube axis, while insulating across, an extremely high mechanical modulus in direction of the tube axis, while being flexible in other directions. Applications have been proposed in a wide range of areas, from field emission sources, actuators and nano-electronics (who has not visited the IBM website showing a single nanotube transistor?), all the way to chemical and biological nano-sensors or as mechanical enforcement materials in polymers.

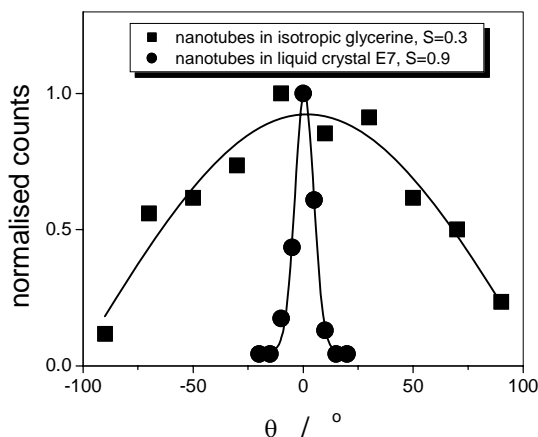


Fig.1: Orientational distribution function of dispersed multi-wall nanotubes in the isotropic host glycerine (squares) and in the nematic liquid crystal host E7 (circles). A pronounced ordering effect is observed for the liquid crystal host, while the slight ordering in the case of glycerine is due to flow alignment during cell filling.

But nanotube applications do not come easy. The tubes are generally not aligned, they physically entangle, and they form bundles due to van-der-Waals forces. In fact, non-treated single-wall nanotubes very

much look like a plate of spaghetti only somewhat smaller. We therefore proposed to use the self-organisation of liquid crystals to impose order on dispersed nanotubes of both the single- and the multi-wall type.

The result is shown in fig. 1, comparing the order distribution function of multi-wall nanotubes in nematic liquid crystal E7 (circles) and isotropic glycerine (squares, a liquid of comparable viscosity). In the former case, the nanotubes are clearly ordered along the liquid crystal director with a very high order parameter of $S \approx 0.9$, while in the latter case only slight ordering is observed, which is indeed only due to flow alignment effects during cell filling. We have thus given nanotubes a sense of order through exposing them to the director field of a nematic liquid crystal.

But, can we also influence the direction of nanotube orientation? The answer is yes! By exploiting the Fredericksz transition of the liquid crystal matrix. Applying an electric field to a cell with planar boundary conditions, filled with a nanotube-doped liquid crystal host with positive dielectric anisotropy, causes a director field re-orientation from planar to homeotropic.

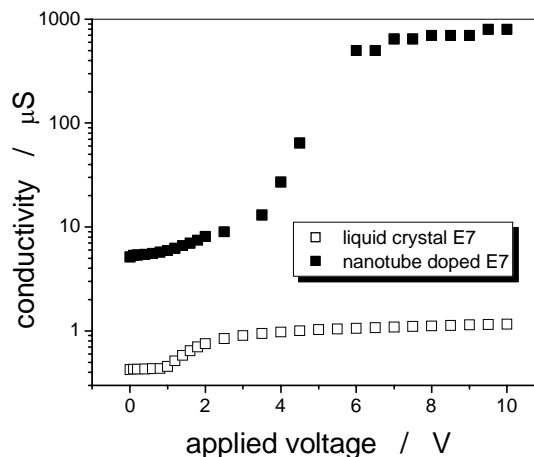


Fig. 2: Electric conductivity as a function of applied electric field for the neat E7 liquid crystal (open squares) and the corresponding nanotube dispersion (closed squares). The conductivity for both systems does not scale, thus eliminating effects of ionic contamination. Note the logarithmic scale of the conductivity axis. The device represents an electrically steered OFF-ON liquid crystal – nanotube switch

Since the conductivity of nanotubes is large along the tube axis and absent in perpendicular direction, this

should result in a significant increase of conductivity for applied voltages above the liquid crystal threshold voltage, provided that the nanotubes actually follow the director re-orientation. Fig. 2 shows that this scenario is indeed observed and that the increased conductivity is not due to the addition of ionic impurities, because in that case the conductivity of the pure liquid crystal and that of the liquid crystal - nanotube dispersion should scale, which it clearly does not.

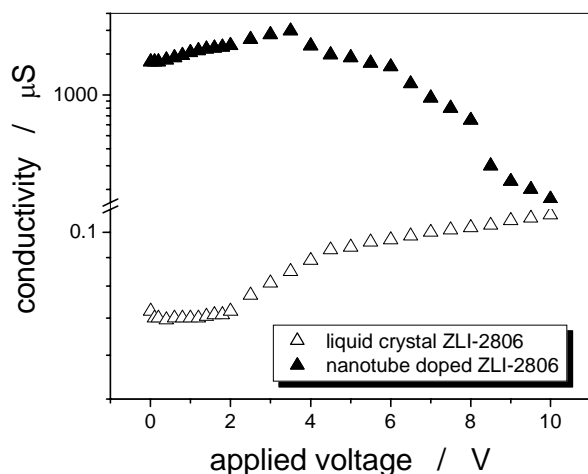


Fig. 3: Electric conductivity as a function of applied electric field for the neat ZLI-2806 liquid crystal with negative dielectric anisotropy (open squares) and the corresponding nanotube dispersion (closed squares). Note the logarithmic scale of the conductivity axis and

the axis break. The device represents an electrically steered ON-OFF liquid crystal-nanotube switch.

Fig. 3 provides the required evidence for the sceptic. If the nanotubes really follow the director re-orientation of the liquid crystal host, then application of an electric field to a dispersion with negative dielectric anisotropy, subjected to homeotropic boundary conditions, should display a strong decrease in conductivity as the liquid crystal threshold voltage from homeotropic to planar orientation is passed. Nanotubes should reorient from the conducting to the non-conducting state. This is exactly what is depicted in fig. 3.

In conclusion, we have demonstrated the alignment of carbon nanotubes through the imposed self-organisation of a liquid crystal host. We further demonstrated their re-orientation through elastic interactions with the nematic director field under electric field application, exerting a torque on the dispersed nanotubes and causing them to re-orient into the direction of the director. The two dispersions discussed, represent electrically steered molecular OFF-ON and ON-OFF liquid crystal – carbon nanotube switches. Other steering mechanisms, like magnetic or optical fields, can be envisioned. Such investigations are currently ongoing.

[1] I. Dierking, G. Scalia, P. Morales, D. LeClere, *Adv. Mater.*, **16**, 865 (2004).

[2] I. Dierking, G. Scalia, P. Morales, *J. Appl. Phys.*, **97**, 044309 (2005).

Dates for the diary

- Eurodisplay 2005, 19th to 2nd September 2005, Edinburgh International Conference Centre (EICC)
- 12th Colloque Francophone sur les Cristaux Liquides, September 13-16, 2005, Montpellier, France
- FLC 2005: 10th International Conference on Ferroelectric Liquid Crystals, September 12 - 17, 2005, Stare Jablonki, Poland
- XVI Conference on Liquid Crystals: Chemistry, Physics and Applications, September 12 - 17, 2005, Stare Jablonki, Poland
- ILCEC: International liquid crystal elastomer conference, 21-23 September 2005, Corpus Christi College, Cambridge
- 11th International Topical Meeting on Optics of Liquid Crystals (OLC), October 2 - 7, 2005, Tampa Bay, Florida, USA
- 14th International Symposium on Advanced Display Technologies, 10 - 14 October 2005 Crimea, Ukraine
- Royal Society Meeting: New directions in liquid crystal science, 4th to 6th December 2005, The Royal Society, London
- IDW/Asia Display '05, 06 - 09 December, 2005, Takamatsu, Japan
- Symposium "Self-Assembled Materials and Liquid Crystals" (#31) at Pacificchem 2005, December 15 - 20, 2005, Honolulu, Hawaii, USA
- 34. Arbeitstagung Flüssigkristalle, 29 - 31 March 2006, Freiburg, Germany
- BLCS Annual Meeting, 11th to 13th April 2006, University of York, York
- Display 2006 - 2nd International FPD Expo concurrent with 16th FPD R&D Manufacturing Technology Expo & Conference/Finetech, April 19-21, 2006, Tokyo, Japan
- SID 2006, June 4-9, 2006 San Francisco, USA
- 21st International Liquid Crystal Conference, 2-7 July 2006, Colorado, USA

British Liquid Crystal Society Registered Charity (328163)

Balance Sheet at 18th March 2005

Description of Income	£	£
Cash at Bank		
General Fund	14675.19	
Sturgeon Fund	5824.99	
Total Cash at Bank		20500.18
Subscriptions		
General	70.00	
Total Subscriptions		70.00
University College, London Conference (2002)		200.00
Interest (1/4/03 to 31/3/04)		
General Fund	339.95	
Sturgeon Fund	134.94	
Total Interest		474.89
Total Income		21245.07
Description of Expenditure	£	£
BLCS Young Scientist Prize 2004		250.00
GW Gray Medal 2004		257.39
BLCS Bursaries (2004-2005)		1000.00
Exeter Conference (2005) loan for expenses		1500.00
Cash at Bank		
General Fund	12277.75	
Sturgeon Fund	5959.93	
Total Cash at Bank		18237.68
Total Expenditure		21245.07

Treasurer's Annual Report

The General Fund at the start of the financial year showed a very healthy £14675.19 plus a further £5824.99 in the Sturgeon Fund, giving a total of £20500.18.

The Society's bursary scheme to facilitate students attending conferences had only five applications in the financial year. All these applications were of a very high standard, and all were approved at the rate of £200.00 each.

The 2002 BLCS annual conference at University College, London (a one day event) raised £200.00. A most welcome bonus for the accounts of BLCS. The financial position of the annual conferences at Cambridge (2003) and Manchester (2004) are yet to be finalized.

Over the last couple of years, the BLCS Winter Workshop at Hull has become very difficult to operate on a sound financial footing, due to increased costs and a smaller number of delegates (particularly industrial delegates). The 2004 event was particularly hard hit with only 20 delegates attending, resulting in a loss to the society of £852.22, which will appear in the accounts next year.

A loan of £1500.00 was made to the University of Exeter to cover some expenses for the 2005 BLCS annual conference.

Income from subscriptions was extremely low this year (£70.00), however, 14 new members were recruited for 3 years at the 2004 BLCS annual conference in Manchester, raising £294.00, and will be included in the

2006 accounts.

Interest earned on the Society's funds is now back to a reasonable level (£474.89), with the vast majority of the Society's funds in a high interest charity account with Yorkshire Building Society. The Society is a Registered Charity and so all interest is paid without the deduction of tax.

The capital value of the Sturgeon Fund has increased, due to the addition of interest, however, expenses of £420.73 in respect of the 2004 annual conference will be included in the 2006 accounts.

Funds have been used over the past two to three years to good effect in supporting the attendance of students at conferences, and also the attendance of

students, and others new to the field of liquid crystals, at the BLCS Winter Workshops which have been generously subsidized by the Society in recent years. Ignoring the conference loan made to the University of Exeter, the Society's cash at the bank is still reasonably substantial.

This is Mike's final report as BLCS treasurer. Mike has been doing a superb job managing the BLCS finances for which we are extremely grateful. His successor will be Avtar Matharu. - ed

Dr Mike Hird
BLCS Treasurer

Editor: Tim Wilkinson
Contributions to tdw@eng.cam.ac.uk

I would like to do an issue earlier in the year, but to do this I need contributions, think of it as a cheap publication!

Disclaimer

The contents of Liquid Crystal News does not necessarily represent the views or policies of the BLCS. Publication of items in Liquid Crystal News does not imply endorsement of any views or statements or products / services advertised by either the editor or the BLCS.



Can you identify this LC phase?

Procedures for the Ben Sturgeon Award

Eligibility for the Award

1. Young Scientists or Engineers (under 40).
2. Must have made significant contributions to the displays field over the past 10 years.
3. Ideally the work they are nominated for should be in the liquid crystal display field (this includes all aspects of technology used in LCDs).
4. Under exceptional circumstances nominees from other display areas will be considered. In that case the international value of the work must be clearly demonstrated.

The Nominations

1. Letter of nomination clearly setting out the value of the nominees' work.
2. Additional letters of support are helpful but not essential.
3. CV for the nominee.
4. Publications (papers and patents) list.
5. Copies of key papers.
6. Nominations should be sent to the Chair of SID (UK).

The Role of SID (UK)

1. The SID (UK) Committee will appoint two of its members to the Ben Sturgeon Award sub-committee to review nominations for the Ben Sturgeon Award and make recommendations to the SID Committee.
2. The SID (UK) committee will publicise the award through the SID Newsletter, the SID (UK) Homepage, through EPSRC, DTI and through individual networking.
3. The Ben Sturgeon Award Sub-Committee is responsible for selecting the winner (s). The decision of the Sub-Committee will except in exceptional circumstances (e.g. where the Sub-Committee is unable to come to a majority decision) be approved by the SID (UK) Committee which is responsible for making the award. In any such exceptional case the SID (UK) Committee will make the final selection of the winner based on the information presented by the sub-committee, through a majority vote. In this case the vote will exclude the two SID (UK) nominees to the Ben Sturgeon Award sub-committee.
4. SID (UK) will present the award at their annual autumn conference (usually in association with EID) unless the recipient cannot attend that meeting. In that case SID will make the award at the next SID (UK) Technical meeting.

The Role of BLCS

1. The BLCS committee will appoint two members of the BLCS to the Ben Sturgeon Award sub-committee to review nominations and make recommendations to the SID (UK) Committee. This will allow the BLCS Committee to select the best-qualified people taking into account the candidates nominated. In practice the Sub-Committee members would be appointed from BLCS Committee members provided they have appropriate expertise.
2. BLCS will publicise the award through their Newsletter and the BLCS Homepage, through individual networking and other appropriate routes.

The Role and Constitution of the Ben Sturgeon Award Sub-committee

1. The sub-committee is constituted of two members from the SID (UK) committee and two members from the BLCS committee, selected by the BLCS.
2. One of the two SID (UK) Committee members will be appointed by the SID (UK) Committee as co-ordinator.
3. The SID sub-committee members are responsible for writing the call for nominations in consultation with BLCS.
4. The members of the sub-committee should individually review all nominations and then either meet or through other means come up with recommendations for the award. The recommendations should include a ranking of all the nominations and a justification.
5. In the exceptional case that the sub-committee cannot agree, individual recommendations (with justifications) should be made to the SID (UK) Committee. The Sub-Committee can also recommend two awards being made

Timetable

Nominate SID Sub-committee members	February
Write call for nominations	March
Issue call for nominations	March/April
Deadline for submission of nominations	June
Appoint BLCS Sub-Committee members	July
Review of nominations	July/August
Sub-committee recommendations	End August
Selection of award winner	Early September
Inform winner	Early/Mid Sept
Publicise Award ceremony (EID)	September
SID order plaque	Mid September
Award ceremony EID	November