Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713926090

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To cite this Article Alonso, I. , Martinez-Perdiguero, J. , Ortega, J. , Folcia, C. L. and Etxebarria, J.(2007) 'Characteristics of a liquid crystal display using optically isotropic phases of bent-core mesogens', Liquid Crystals, 34: 5, 655 — 658
To link to this Article: DOI: 10.1080/02678290701251377
URL: http://dx.doi.org/10.1080/02678290701251377

Liquid Crystals, Vol. 34, No. 5, May 2007, 655–658

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Characteristics of a liquid crystal display using optically isotropic phases of bent-core mesogens

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(*Received 12 October 2006; accepted 14 December 2006*)

A liquid crystal display (LCD) mode based on non-oriented samples of bent-core molecules is presented. The display uses an optically isotropic phase, which is relatively common in bent-core compounds. The LCD switches between the isotropic phase (off-state), and a conventional SmCP phase (on-state) that gives rise to the bright state. The device exhibits good performance: fast response (~0.1 ms), quite large contrast ratio (>100:1), continuous grey levels and wide viewing angle. These characteristics have been observed down to 80°C. Other remarkable advantages are the robustness of the cells and the simplicity of their preparation, since the material need not be aligned.

1. Introduction

The discovery of bent-core mesogens [1] has opened broad prospects in the field of thermotropic liquid crystals. A variety of interesting phenomena, especially related to chirality and polarity, has been found in these materials, and the topic has been object of several reviews [2–6]. However, despite this intensive activity in basic research, very few studies refer to possible applications of bent-core liquid crystals. This is due to several factors such as the chemical instability of many of these materials and the difficulty of obtaining well aligned cells. In addition, there is still a certain lack of knowledge in some important aspects of the physics of several mesophases. Up to now, only two liquid crystal display (LCD) applications with bent-core mesogens have been proposed [7, 8].

One proposal is a scattering-type LCD using SmCP phases and is based on the different scattering cross-sections of an unaligned sample depending on the clinicity of the phase [7]. This phenomenon has been explained [9] in terms of the different sizes of the sample regions where the macroscopic optic tensor is homogeneous. This size is larger for anticlinic states which, therefore, are more transparent than the synclinic states. In any case, the difference between the transmission of both states is difficult to control and small in practice. Thus the contrast of this device is very poor and, additionally, does not permit the possibility of easily attaining grey levels.

The second LCD mode using bent-core materials has been proposed very recently [8]. In this mode a SmA-type phase is used. This phase is not a classical SmA phase but an unusual uniaxial, polarly ordered phase with a randomized interlayer structure. It was called $SmAP_R$ [10] and can be aligned homeotropically using standard silane coupling agents. In the absence of an electric field the sample is black between crossed polarizers; by applying an in-plane field, light transmission is attained. The characteristics of the resulting display are very good: high contrast, wide viewing angle, short response time, continuous grey level and small threshold voltage. One possible problem is that the compounds possessing this phase are scarce, especially if a wide temperature range is required.

2. Results and discussion

In this paper we present an alternative type of LCD using another type of phase often found in bent-core liquid crystals. The structure of interest here is an optically isotropic mesophase that can be sometimes produced by electric field treatment of normal SmCP phases or appear spontaneously on cooling the isotropic liquid [11, 6]. In most cases chiral domains are visible under the microscope by slightly uncrossing the polarizers, see figure 1 (*a*); sometimes these domains are not observed, suggesting a racemic structure, figure 1 (*b*) [12].

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Liquid Crystals
ISSN 0267-8292 print/ISSN 1366-5855 online © 2007 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/02678290701251377

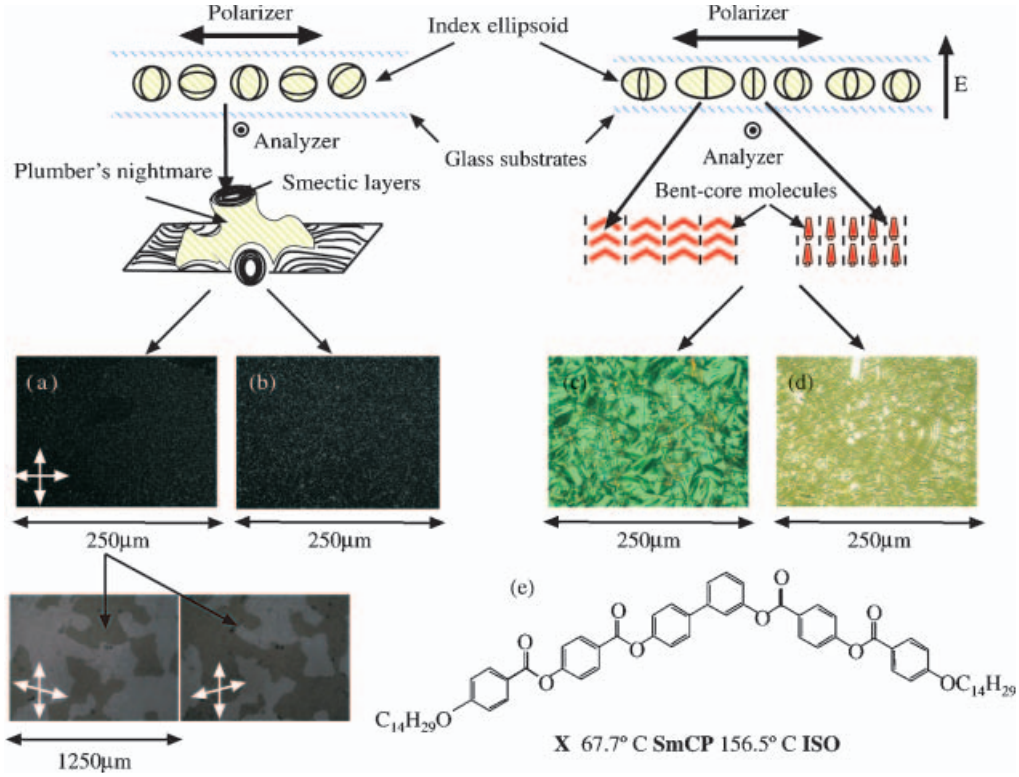

Figure 1. Working mechanism of the display. In the field-off state (left side cartoon) the smectic layers are strongly folded at a mesoscopic scale ('plumber's nightmare' structure) and as a result the material is perfectly isotropic. In the field-on state (right side cartoon) the smectic layers flattens to form a SmCP phase composed of very small domains oriented at random. In this state the material presents birefringence, which gives rise to the bright state of the display. In the figure the view of the molecular arrangement corresponding to some index ellipsoids is also depicted. (*a*) Texture of the homochiral isotropic state under crossed polarizers. On uncrossing the polarizers slightly, the chirality domains are observed. (*b*) Texture of the racemic isotropic state. (*c*), (*d*) Textures of the material under crossed polarizers in the field-on state for the homochiral and racemic samples, respectively. (*e*) Chemical structure and phase sequence of the material.

The structure of the optically isotropic fluid phases is not fully clarified. The first structural models considered these phases as normal SmCP structures with very small domains oriented at random [13]. However, currently it is believed that the disordered arrangement of the domains is not extrinsic but inherent to the nature of the phases themselves. Recently it has been proposed [14] that they could be a disordered version of the kind of structures assigned to the smectic blue phase by DiDonna and Kamien [15]. According to these models, in these phases the smectic planes are strongly folded and the resulting structure is stabilized by a high negative value of the saddle–splay elastic constant K_{24}. One possibility for the phase construction is based on the so-called Schwartz P surface or 'plumber's nightmare' (see figure 1), although other surfaces with more negative saddle–splay energy have been also proposed. The isotropy is explained as due to the small size of the locally flat smectic regions (smaller than the optical wavelength).

The chemical structure of the material studied in this work, together with its phase sequence in the absence of field, is shown in figure 1 (*e*). The synthesis and a preliminary characterization of the compound have been published previously [16], and further studies have been reported [12, 17, 18]. Figure 1 (*a*) shows the optical textures at $T=146^{\circ}$C after cooling the material from the isotropic phase under a strong square-wave field ($12\,\mathrm{V\,\mu m^{-1}}$, 10 Hz) and its subsequent removal. The optically isotropic phase with the chiral domains is clearly visible by slightly uncrossing the polarizers. On further application of an electric field, the texture becomes highly birefringent ($\Delta n=0.14$), see figure 1 (*c*). This indicates a SmC_SP_F structure. A different behaviour results if the field is applied after cooling the material into the normal SmCP phase. In this case, again, a dark texture is obtained after field removal but now there are no chiral domains, figure 1 (*b*). Furthermore, the birefringence of the texture after a subsequent field application is clearly smaller ($\Delta n=0.06$) than in the

preceding case, see figure 1 (*d*). Although the presence of an electric field is necessary to induce the optically isotropic phases, once formed they remain stable with no sign of relaxation into the normal SmCP phase, at least for time periods of a few days.

The working principles of the display are simple and are sketched in figure 1. Without field the cells are dark between crossed polarizers, figures 1 (*a*) and 1 (*b*). Under an electric field the smectic layers become partially unfolded and the material presents light transmission, since now the sample is a disordered cell of a SmCP-type phase, figure 1 (*c*) and 1 (*d*). Both in the homochiral and racemic variants, the field-on state consists of very small domains oriented at random. The switching is reversible and, due to the averaging process of the domains, the amount of light transmitted through an integrated area larger than $100 \times 100\,\mu m^2$ is independent of the field polarity (figure 2).

Some characteristics of the display are shown in figure 3. Under the action of a bipolar step wave the resulting rise and fall times of the electro-optic response are plotted as a function of the amplitude of the electric field. For these measurements Linkam cells 5 µm thick were used. The field was applied with an Agilent arbitrary waveform generator and a Kepco amplifier. Almost no field dependence is found for the fall times whereas the response upon field application varies between 0.35 and 0.08 ms. These characteristic times increase somewhat with decreasing temperature, but fast response below 0.5 ms is achieved in all the temperature range.

Figure 4 shows the transmission as a function of the electric field. An almost perfect V-shaped switching is achieved with no threshold field for the electro-optic response. This permits the realization of continuous grey levels. The contrast ratio is rather high (about 300:1) for the homochiral variant and somewhat smaller (about 100:1) for the racemic variant. This is due to the presence of more defects in the ground state of the latter.

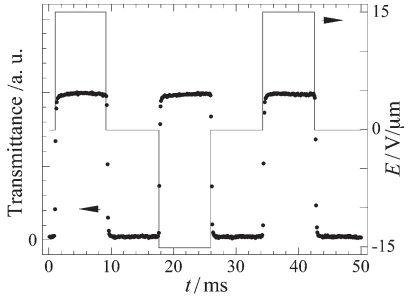

Figure 2. Transmittance of the sample between crossed polarizers at 146°C in the racemic phase (points) together with the applied electric field (lines).

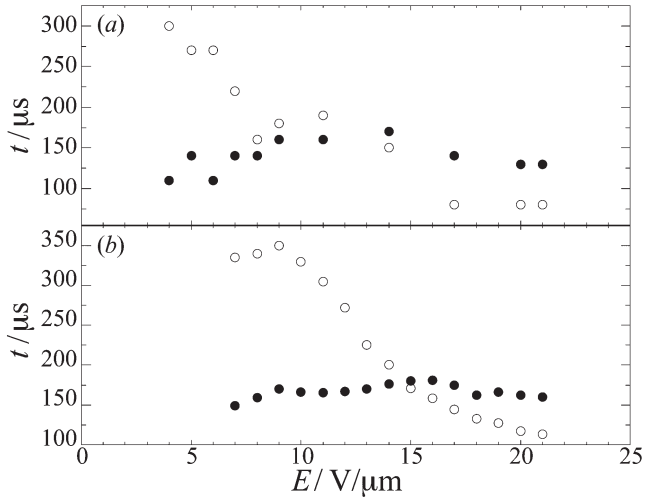

Figure 3. Optical transmission fall times (full circles) and rise times (open circles) obtained under a bipolar step wave, (similar to that shown in figure 2) at 146°C for (*a*) homochiral and (*b*) racemic phases.

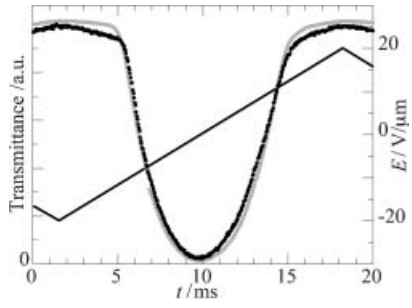

Figure 4. Optical transmission measurement as a function of time performed under a 30 Hz triangular wave field at 146°C for homochiral (grey symbols) and racemic (black symbols) phases. No threshold field is observed in the switching for any of the phases. The graphs are adapted to the optimum cell thickness for maximum transmission under field.

With regard to the viewing angle of the device, although no detailed analysis has been carried out, a rather wide viewing angle is expected for the display. This idea is based on the perfect isotropy of the field-off states (rigorously independent of the illumination direction) and on the compensation effects on the angle dependence of the light transmission that the random orientation and small size of the domains produce in the field-on states see figures 1 (*c*) and 1 (*d*). In particular, due to these specific characteristics of our device the contrast ratio does not depend on the azimuth of the viewing direction.

3. Summary

We have described an LCD mode based on the optically isotropic phases shown by some bent-core molecules. The LCD is fast, has quite large contrast ratio, achieves

continuous grey levels, and has wide viewing angles. As an additional advantage, there is no necessity for alignment, which is very important in practice and adds robustness to the device. The reported LCD mode compares very favourably with other existing display types such as vertical alignment, in-plane switching and ferroelectric LCD modes. More synthetic work is necessary to obtain materials possessing the adequate phases and characteristics in appropriate temperature ranges.

Acknowledgements

Two of us (I.A. and J.M) thank the Ministry of Education of Spain and the Basque Country Government for a grant. We thank Dr M.B. Ros for supplying the material under test. This work was supported by the CICYT-FEDER of Spain-EU (Project No. MAT2003-07806-C02) and the University of the Basque Country (Project No. 9/UPV 00060.310-13562/2001).

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