

Long Term Stability of Polymer Stabilized Blue Phase Liquid Crystals

Joshi, P.; De Smet, Jelle; Chang, Xioabing; Willekens, Oliver; Cuypers, Dieter; Van Steenberge, Geert; Chojnowska, Olga; Kula, Przemyslaw; Van Vlierberghe, Sandra; Dubruel, Peter; De Smet, Herbert

Published in:
Journal of Display Technology

DOI:
[10.1109/JDT.2015.2431442](https://doi.org/10.1109/JDT.2015.2431442)

Publication date:
2015

Document Version:
Final published version

[Link to publication](#)

Citation for published version (APA):

Joshi, P., De Smet, J., Chang, X., Willekens, O., Cuypers, D., Van Steenberge, G., Chojnowska, O., Kula, P., Van Vlierberghe, S., Dubruel, P., & De Smet, H. (2015). Long Term Stability of Polymer Stabilized Blue Phase Liquid Crystals. *Journal of Display Technology*, 11(9), 703-708. <https://doi.org/10.1109/JDT.2015.2431442>

Copyright

No part of this publication may be reproduced or transmitted in any form, without the prior written permission of the author(s) or other rights holders to whom publication rights have been transferred, unless permitted by a license attached to the publication (a Creative Commons license or other), or unless exceptions to copyright law apply.

Take down policy

If you believe that this document infringes your copyright or other rights, please contact openaccess@vub.be, with details of the nature of the infringement. We will investigate the claim and if justified, we will take the appropriate steps.

Long Term Stability of Polymer Stabilized Blue Phase Liquid Crystals

Pankaj Joshi, Jelle De Smet, Xiaoqing Shang, Oliver Willekens, Dieter Cuypers, Geert Van Steenberghe, Olga Chojnowska, Przemysław Kula, Sandra Van Vlierberghe, Peter Dubruel, and Herbert De Smet

Abstract—The issue of long term stability of polymer stabilized blue phase liquid crystals was investigated. It was found that for certain liquid crystals and commonly used chiral dopant combinations, polymer stabilized blue phase liquid crystals develop dendrite like structures. These features are highly scattering and are detrimental to the uniformity of texture. Various possible causes were looked into and it was identified that crystallization of the chiral dopant leads to dendrites and a possible remedy is proposed.

Index Terms—Chiral dopants, dendrites, long term stability, polymer stabilized blue phase liquid crystals (BPLCs).

I. INTRODUCTION

BLUE PHASES (BPs) are thermodynamically frustrated phases existing in highly chiral liquid crystals (LCs) between cholesteric and isotropic phases. BPs are widely believed to be of three types namely, BPI, BPII, and BPIII in the order of increasing temperatures at which they exist. BPI and BPII have body centered and simple cubic lattice structures in their director fields, respectively [1], [2]. BPIII is amorphous with randomly distributed double twisted cylinders [3]. Inherent periodicity in BPI and BPII leads to the presence of Bragg reflection in

Manuscript received March 10, 2015; revised April 20, 2015; accepted May 05, 2015. Date of publication May 11, 2015; date of current version August 10, 2015. This work is supported in part by the Research Foundation Flanders through the project 3GA04711 (“Study of liquid crystals dispersed in micro-structured elastic host materials”); and in part by the IWT through the SBO project SECONDOS, IWT-120019. Part of this work was conducted within the framework of ICT COST Action IC1208, “Integrating devices and materials: a challenge for new instrumentation in ICT”.

P. Joshi, J. De Smet, and X. Shang are with the Department of Electronics and Information Systems, Ghent University, CMST/TFMG Microsystems, B-9052 Gent, Belgium (e-mail: pankaj.joshi@elis.ugent.be; Jelle.DeSmet@elis.ugent.be; xiaobing.shang@elis.ugent.be).

O. Willekens is with Department of Electronics and Information Systems (ELIS); Liquid Crystal and Photonics Group, Ghent University, B-9000 Gent, Belgium (e-mail: oliver.willekens@elis.ugent.be).

D. Cuypers, G. Van Steenberghe, and H. De Smet are with the Department of Electronics and Information Systems, Ghent University, CMST/TFMG Microsystems, B-9052 Gent, Belgium, and also with the IMEC-CMST, Gent, Belgium (e-mail: dieter.cuypers@elis.ugent.be; geert.vansteenbergh@elis.ugent.be; herbert.desmet@elis.ugent.be).

O. Chojnowska and P. Kula are with the Institute of Chemistry, Military University of Technology, 00-908 Warsaw, Poland (e-mail: ochojnowska@wat.edu.pl; pkula@wat.edu.pl).

S. Van Vlierberghe is with Polymer Chemistry & Biomaterials Research Group, Ghent University, 9000 Ghent, Belgium, and also with Brussels Photonics Team (B-Phot), Department of Applied Physics and Photonics-TONA, Vrije Universiteit Brussel, Brussels, Belgium (e-mail: sandra.vanvlierberghe@ugent.be).

P. Dubruel is with Polymer Chemistry & Biomaterials Research Group, Ghent University, 9000 Ghent, Belgium; Peter.Dubruel@ugent.be.

Color versions of one or more of the figures are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/JDT.2015.2431442

these crystals. Colorful platelets of BPs are due to different crystallographic domains selectively Bragg reflecting in different regions of the visible spectrum. The peak Bragg reflection wavelength can be tuned by an electric field over the entire visible spectrum, opening the possibility of reflective displays without color filters [4]. In nature they exist only in a very small temperature interval, typically 1 °C to 2 °C. Various techniques viz. doping with nano-particles [5], [6], doping with dendron shaped molecules [7], addition of short-chain polystyrene [8], synthesis of bimesogenic compounds [9], polymer stabilization [10], [11], etc., have been applied to broaden the temperature range. Out of these techniques, polymer stabilization is the most convenient and successfully increases the temperature range by tens of degree Celsius [10], including room temperature. With the most severe limitation of narrow temperature range solved, this phase of LCs has become a promising material for future displays and myriad non-display photonic components [12]–[16]. With sub-millisecond switching times, polymer-stabilized blue phase liquid crystals (PSBP-LC) are at least one order of magnitude faster than their nematic counterparts. Non-requirement of alignment layers and polarization independent characteristics further increase their appeal. Previously researchers have also investigated other interesting aspects viz. the effect of polymer network on electro-optical properties [17] and the means of reducing operating voltages [18].

Polymer stabilization does enhance the temperature range of BP, however in some cases long term stability of PSBP-LC remains a problem. In this paper, we report a thorough study on appearance of highly scattering crystalline structures, which are undesirable as they compromise the long term stability of PSBP. Its root cause is identified and a possible remedy is proposed.

II. EXPERIMENTS

We prepared various BPLC samples using different base nematic liquid crystals JC-1041XX (Chisso Corporation, Japan), 5CB (Sython Chemicals, Germany), HTG135400 (HCCH, China), HBG980000 (HCCH, China); two types of chiral dopants (CD) ZLI-4572 (Merck, Germany), R5011 (HCCH, China); monomer 2-Ethylhexyl Acrylate (EHA, Sigma Aldrich, Belgium); cross linker RM257 (Sython Chemicals, Germany) and photo-initiator 2,2-dimethoxy-2-phenylacetophenone (DMPAP, Sigma Aldrich, Belgium). The compositions for difference mixtures in weight percentages are listed in Table I.

LC cells were assembled by using 0.7 mm thick white float glass and 1.1 mm thick ITO coated glass, Corning 1737F with sheet resistance of 20 Ω/sq (both from PGO, Germany). Prior to cell fabrication glass plates were thoroughly rinsed in a sequence of steps involving overnight soaking in a RBS deter-

TABLE I
COMPOSITION OF LC MIXTURES IN WEIGHT PERCENTAGES AND SAMPLE DETAILS

Mixture name	LC	Concentration	CD	CD Concentration	EHA	RM257	DMPAP	Sample name	Polymerization state
A1	LC1 ^a + LC2 ^b	44.2 + 34.1	ZLI-4572	10.1	4.2	7.0	0.4	I	polymerized
								II	unpolymerized
A2	LC3 ^c	77.3	ZLI-4572	9.9	4.6	7.2	1.0	III	polymerized
								IV	unpolymerized
A3	LC ^d	79.0	ZLI-4572	10.2	3.3	6.8	0.6	V	polymerized
								VI	unpolymerized
B1	LC1 + LC2	47.9 + 38.9	R5011	2.9	3.3	6.4	0.5	VII	polymerized
								VIII	unpolymerized
B2	LC3	88.0	R5011	3.1	4.1	4.4	0.4	IX	polymerized
								X	unpolymerized
B3	LC4	88.4	R5011	3.0	3.5	4.5	0.5	X	polymerized
								XII	unpolymerized

^a is JC1041-xx; ^b is 5CB, ^c is HTG135400 and ^d is HBG980000

* Concentration: A1 is adopted from [10] and rest are optimized in our lab

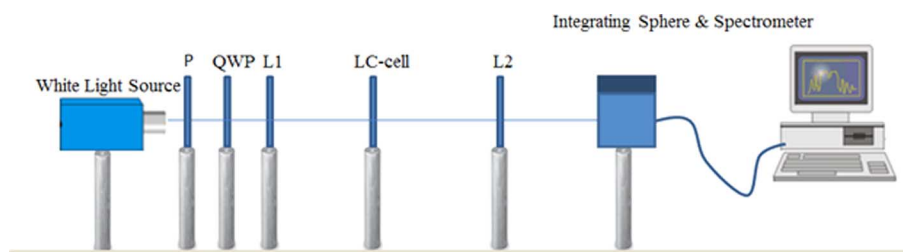


Fig. 1. Experimental setup for the measurement of transmission spectra of PSBP-LC. White light is converted to circularly polarized light by a polarizer (P) with pass axis at 45° with respect to the c-axis of subsequent Quarter Wave Plate (QWP), L1 focuses the beam to a small spot on the LC cell and L2 focuses the beam onto the integrating sphere which collects the light to the USB spectrometer.

gent solution followed by rinsing in isopropanol and de-ionized water. Polymer spacer balls of $10 \mu\text{m}$ diameter (dispensed in Methanol) were spin coated on one of the glass plates and UV curable glue OG116-31 (from Epoxy Technology, USA) was dispensed along the perimeter of the other, leaving two small openings for capillary filling. These glass plates were then glued together by curing the glue using flood exposure of UV (365 nm at 60 mW/cm^2) for four minutes. No alignment layers were applied to any of the glass substrates.

LC mixtures were introduced in the LC-cells at 10°C above the BP-Isotropic transition temperature. The mixtures were then cooled to the temperature at which BP appeared at a cooling rate of 0.1°C/min , in line with the standard practice from literature [12], [19]–[21]. A *TS-4* thermal microscope stage (from Physitemp, USA) was used to control the temperature precisely. Monomers were polymerized by exposing the samples to 1.5 mW/cm^2 uniform UV at 365 nm (Lightning Cure LC08 from Hamamatsu, with collimating lens) for 30 minutes.

For additional confirmation of the BP-like nature of the texture observed in a polarization optics micrograph (POM), we measured the transmission spectrum between 500 and 700 nm using a USB2000 spectrometer (from Ocean Optics, USA) and a Xenon white light source (Hamamatsu, Japan). The schematics of the setup are shown in Fig. 1.

III. RESULTS AND DISCUSSION

Taking cue from literature on concentration we prepared sample I. On gradual cooling from isotropic state as the characteristic texture of BP appeared, UV polymerization was used to stabilize the phase. Response times were measured to be in the sub-millisecond range and the results from tuning the Bragg reflection peak with an electric field were found to be in tune with literature, for PSBP. However, it was found that after a period of roughly 24 hours, the uniform BP texture was disturbed by the presence of dendritic structures as can be seen from Fig. 2(a). The samples were stored in darkness at a constant temperature of 21°C and humidity controlled at 40% in the clean room. Such features are highly undesirable as they defeat the purpose of polymer stabilization. In order to eliminate the hypothesis of the polymerization process itself being a cause; we prepared sample II, an unpolymerized version of I. In due course of time this cell also developed undesired defects as can be seen from Fig. 2(b), which compromised the uniformity of texture. Although the physical appearance of the latter differed greatly from its polymerized counterpart, this observation absolves the polymerization process. The reason behind the difference in appearance is discussed later. These

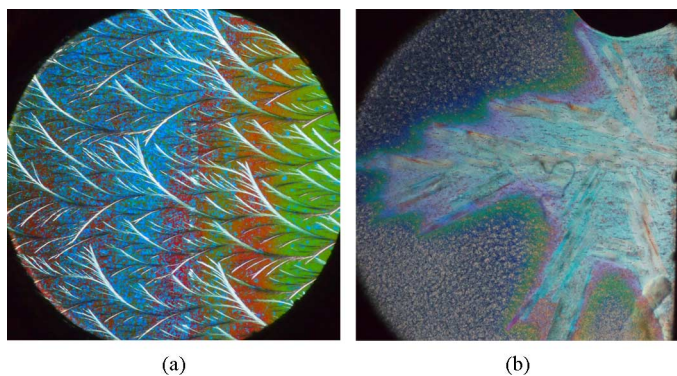


Fig. 2. POM showing dendritic structures in liquid crystal cells between crossed polarizers of LC mixture A1 at room temperature (a) Sample I. (b) Sample II.

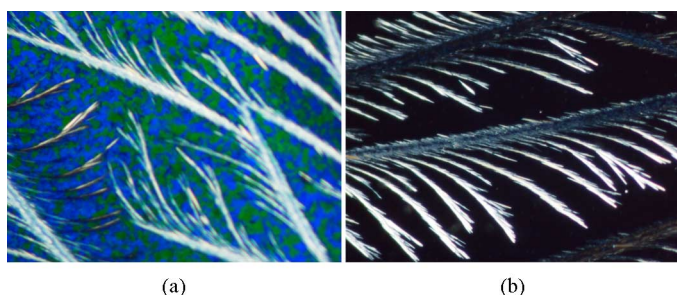


Fig. 3. Response of LC-cell with dendrites in it (a) $V = 0$ volts and (b) $V = 140$ volts DC.

structures invariably start from the filling end of the LC cell and continue to grow till they cover the entire cell.

To understand the dendrite-like structures better and to identify the mechanism responsible for their appearance, we studied their response to an electric field. The dendrites were found to be uninfluenced by the presence of an electric field. In Fig. 3(a) the characteristic platelet texture of BP can be clearly seen surrounding the dendrites. The cell is mounted between crossed polarizers. When a high DC voltage (140 V) was applied, regions with dendrites remained highly scattering while the rest of the cell turned dark as the liquid crystals switched, Fig. 3(b). From this observation, it can be safely inferred that molecules in liquid crystalline state are not present in the dendritic regions. However their mere absence from the region is not enough evidence to conclude that liquid crystals have no role to play in the manifestation of this phenomenon. It is worth noting that properties of PSBP in the regions free from dendrites remain unchanged. The reason for this explained later. Fig. 4. shows transmission versus voltage curve and Bragg reflection before and after appearance of defects. The switching on and off times (10%–90% of transmission), before (after) were $668 \mu\text{s}$ ($645 \mu\text{s}$) and $\sim 950 \mu\text{s}$ ($759 \mu\text{s}$) respectively.

We next prepared a sample without monomers, cross-linker or photoinitiator. The concentration of ZLI-4572 (9.87%) and the ratio of concentrations of JC-1041XX (50.07%) to 5CB (40.06%) are kept the same as in the LC mixture A1. A POM of these samples, Fig. 5(b) taken roughly 24 hours after filling, reveals the presence of dendrites in the region close to the hole used for capillary filling, whereas the central portion of LC cell, Fig. 5(a) remains uniform and devoid of these defects. The whole cell

gets covered by dendrites in due course of time. The presence of dendritic structures in these samples exonerates monomers, cross-linker and photoinitiator from having any role in dendrite formation. Normally the openings for capillary filling are left open after carrying out the polymer stabilization. In order to preclude external influences such as dust, atmospheric gases and moisture from interacting with liquid crystals, openings were hermetically sealed. This did not have any influence on the formation of crystals either. Clearly, this leaves us with, either liquid crystals or chiral dopant or a combination of both being the cause of dendrites.

Replacing the base nematic JC-1041XX with HTG135400 and HBG980000, we prepared samples III, IV, V and VI. As can be seen from Figs. 6(a) and 7(a), dendrites start to appear roughly after 24 hours of polymer stabilization and affect the complete cell in samples III, IV, V, and VI respectively. The same behavior is observed in their respective unpolymerized counterparts, Figs. 6(b) and 7(b), respectively.

From these experiments it can be concluded that dendrite formation is not linked to a particular liquid crystal mixture or their interactions with a specific chiral dopant.

In the samples with slightly lower concentration of chiral dopant, ZLI-4572 (9.0%) with JC-1041XX (51.4%) and 5CB (39.6%), BP was not found to be present. On cooling from isotropic phase at the cooling rate of $0.1 \text{ }^\circ\text{C}/\text{min}$, the LC directly transformed to cholesteric droplets [22] shown in Fig. 8(a). However, these samples did not develop any dendritic structures. Hence the concentration of chiral dopant is suspected to be a crucial parameter. The concentration dependence of the phenomenon points towards crystallization being involved. Although LC mixture is composed of components which are solid at room temperature, the probability of their crystallization is rather low. This leaves us with chiral dopant, which is also a solid at room temperature with limited solubility in LC mixture. This hypothesis is further supported by the shape of dendrites in polymer stabilized and non-polymer stabilized samples. In the case of unobstructed growth, crystals prefer to grow in a highly directional fashion. However the polymer network of PSBP presents an obstruction and forces them to bend, resulting in a branch like texture. This experiment also reveals that the minimum concentrations required to achieve critical chirality, for the BPs to be established, happens to be close to the solubility limit of chiral dopant in the nematic base.

Having established that the dendrite formation is a result of crystallization of chiral dopant we can explain, why properties of PSBP in regions free from them remains unaltered. Crystallization proceeds with local phase separation of chiral dopant. In regions free from it the concentrations remain unchanged so do optical and electro-optical properties. Also, it was recently reported that the polymer network in itself is capable of preserving and inducing chirality to achiral molecules. This capability of polymer networks has been demonstrated by using them as a template to induce BP in achiral liquid crystals [23].

Having arrived at this conclusion, the obvious step was to replace the chiral dopant. Knowing that the critical concentration of chiral dopant required to induce BP is inversely proportional to its HTP, we chose R5011, a chiral dopant with an HTP value greater than $100 \mu\text{m}^{-1}$ [24]. The HTP of ZLI-4572 is reported to be $37.6 \mu\text{m}^{-1}$ [25]. Samples VII to XII were prepared

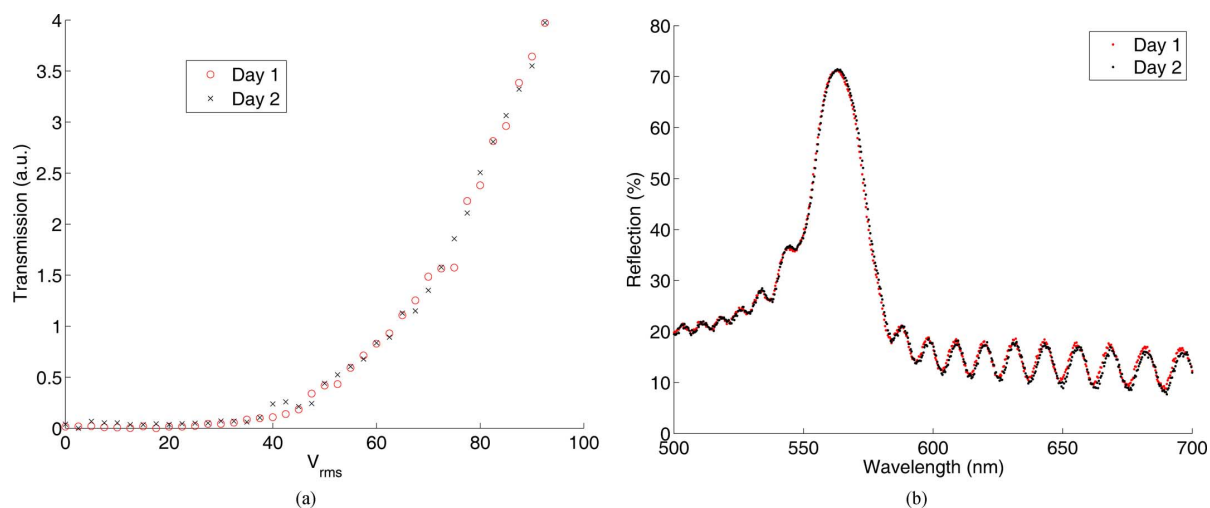
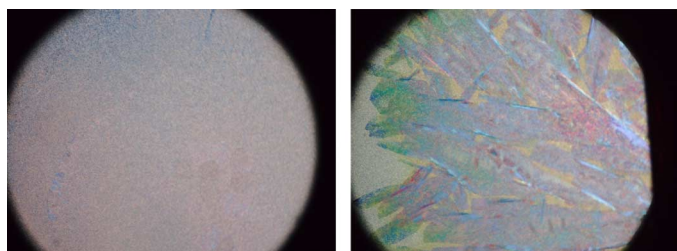
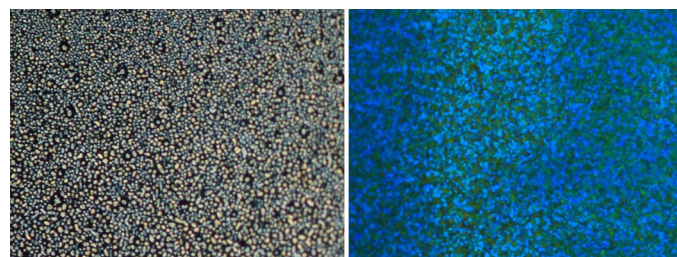


Fig. 4. (a) Transmission versus Voltage through the PSBP and (b) Bragg reflection in Sample B2 before and after appearance of dendrites.



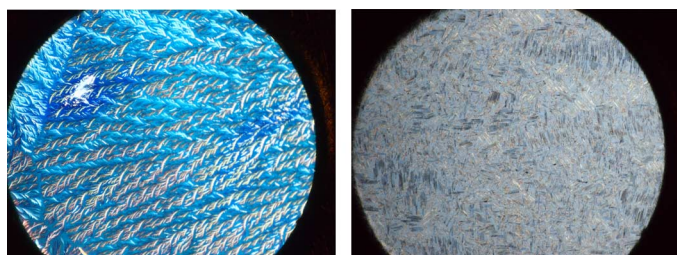
(a) (b)

Fig. 5. POM of the sample without monomer, crosslinker and photoinitiator after 24 h of filling (a) central region of the cell and (b) region near the filling end.



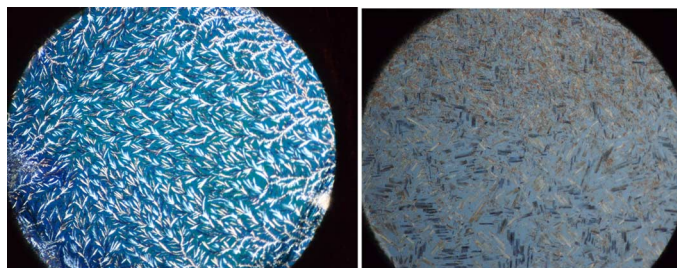
(a) (b)

Fig. 8. (a) POM of a sample with low chiral dopant concentration (b) POM of a sample without dendrites days after polymerization.



(a) (b)

Fig. 6. POM showing dendritic structures in liquid crystal cells between crossed polarizers of LC mixture A2 at room temperature. (a) Sample III and (b) Sample IV.



(a) (b)

Fig. 7. POM showing dendritic structures in liquid crystal cells between crossed polarizers of LC mixture A3 at room temperature. (a) Sample V and (b) Sample VI.

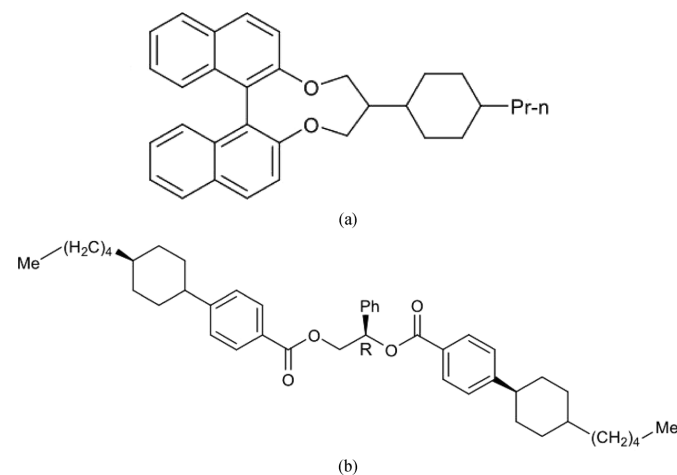


Fig. 9. Chemical structures of the two chiral dopants involved in this study. (a) R5011 and (b) ZLI-4572.

with R5011 with concentrations listed in Table I. The difference between the molecular structures of the two chiral dopants is shown in Fig. 9.

Chiral dopants can be broadly classified in two categories: asymmetric center and axially asymmetric chiral compounds. R5011 belongs to axially asymmetric chiral binaphthyl derivatives which are typical atropisomeric chiral dopants [26]. Being conformationally rigid these chiral dopants manifest high HTP

values [27], which results in appearance of BP with lower concentrations of chiral dopants.

Samples VII, IX and XI then resulted in PSBP which were stable in true sense, by remaining devoid of any undesired manifestations for months. No such defect appeared in their unpolymerized counterparts, samples VIII, X and XII either. The POM of PSBP in sample VII free from dendrites is shown in Fig. 8(b).

IV. CONCLUSION

We investigated the long term stability problems of polymer stabilized blue phase liquid crystals. Undesirable dendritic structures in PSBP-LC were thoroughly studied and their origin was found to be the crystallization of medium HTP chiral dopant, ZLI-4572. Substituting ZLI-4572 with an asymmetric-center chiral dopant with a higher HTP, atropisomeric chiral dopant, resolves the problem. It was recently reported that, contrary to popular believe, chiral dopants with relatively lower values of HTP induce BPs with wider temperature range. Our study unequivocally highlights the fact that, a good balance of HTP and compatibility of chiral dopant with base nematic must be ensured if long term stability has to be guaranteed.

ACKNOWLEDGMENT

The authors would like to thank JNC Corporation, Japan, for providing them with the liquid crystal mixture JC-1041XX.

REFERENCES

- [1] E. Dubois-Violette and B. Pansu, "Frustration and related topology of blue phases," *Mol. Cryst. Liq. Cryst.*, vol. 165, no. 1, pp. 151–182, 1988.
- [2] H. Stegemeyer, T. Blmel, K. Hiltrop, H. Onusseit, and F. Porsch, "Thermodynamic, structural and morphological studies on liquid-crystalline blue phases," *Liq. Cryst.*, vol. 165, no. 1, pp. 3–28, 1986.
- [3] H. S. Kitzerow, P. P. Crooker, and G. Heppke, "Line shapes of field-induced blue-phase-III selective reflections," *Phys. Rev. Lett.*, vol. 67, p. 2151, 1991.
- [4] S. Y. Lu and L. C. Chien, "Electrically switched color with polymer-stabilized blue-phase liquid crystals," *Opt. Lett.*, vol. 35, no. 4, pp. 562–564, 2010.
- [5] E. Karatouri *et al.*, "Nanoparticle-induced widening of the temperature range of liquid-crystalline blue phases," *Phys. Rev. E.*, vol. 81.4, 2010.
- [6] L. Wang *et al.*, "Polymer-stabilized nanoparticle-enriched blue phase liquid crystals," *J. Mater. Chem. C*, no. 40, pp. 6526–6531, 2013.
- [7] S. Shibayama, H. Higuchi, Y. Okumura, and H. Kikuchi, "Dendron stabilized liquid crystalline blue phases with an enlarged controllable range of the photonic band for tunable photonic devices," *Adv. Funct. Mater.*, vol. 23.19, pp. 2387–2396, 2013.
- [8] N. Kasch, I. Dierking, and M. Turner, "Stabilization of the liquid crystalline blue phase by the addition of short-chain polystyrene," *Soft Mater.*, no. 19, pp. 4789–4793, 2013.
- [9] H. J. Coles and M. N. Pivnenko, "Liquid crystal blue phases with a wide temperature range," *Nat.*, pp. 997–1000, 2005.
- [10] H. Kikuchi, M. Yokota, Y. Hisakado, H. Yang, and T. Kajiyama, "Polymer-stabilized liquid crystal blue phases," *Nat. Mater.*, pp. 64–68, 2002.
- [11] H. S. Kitzerow, H. Schmid, A. Ranft, G. Heppke, R. A. M. Hikmet, and J. Lub, "Observation of blue phases in chiral networks," *Liq. Cryst.*, vol. 14, no. 3, pp. 911–916, 1993.
- [12] S. T. Hur, B. R. Lee, M. J. Gim, K. W. Park, M. H. Song, and S. W. Choi, "Liquid crystalline blue phase laser with widely tunable wavelength," *Adv. Mater.*, vol. 25, no. 21, pp. 3002–3006, 2013.
- [13] J. Yan, Y. Li, and S. T. Wu, "High-efficiency and fast-response tunable phase grating using a blue phase liquid crystal," *Opt. Lett.*, vol. 36, no. 8, pp. 1404–1406, 2011.

- [14] Y. H. Lin, H. S. Chen, H. C. Lin, Y. S. Tsou, H. K. Hsu, and W. Y. Li, "Polarizer-free and fast response microlens arrays using polymer-stabilized blue phase liquid crystals," *Appl. Phys. Lett.*, vol. 96, no. 11, p. 113505, 2010.
- [15] C. H. Lin, Y. Y. Wang, and C. W. Hsieh, "Polarization-independent and high-diffraction-efficiency Fresnel lenses based on blue phase liquid crystals," *Opt. Lett.*, vol. 36, no. 4, pp. 502–504, 2011.
- [16] J.-L. Zhu *et al.*, "1D/2D switchable grating based on field-induced polymer stabilized blue phase liquid crystal," *J. Appl. Phys.*, vol. 111, no. 3, p. 033101, 2012.
- [17] Y. Jin and S. T. Wu, "Effect of polymer concentration and composition on blue phase liquid crystals," *J. Disp. Technol.*, vol. 7, no. 9, pp. 490–493, Sep. 2011.
- [18] L. Rao, Z. Ge, S. T. Wu, and S. H. Lee, "Low voltage blue-phase liquid crystal displays," *Appl. Phys. Lett.*, vol. 95, no. 23, 2009, Art ID 231101.
- [19] I. Takashi *et al.*, "Control of cross-linking polymerization kinetics and polymer aggregated structure in polymer-stabilized liquid crystalline blue phases," *Macromol.*, vol. 42, no. 6, pp. 2002–2008, 2009.
- [20] H. Yoshida, S. Yabu, H. Tone, Y. Kawata, H. Kikuchi, and M. Ozaki, "Secondary electro-optic effect in liquid crystalline cholesteric blue phases," *Opt. Mater. Express.*, vol. 4, no. 5, pp. 960–968, 2014.
- [21] H. S. Chen, Y. H. Lin, C. H. Wu, M. Chen, and H. K. Hsu, "Hysteresis-free polymer-stabilized blue phase liquid crystals using thermal recycles," *Opt. Mater. Express.*, vol. 2, no. 8, pp. 1149–1155, 2012.
- [22] I. Dierking, *Texture of Liquid Crystals. Color Plates; Plate 23.*, p. 175.
- [23] F. Castles *et al.*, "Blue-phase templated fabrication of three-dimensional nanostructures for photonic applications," *Nat. Mater.*, vol. 11, no. 7, pp. 599–603, 2012.
- [24] Y. Chen and S. T. Wu, "Recent advances on polymerstabilized blue phase liquid crystal materials and devices," *J. Appl. Polym. Sci.*, vol. 131, no. 13, p. 40556, 2014.
- [25] H. C. Jeong, S. Aya, S. Kang, F. Araoka, K. Ishikawa, and H. Takezoe, "Are chiral dopants with higher twisting power advantageous to induce wider temperature range of the blue phases?," *Liq. Cryst.*, vol. 40, no. 7, pp. 951–958, 2013.
- [26] M. Goh, J. Park, Y. Han, S. Ahn, and K. Akagi, "Chirality transfer from atropisomeric chiral inducers to nematic and smectic liquid crystals synthesis and characterization of di- and tetra-substituted axially chiral binaphthyl derivatives," *J. Mater. Chem.*, vol. 22, no. 48, pp. 25011–25018, 2012.
- [27] G. Gottarelli, M. Hibert, B. Samori, G. Solladie, G. P. Spada, and R. Zimmermann, "Induction of the cholesteric mesophase in nematic liquid crystals: Mechanism and application to the determination of bridged biaryl configurations," *JACS*, vol. 105, no. 25, pp. 7318–7321, 1983.



Belgium, in Prof. Herbert De Smet's research group on the topic of "Polymer Stabilized Blue Phase Liquid Crystals".



Pankaj Joshi received the B.S. degree from Kumaun University, Nainital, India, in 2002, and the B. Tech. degree in engineering physics from Indian Institute of Technology, New Delhi, India, in 2006. He was awarded Erasmus Mundus scholarship in 2009 to pursue Master of Science in Photonics, which was awarded to him in 2011, from Ghent University, Belgium, and Royal Institute of Technology, Stockholm, Sweden, and is currently working toward the Ph.D. degree from the Department of Electronics and Information Systems, Ghent University, Ghent, Belgium, in Prof. Herbert De Smet's research group on the topic of "Polymer Stabilized Blue Phase Liquid Crystals".

Jelle De Smet graduated in engineering physics and received the Ph.D. degree in engineering from Ghent University, Ghent, Belgium, in 2007 and 2014, respectively.

He is a member of the Centre for Microsystems Technology (CMST), imec's associated lab at Ghent University, where his research is focused on smart contact lenses and contact lens display technology. Among others, he is currently targeting the development of active multifocal contact lenses. He is the author or co-author of 6 publications in international journals and 19 publications in international conference proceedings.

Dr. De Smet is an SID student member, vice-president of the SID Ghent-Lowlands Student Branch.



Xiaobing Shang received the B.Eng. degree from Dalian Polytechnic University in 2007, and the M.Sc. degree from Dalian Maritime University, in 2009, and since 2013, he is working toward the PhD degree, supervised by Prof. Herbert De Smet, from Ghent University, Gent, Belgium.

His research interest includes the micro-optical component fabrications, LC beam steering devices, and new LC display technologies. He has authored or coauthored 10 international conference and journal publications and 7 patents.

Mr. Shang is a student member of SPIE and SID.



Oliver Willekens received the B.Eng. degree in electronics engineering and the M.Sc.Eng. degree (with distinction) in photonics from Ghent University, Gent, Belgium, in 2008 and 2010, respectively. He then started working at the satellite telecommunications company Newtec, after which he returned to the academia where he is currently working toward the Ph.D. degree with the Liquid Crystals and Photonics group at Ghent University.



Dieter Cuypers graduated in electromechanical engineering and received the Ph.D. degree from University of Ghent, in 1997 and 2005, respectively.

He has been working at the Electronics and Information Systems department since his graduation, doing research for both the university and IMEC, Ghent, Belgium. His research is situated in the field of visualization technology, with a strong focus on microdisplays, but also stretches into other areas like optics and thin-film processing. He is author or co-author of over 60 papers.

Dr. Cuypers is a member of SID and SPIE.

Geert Van Steenberge, photograph and biography not available at time of publication.

Olga Chojnowska, photograph and biography not available at time of publication.

Przemysław Kula, photograph and biography not available at time of publication.



Sandra Van Vlierberghe was born in 1981. She graduated as a Master in Chemistry with high distinction with majors in Polymer Chemistry in 2003 and received the Ph.D. degree in sciences in 2008, both from Ghent University.

She holds a 10% professorship at the Faculty of Engineering of the Vrije Universiteit Brussel, a 10% professorship at the Department of Chemistry of the University of Antwerp and is affiliated to the Polymer Chemistry & Biomaterials Group at Ghent University. She has acquired expertise related to the synthesis, the modification and the characterization of a variety of (bio) polymers including thermoplasts (e.g., polyesters) and hydrogels (e.g., proteins and polysaccharides) for a plethora of applications in the fields of optics and regenerative medicine. In addition, she is experienced in the field of polymer processing using 3D printing, electrospinning and two-photon polymerization (2PP).



Peter Dubrel was born in 1976.

He currently heads a group of over 30 people and has published over 140 A1 papers. Since the start of 2006, he has been involved in several EU projects (3FP6 and 4 FP7, 1 as a coordinator). Since 2006, he has delivered over 20 invited lectures. He has been the spokesperson of the Young Scientist Forum (YSF) from the European Society for Biomaterials (ESB) for more than 5 years. He is part of the editorial team of BIOMAT.net and the journal *Biomaterials*. In 2010 and 2012, Dr. Dubrel was

awarded, respectively, the YSF Excellence Award from the Romanian Society for Biomaterials and the Jean Leray Award from the ESB.



Herbert De Smet received the M.Sc. degree in physics engineering and the Ph.D. degree in electronics engineering from Ghent University, Belgium, in 1988 and 1994, respectively.

Since 1995, he is responsible in IMEC for several European research projects concerning (micro) displays and projection. He heads a research group inside the Centre for Microsystems Technology (CMST) focusing on display technology, smart lenses and tunable electro-optic components. He is a Full Professor at Ghent University, teaching courses about microsystems, sensors and actuators and photonics. He authored over 200 publications, 98 of which are listed in the Web of Science, promoted 9 Ph.D. graduates, and is the co-inventor of 4 granted patents and 3 running patent applications.