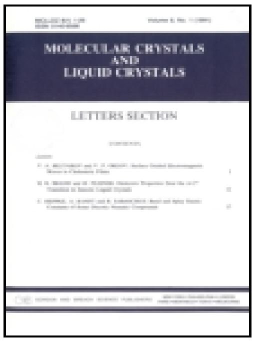

Taylor & Francis
Taylor & Francis Group

Molecular Crystals and Liquid Crystals

ISSN: 1542-1406 (Print) 1563-5287 (Online) Journal homepage: http://www.tandfonline.com/loi/gmcl20

The Effect of Different Liquid Crystal Compounds on Conduction Mechanism of 4-Cyano-4ʹ-n-heptybiphenyl (7CB) by Using I-V Characteristics

N. Yilmaz Canli, Z. Güven Özdemir & B. Bilgin Eran

To cite this article: N. Yilmaz Canli, Z. Güven Özdemir & B. Bilgin Eran (2015) The Effect of Different Liquid Crystal Compounds on Conduction Mechanism of 4-Cyano-4ʹ-n-heptybiphenyl (7CB) by Using I-V Characteristics, Molecular Crystals and Liquid Crystals, 608:1, 47-54, DOI: 10.1080/15421406.2014.949595

To link to this article: http://dx.doi.org/10.1080/15421406.2014.949595

Published online: 03 Mar 2015.

Mol. Cryst. Liq. Cryst., Vol. 608: pp. 47–54, 2015

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2014.949595

The Effect of Different Liquid Crystal Compounds on Conduction Mechanism of 4-Cyano-4′-*n*-heptybiphenyl (7CB) by Using *I*-*V* Characteristics

N. YILMAZ CANLI,[1,*] Z. GÜVEN ÖZDEMİR,[1] AND B. BİLGİN ERAN[2]

[1]Yildiz Technical University, Department of Physics, Istanbul, Turkey
[2]Yildiz Technical University, Department of Chemistry, Istanbul, Turkey

We have investigated the current-voltage characteristics of 7CB (4-cyano-4′-n-heptybiphenyl), 7CB:LC1 (5-(10-undecenyloxy)-2-[[[4-hexylphenyl]imino]methl] phenol) and 7CB:LC2 (5-(10-undecenyloxy)-2-[[[4-hexyloxyphenyl]imino]methl] phenol) by means of negative differential resistance and conductivity mechanism. According to differential resistance calculations, only 7CB and 7CB:LC1 exhibit N-shaped voltage-controlled NDR effect. The electrical conductivity mechanism of the related LCs has been investigated by natural logarithmic current-voltage curves. The nonlinear property of I-V characteristics has been explained by space charge limited conduction mechanism for 7CB:LC2.

Keywords Differential conductivity; liquid crystal; negative differential resistance; salicylaldimine compounds; space charge-limited conduction

1. Introduction

Liquid crystals (LCs) have properties between liquid and solid [1]. For instance, LCs may flow like a liquid, but their molecules may be oriented in a crystal-like way. There are many different types of liquid-crystal phases, which can be distinguished by their different optical properties [2]. The physical and optical properties of LCs can be developed by doping of different LCs (composites) and in this way, electronic features are improved [3]. Composites based LCs have attracted much interest over a number of years because of their unique electro and magneto-optic properties and novel display applications [4, 5].

Due to increasing attention of technological device applications of LCs, determination of their electrical properties becomes important. Especially, negative differential resistance (NDR) phenomenon and electrical conductivity mechanism have a crucial importance on both theoretical and experimental point of view. The concept of NDR, which is characterized by a decreasing current with an increasing of the voltage applied, becomes significant

---

*Address correspondence to N. Yilmaz Canli, Yildiz Technical University, Department of Physics, 34210 Istanbul, Turkey. Tel: +902123834278; Fax: +90212383423. E-mail: niyilmaz @yahoo.com

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/gmcl.

especially for the ongoing researches on digital logic and memory [6, 7]. The NDR phenomenon has also been observed in LCs since 1970s [8–11].

The highly nonlinear response of *I-V* curves, at which NDR effect is observed, is theoretically explained by some conduction mechanism models such as Richardson–Schottky (RS), Poole–Frenkel (PF), or space charged-limited conduction (SCLC) [12]. The validity of which model is responsible of the conductivity of the system investigated is determined by the natural logarithmic *I-V* curves.

The aim of this study is to prepare new LC material and develop its electronic properties. We have focused on ***4-cyano-4′-n-heptybiphenyl*** (7CB) due to their extraordinary properties and their promising technologic applications [13–18]. As is known, 7CB, as well as other members of the *n*CB homologous series, has crucial importance for the applications due its strong dipole moment, good chemical stability and a convenient temperature range of the nematic phase [19]. In this context, we have prepared 7CB:**LC1** and 7CB:**LC2** LCs composites to develop current-voltage characteristics and NDR behavior of 7CB.

2. Experimental

2.1. Mesomorphic Properties of LC Compounds

The reference LCs 7CB and chemicals for synthesis and purification were purchased from Sigma-Aldrich Company. The salicylaldimine compounds of **LC1** and **LC2** were already reported previously and the preparation procedures and spectroscopic data for these compounds are given in Refs. [3, 20–23]. The chemical structures of the reference LCs 7CB, **LC1** and **LC2** compounds have been shown in Fig. 1.

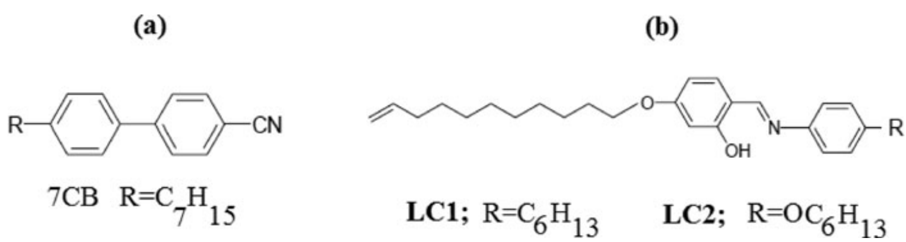

Figure 1. Chemical Structures of liquid crystals **(a)** 7CB **(b) LC1** and **LC2**.

Table 1. Phase transition temperatures T (°C) and enthalpies ΔH (J/g) of **LC1** and **LC2** compounds

Liquid crystal	Phase transition temperatures °C (enthalpies, J/g)
LC1	Cr 37.3 (55.2) SmC 64.5 (2.6) SmA 89.5 (12.2) Iso
	Iso 84.3 (−11.6) SmA 58.3 (−3.8) SmC −4.6 (−33.3) Cr
LC2	Cr 60.9 (75.8) SmA 118.6 (12.2) Iso
	Iso 114.1 (−12.2) SmA 19.1 (−62.1) Cr

Cr: Crystalline, SmC: Smectic C, SmA: Smectic A, Iso: Isotropic phase. Transition temperatures and enthalpy values were determined by DSC (Perkin-Elmer DSC-7; heating rates 10 K min^{-1}).

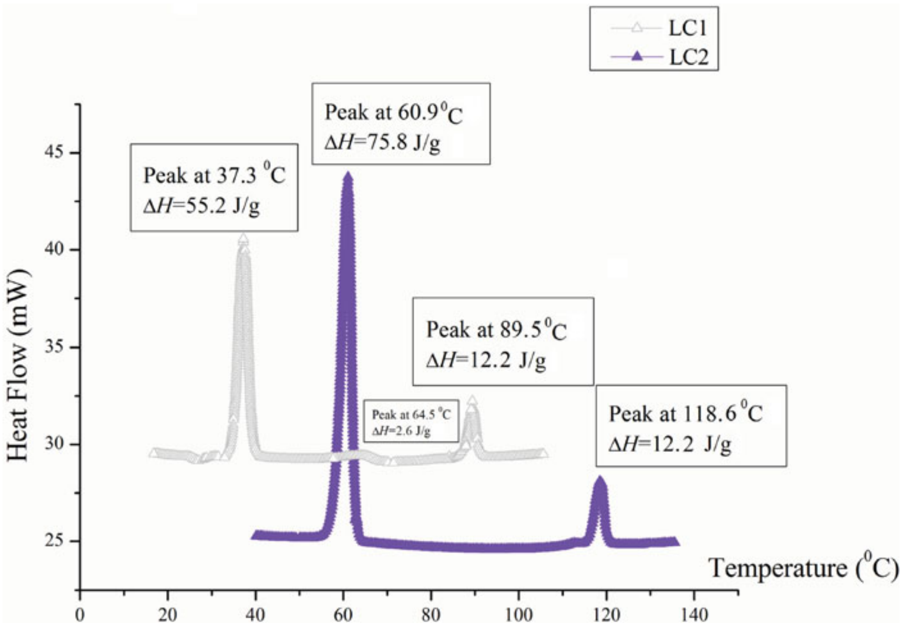

Figure 2. DSC thermogram during the second heating process for **LC1** and **LC2** compounds (10 K min^{-1}).

Differential Scanning Calorimetry experimental data of **LC1** and **LC2** were obtained using a Perkin-Elmer DSC-7. The related DSC traces of **LC1** and **LC2** compounds have been given in Figs. 2 and 3, respectively.

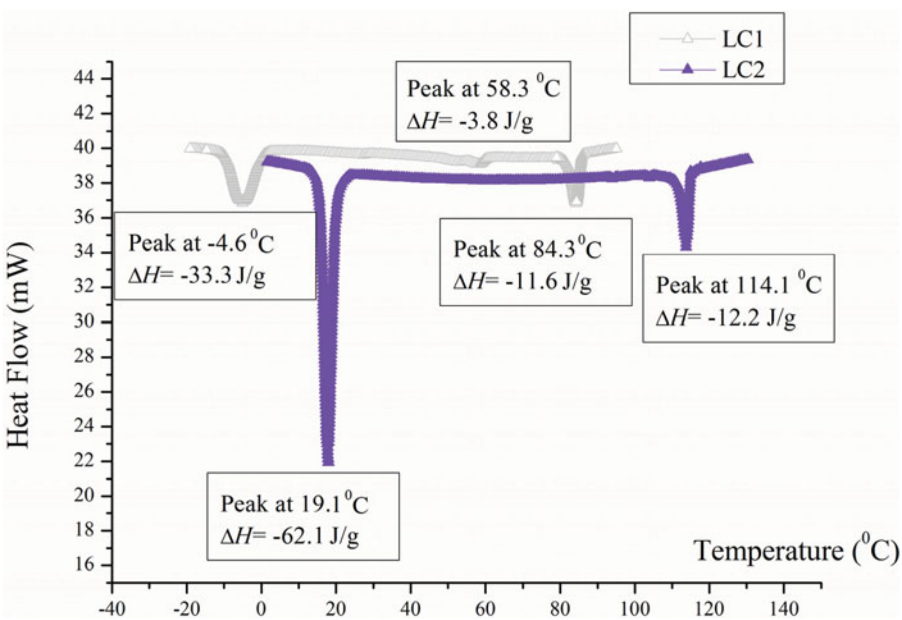

Figure 3. DSC thermogram during the second cooling process for **LC1** and **LC2** compounds (10 K min^{-1}).

According to heating and cooling process of DSC data, the temperatures at which phase transitions occur and the related enthalpy values have been summarized in Table 1.

The mesomorphic properties of the salicyaldimine compounds **LC1** and **LC2** have been studied by polarizing microscopy technique using a Linkam THMS 600 hot stage and a Linkam TMS 93 temperature control unit in conjunction with a Leitz Laborlux 12 Pol polarizing microscope. Polarizing microscopic and morphologic investigations showed that SmC and SmA mesophases take place in the compound **LC1**. The compound **LC2** exhibits only one type of (SmA) liquid crystalline mesophase. According to the textures and DSC curves, it is concluded that adding an oxygen fragment to molecule causes a disappearance of Smectic C mesophase [20].

2.2. Sample Preparation

The doped samples were prepared by the dispersion of LCs in 7CB in the concentration of approximately 1% (w/w). The reference LC 7CB, 7CB:**LC1** and 7CB:**LC2** samples were injected into a sandwich type cell of 5.4 μm that consists of two indium tin oxide-coated glass substrates by capillary action at temperature which is slightly higher than its isotropic temperature [3].

2.3. Current-Voltage (I-V) Characteristics

Current-voltage characteristics of the all samples have been shown in Fig. 4. According to *I-V* characteristics given in Fig. 4, 7CB and 7CB:**LC1** compounds exhibit "N shaped" NDR effect. N shaped voltage controlled NDR effect manifests itself as an increase in the voltage results in the decrease current on the middle region of *I-V* characteristics of 7CB and 7CB:**LC1** compounds. The detailed examination of NDR effect has been discussed in the Result section (see Fig. 5).

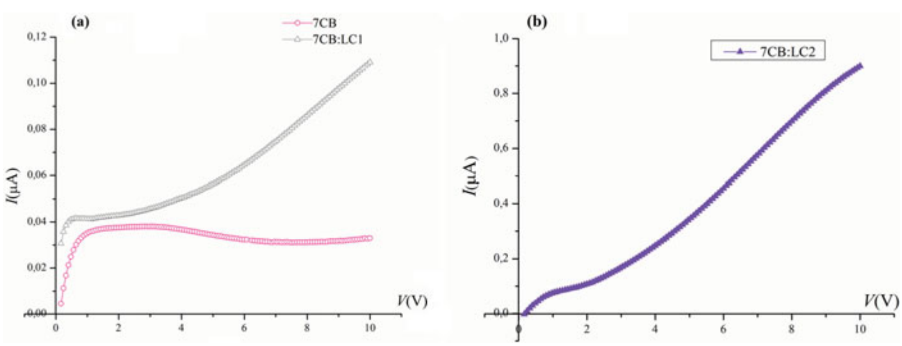

Figure 4. Current-voltage characteristics of **(a)** 7CB and 7CB:**LC1** **(b)** 7CB:**LC2**.

3. Results and Discussions

NDR effect has been observed for the 7CB and 7CB:**LC1** in the current (voltage) interval of 31–38nA (0.72–3.12V) and 41.28–41.62 nA (0.64–1.12V), respectively (Fig. 4). By comparing voltage intervals at which NDR occurs, it is clearly seen that doping **LC1** to 7CB remarkably narrows NDR region. On the other hand, NDR is not observed for the

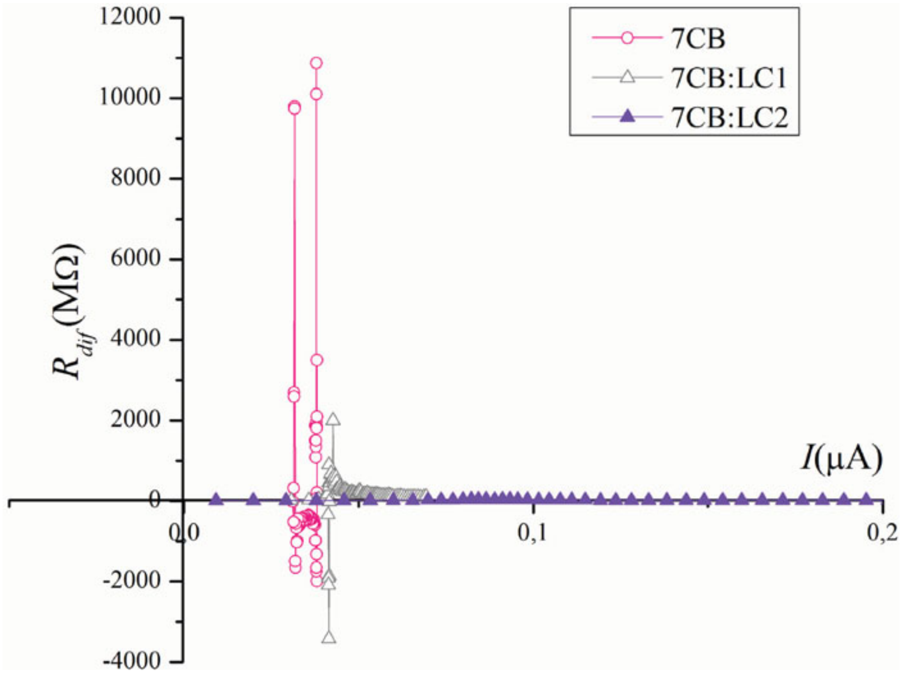

Figure 5. Differential resistance of liquid crystal compounds. NDR phenomenon is not observed on 7CB:**LC2** compound.

7CB:**LC2**. Moreover, the absolute value of the magnitude of R_{dif} varies from 15 MΩ to 1987 MΩ for the 7CB:**LC1**, whereas R_{dif} changes its value from 7.5 to 38 MΩ for the 7CB:**LC2** compound (Fig. 5). Consequently, it has been revealed that changing terminal chain in the LC causes the disappearance of NDR behavior and decrease in resistance values.

To analyze the effect of different LC compounds on conductivity of the 7CB, the differential conductivity has been calculated by Eq. (1)

$$\sigma_{\text{dif}} = \left(\frac{\mathrm{d}I}{\mathrm{d}V}\right)\frac{\ell}{A} \tag{1}$$

where ℓ and A represent the thickness of the samples ($\ell = 5.4\ \mu$m) and the electrode active area ($A = 1 \times 10^{-4}\ \text{m}^2$), respectively. The variations of differential conductivity with voltage for the LC samples have been given in Fig. 6.

As is seen from Fig. 6, differential conductivity of all samples are in the order of 10^{-9} $(\Omega\text{m})^{-1}$. Initial decrease in σ_{dif} conductivity at low voltage region has been observed as an intrinsic property for all LCs investigated. Moreover, a saturation has been determined for the 7CB and 7CB:**LC1** compounds in the voltage interval of 2V–10 V. When the terminal chain is changed, no saturation has been observed for the 7CB:**LC2** (See Fig. 6b). Furthermore, the differential conductivity of the 7CB:**LC2** alters its characteristics with a sharp increase and decrease for the related voltage interval.

The differential resistance curves for both 7CB and 7CB:**LC1** samples display a transition from positive and NDR (Fig. 5). Referring the transitions mentioned above, it has been deduced that the LC system possesses different conduction states, i.e., mechanisms.

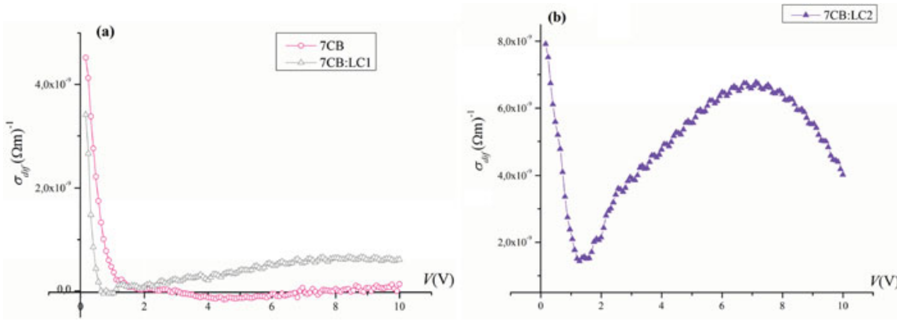

Figure 6. Differential conductivity versus voltage applied for **(a)** 7CB and 7CB:**LC1** **(b)** 7CB:**LC2**.

In order to explain the conductivity mechanism of LC system, natural logarithmic current-voltage curves (Fig. 7) have been investigated.

The 7CB shows a nonlinear relationship between ln(I)-ln(V) as shown in Fig. 7. However, a linear relationship between ln(I)-ln(V) has been observed on the 7CB:**LC1** and 7CB:**LC2** for the voltage interval of 4.5–10 and 2.75–10 V, respectively. The slope, n of the ln(I) vs. ln(V) curve determines the conductivity mechanism of the materials. The value of exponent, n is found to be nearly equal to 1 for A-B region of the 7CB:**LC1** composite. Due to this reason the conductivity mechanism exhibit Ohmic behavior in A-B region. On the other hand, the values of exponent n have been calculated for regions I-II and III-IV of 7CB:**LC2** as 1.52 and 1.45, respectively. From this point of view, it has been revealed

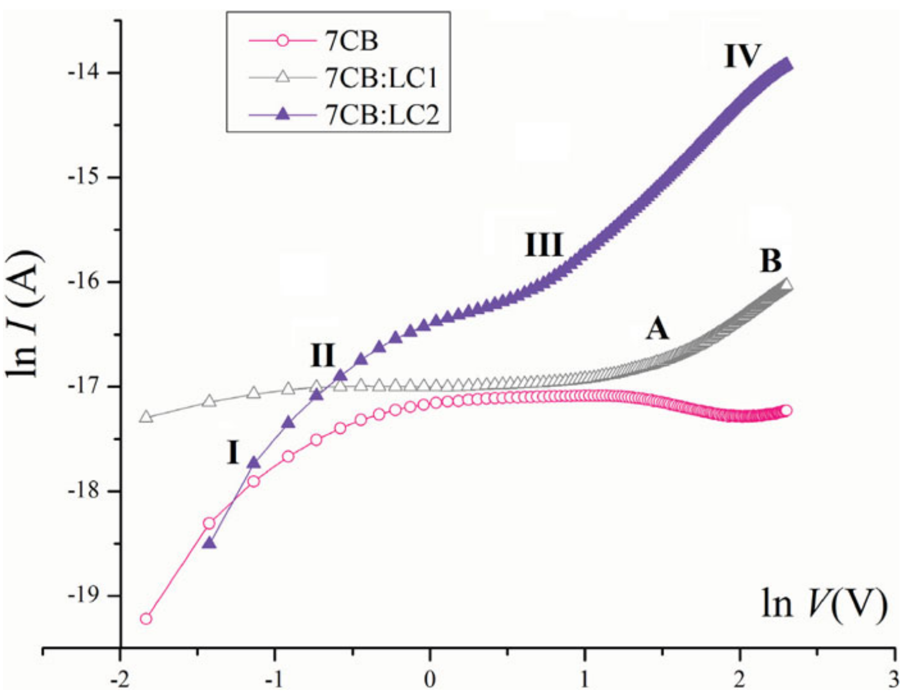

Figure 7. ln(I) vs. ln(V) curves of 7CB, 7CB:**LC1** and 7CB:**LC2**.

that the conduction mechanism corresponds to SCLC which is influenced by traps [24, 25]. Thus, addition of oxygen fragment to LCs leads to significant changes on conduction mechanism.

4. Conclusions

In this work, **LC1** and **LC2** with different terminal chains have been doped to 7CB and their current-voltage characteristics have been analyzed by means of NDR (NDR) behavior and conductivity mechanism. N-shaped voltage controlled NDR behavior has been observed on 7CB and 7CB:**LC1**. The differential resistance and conductivity have been calculated and the effect of terminal chain to these physical parameters has been examined. The nonlinear property of *I-V* characteristics has been researched by natural logarithmic *I-V* curves. It has been emphasized that while 7CB:**LC2** has a SCLC mechanism, 7CB:**LC1** displays Ohmic behavior in a particular voltage region. The different conduction mechanisms for 7CB:**LC1** and 7CB:**LC2** can be attributed to the change of alignment of molecules with electric field applied.

Acknowledgments

The authors acknowledge to Prof. Dr. Fahrettin Yakuphanoğlu for providing the experimental facilities of Firat University Physics Department. The authors also wish to thank Prof. Dr. Ahmet Altindal for his fruitful discussions.

References

[1] Chandrasekhar, S. (1992). *Liquid Crystals* (2nd ed.), Cambridge University Press: Cambridge.
[2] Dierking, I. (1978). *Textures of Liquid Crystals*, Wiley-VCH: Verlag, Weinheim.
[3] Yilmaz Canli, N., Yakuphanoglu, F., & Bilgin Eran, B., (2009). *OAM-RC*, *3*, 731.
[4] Ouskova, E., Buchnev, O., Reshetnyak, V., & Reznikov, Yu. (2003). *Liq. Cryst. 30*, 1235.
[5] De Jeu, W. H. (1991). *Physical Properties of Liquid Crystalline Materials*, Gordon & Breach: London.
[6] Lin, J., & Ma, D., (2008). *J. Appl. Phys.*, *103*, 124505.
[7] Xie, M., Aw, K. C., Langlois, M., & Gao, W., (2012). *Solid State Commun.*, *152*, 835.
[8] Tani, C., (1971). *Appl. Phys. Lett.*, *19*, 241–242.
[9] Iwasa, Y., Koda, T., Koshihara, S., Tokura, Y., Iwasawa, N., & Saito, G. (1989). *Phys. Rev. B. 39*, 10441.
[10] Karzari, Y., Cornil, J., & Bredas, J. L. (2001). *J. Am. Chem. Soc.*, *123*, 10076.
[11] Roşu, C., Manaila-Maximean, D., Circu, V., Molard, Y., & Roisnel, T. (2011). *Liq. Cryst.*, *38*, 757.
[12] Dieter, K. S. (2006). *Semiconductor Material and Device Characterization* (3rd ed.), Wiley-IEEE Press: USA.
[13] Jewell, S. A., Hendry, E., & Sambles, J. R. (2008). *Mol. Cryst. Liq. Cryst.*, *494*, 320.
[14] Dolgov, L., Yaroshchuk, O., & Lebovka, M. (2008). *Mol. Cryst. Liq. Cryst.*, *496*, 212.
[15] Muravsky, A., Murauski, A., & Chigrinov, V. *et al.* (2008). *J. Soc. Inform. Display*, *16*, 927.
[16] De Jeu, W. H., Longa, L., & Demus, D. (1986). *J. Chem. Phys.*, *84*, 6410.
[17] Treybig, A., Weissflog, W., Plass, M., & Kresse, H. (1997). *Mol. Cryst. Liq. Cryst.*, *300*, 127.
[18] Caerels, J., Glorieux, C., & Thoen, J. (2002). *Phys. Rev. E*, *65*, 031704(7).
[19] Czub, J., Urban, S., & Würflinger, A. (2006). *Liq. Cryst.*, *33*, 85.
[20] Yilmaz Canli, N., Bilgin-Eran, B., & Nesrullajev, A. (2011). *J. Mol. Struct.*, *990*, 79.

[21] Coskun, N. (2006). *Msc Thesis, Yildiz Technical University*, Graduate School of Natural and Applied Science: Istanbul, Turkey.
[22] Ocak, H., Bilgin Eran, B., Tschierske, C., Baumeister, U., & Pelzl, G. (2009). *J. Mater. Chem.*, *19*, 6995.
[23] Nesrullajev, A., & Bilgin Eran, B. (2005). *Mater. Chem. Phys.*, *93*, 21.
[24] Lampert, M. A. (1956). *Phys. Rev.*, *103*, 1648.
[25] Lampert, M. A. (1963). *RCA Tech. Report* No. PTR, 1445.