

Electrophysical Properties of an Antiferroelectric Liquid Crystal MOPB(H)PBC

ANOOP KUMAR SRIVASTAVA,^{1,*} SEUNG HEE LEE,¹
MYONG-HOON LEE,¹ AND R. DABROWSKI²

¹Research Center for Advanced Materials Development, School of Advanced Materials Engineering, Chonbuk National University, Chonju, Chonbuk, 561-756, Korea

²Institute of Chemistry, Military University of Technology, 00-908, Warsaw (Poland)

Spontaneous polarization (P_s), rotational viscosity (η) and response time (τ) have been determined as a function of temperature at different electric fields for an antiferroelectric liquid crystal [4,4-(1-methyloctyloxy carbonyl)phenyl]-4'-[3-(butanoiloxy)prop-1-oxy]biphenyl carboxylate (MOPB(H)PBC). Spontaneous polarization, rotational viscosity and response time increase with decrease in temperature. Critical electric field (the field at which the spontaneous polarization saturates) was found to be increased with decrease in temperature.

Keywords Antiferroelectric liquid crystal; spontaneous polarization; rotational viscosity; response time

PACS Numbers: 64.70.pp, 42.79.kr, 77.80.e

I. Introduction

The re-orientation of liquid crystals under the application of electric fields is the basic concept behind their use in display devices. Ferroelectric liquid crystals (FLCs) form from chiral, rod-like molecules arranged in (smectic) layers with the average molecular direction tilted with respect to the layer normal. Since the discovery of ferroelectricity in the chiral SmC (SmC*) phase of liquid crystals [1, 2] in the early 1980s, there has been intense interest in studying the switching properties of FLCs as these materials are of both fundamental and technological interest [3–6]. The more recent discovery of related liquid crystal phases, antiferroelectric liquid crystals (AFLCs), posed new challenges to understand interlayer structures, layer geometry in devices and electric-field induced switching mechanisms [7]. Antiferroelectric liquid crystals (AFLCs) are a subclass of tilted smectics in which the director \mathbf{n} in adjacent layers tilts in opposite directions with respect to the layer normal \mathbf{z} . The antiferroelectric liquid crystals (AFLCs) are attractive for tri-state switching behavior, easy DC compensation, microsecond response, hemispherical viewing angle (in plane switching geometry) gray scale capability and no ghost effects [8–13]. In chiral mesophases,

Received September 7, 2007; in final form October 24, 2007.

*Corresponding author. E-mail: srivastava_anoop@rediffmail.com S. H. Lee's e-mail: lsh1@chonbuk.ac.kr

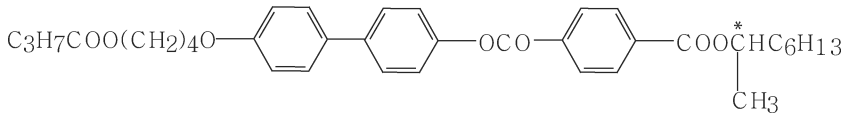
a spontaneous polarization arises as second order parameter due to molecular tilt with respect to the smectic layer normal; spontaneous polarization emerges perpendicular to the tilt plane, reflecting the polar properties of liquid crystal. In this paper spontaneous polarization, rotation viscosity and response time of an AFLC [4,4-(1-methyloctyloxy)carbonyl]phenyl]-4'-[3-(butanoiloxy)prop-1-oxy]biphenyl carboxylate (MOPB(H)PBC) have been studied.

II. Experimental

Different mesophases transition temperatures have been determined with the help of differential scanning calorimeter (DSC) and polarizing microscope (PM). The empty cell with indium tin oxide electrodes and polyimide alignment layer for planar orientation layer were manufactured, where the active area and distance between the electrodes were 0.25 cm^2 and $4.7 \text{ }\mu\text{m}$ respectively. Spontaneous polarization (P_s) and rotational viscosity (γ) have been measured [14–16] with the help of automatic liquid crystal tester (ALCT), by applying a triangular wave of different electric fields ($11.6 \text{ V}/\mu\text{m}$, $15.7 \text{ V}/\mu\text{m}$ and $21 \text{ V}/\mu\text{m}$) and frequency of 8 Hz across a surface stabilized cell with varying temperatures.

III. Results and Discussion

[4,4-(1-methyloctyloxy)carbonyl]phenyl]-4'-[3-(butanoiloxy)prop-1-oxy]biphenyl carboxylate (MOPB(H)PBC) has the following chemical structure:



It shows both ferroelectric (SmC^*) and antiferroelectric (SmC_A^*) phases.

Peak transition temperatures were determined by DSC at different scanning rates ranging between 1.0 and $15.0^\circ\text{C}/\text{min}$. It has been observed that, peak transition temperatures (T_p) vary linearly with scanning rates. Using least square fit plot of T_p with scanning rate (in $^\circ\text{C}/\text{min}$), extrapolated transition temperatures at the scanning rate of $0^\circ\text{C}/\text{min}$ have been determined and they have been taken as true transition temperatures [17]. The MOPB(H)PBC exhibits following phase transition temperature sequence in cooling cycle at extrapolated scanning rate of $0^\circ\text{C}/\text{min}$.

I (108.7°C) SmA^* (98.1°C) SmC^* (88.2°C) SmC_A^* (51.9°C) Crystal

The transition temperatures have also been confirmed by polarizing microscope and dielectric studies [18].

Figure 1 shows the variation of spontaneous polarization with temperature in SmC^* and SmC_A^* phases. No anomaly has been detected on P_s curve at the SmC^* to SmC_A^* phase transition. The continuous line is fit to the power law at the electric field of $21 \text{ V}/\mu\text{m}$

$$P_s (\text{nC}/\text{cm}^2) = P_0 \left(1 - \frac{T}{T_C} \right)^\beta \quad (1)$$

The value of β obtained from fittings is 0.32 respectively which is smaller than theoretical value of $\beta = 0.5$ predicted for second order transition [19]. As shown in Fig. 1, the P_s increases with decrease in temperature at the electric field of $21 \text{ V}/\mu\text{m}$. On the other hand for electric field of $11.6 \text{ V}/\mu\text{m}$, it starts to decrease after reaching the maximum (at 72°C) value. Ray et al. [20] also have reported that the spontaneous polarization decreases after

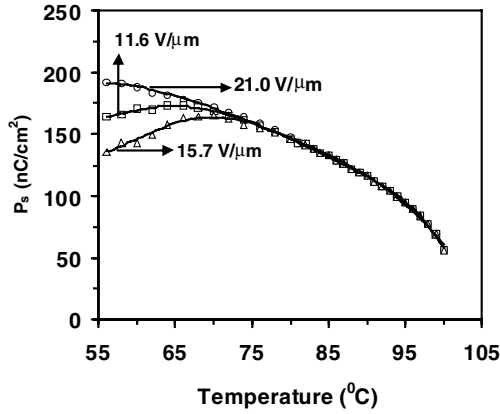


Figure 1. Temperature dependence of spontaneous polarization (P_s) at different electric fields.

particular temperature in SmC_A^* phase. The decrease in spontaneous polarization may be due to supper cooling effect in SmC_A^* phase. Variation of spontaneous polarization with electric field at different temperatures is shown in Fig. 2. It is clear from the Fig. (2) that high electric field is required to get the saturation of P_s with decrease in temperature. At $76^\circ C$, P_s saturates at the electric field of $\sim 10 V/\mu m$ whereas at $62^\circ C$, it is very high ($\sim 21 V/\mu m$).

Variation of rotational viscosity with temperature at different electric fields is shown in Fig. 3. At electric field of $21 V/\mu m$, the rotational viscosity increases with decrease in temperature. However at the electric field of $11.6 V/\mu m$, it starts to decrease after reaching the maximum value (at $65^\circ C$). FLC response time is given by [11]

$$t = \eta / P_s E \tag{2}$$

where, η is the reorientational viscosity and E is the applied electric field. Therefore response time depends upon two competing parameters η and P_s . In general a large P_s and low η are needed for quick electro-optic response. Response time has been estimated using the equation (2) and is shown in Fig. 4. Fast response time of less the $\sim 10 \mu s$ is observed for the electric field of $21 V/\mu m$.

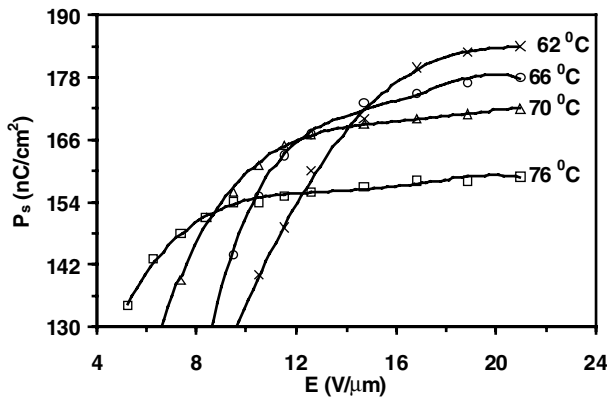


Figure 2. Variation of spontaneous polarization with electric field at different temperatures.

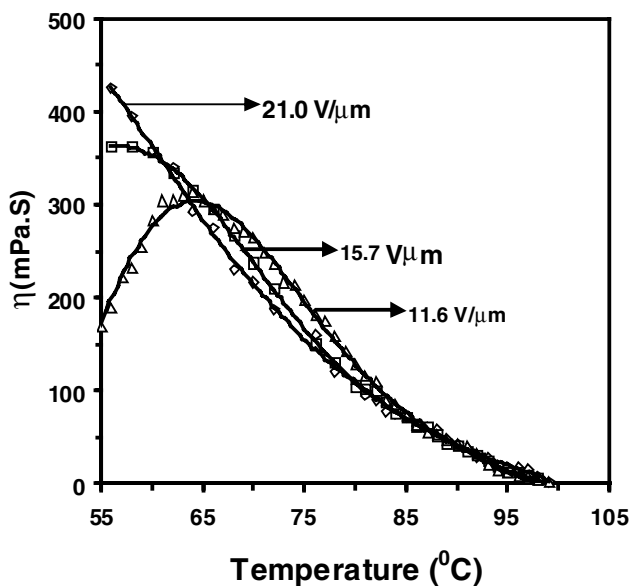


Figure 3. Variation of rotational viscosity with temperatures at different electric fields.

In summary, the spontaneous polarization, rotational viscosity and response time were found to be increased with decrease in temperatures. High electric field is required to get the saturation of P_s with decrease in temperature. MOPB(H)PBC shows high spontaneous polarization of 192 mPs.S and fast response time of less than $\sim 10 \mu\text{S}$.

Acknowledgments

This work was partly supported by postdoc program, Chonbuk National University (2006) and Brain Korea-21 through polymer BIN fusion research team, Chonbuk National University, Jeonju, Korea.

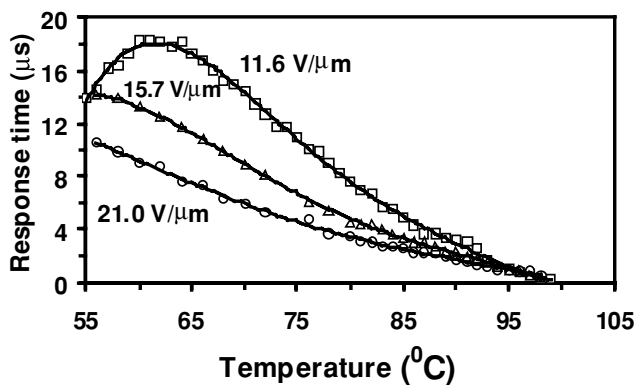


Figure 4. Variation of response time with temperatures at different electric fields.

References

1. R. B. Mayer, Fifth International Liquid Crystal Conference, Stockholm, 17–21 June 1974.
2. R. B. Mayer, L. Lieber, L. Strzelecki and P. Keller, *J. Phys. (Paris), Lett.* **36**, L-69 (1975).
3. N. A. Clark and S. T. Lagerwall, *Appl. Phys. Lett.* **36**, 899 (1980).
4. F. Gouda, Ph. D. Thesis, Dielectric relaxation spectroscopy of chiral smectic liquid crystals, Department of Physics, Chalmers University of Technology Goteborg (1992).
5. T. Carlsson, B. Zeks, C. Filip, and A. Levstik, *Phys. Rev. A* **42**, 877 (1990).
6. A. Mukherjee, S. L. Srivastava, and L. A. Bersesnev, *Ferroelectrics* **200**, 125 (1997).
7. A. D. L. Chandani, T. Hagiwarra, Y. Suzuki, Y. Ouchi, H. Takezoe, and A. Fukuda, *Jpn J. Appl. Phys.* **27**, L729 (1988) L729; A. D. L. Chandani, Y. Ouchi, H. Takezoe, A. Fukuda, K. Terashima, K. Furukawa, and A. Kishi: *Jpn. J. Appl. Phys.* **28**, L1261 (1989). A. D. L. Chandani, E. Gorecka, Y. Ouchi, H. Takezoe, and A. Fukuda: *Jpn. J. Appl. Phys.* **28**, L1265 (1989).
8. P. L. Castillo, J. Otón, R. Dabrowski, A. Lara, X. Quintana and N. Bennis, *Proc. Int. Soc. Opt. Engg. (SPIE)* **5565**, 284 (2004).
9. X. Quintana, P. L. Castillo, J. Otón, N. Bennis, A. Lara and R. Dabrowski, *Proc. Int. Soc. Opt. Engg. (SPIE)* **5565**, 290 (2004).
10. R. Dabrowski, K. Czuprynski, J. Gasowska, J. Oton, X. Quintana, P. L. Castillo and N. Bennis, *Proc. Int. Soc. Opt. Engg. (SPIE)* **5565**, 66 (2004).
11. S. T. Lagerwall, *Ferroelectric and antiferroelectric liquid crystals*, Wiley-VCH, Weinheim (1999).
12. P. Rudquist, J. P. F. Lagerwall, J. G. Meier, K. D'have, and S. T. Lagerwall, *Phys. Rev.* **66**, 061708 (2002).
13. S. Lagerwall, A. Dahlgren, P. Jagemalm, P. Rudquist, K. D'have, H. Pauwels, R. Dabrowski, and W. Drzewinski, *Adv. Func. Mater* **11**, 87 (2001).
14. A. K. Srivastava, V. K. Agrawal, R. Dabrowski, J. M. Otón, and R. Dhar, 2005, *J. Appl. Phys. (USA)* **98**, 013543 (2005).
15. A. Fafara, M. Marzec, W. Haase, S. Wróbel, D. Kilian, M. Godlewska, K. Czuprynski and R. Dabrowski, *Ferroelectrics* **245**, 81 (2000).
16. S. Kundu, T. Ray, S. K. Roy, W. Haase, and R. Dabrowski, *Ferroelectrics* **282**, 239 (2003).
17. S. L. Srivastava, R. Dhar, and M. V. Kurik, *Mol. Mat.* **2**, 261 (1993).
18. A. K. Srivastava, R. Dhar, V. K. Agrawal, and R. Dabrowski: *Proc. Int. Soc. Opt. Engg. (SPIE)* **5565**, 59 (2004).
19. A. Mikulko, M. marzec, S. Wrobel, and R. Dabrowski, *Opto-Electronics Rev.* **14**, 314 (2006).
20. T. Ray, S. Kundu, S. K. Roy, and R. Dabrowski, *J. Mol. Liq.* (2006). Doi: 10.1016/2006.07.007.