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Optical Rotation and Transmittance of Different Phases of Ferroelectric Liquid Crystal Sample ZLI 3654

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Abstract

Objectives: The Phase transition scheme of Ferroelectric Liquid Crystal (FLC) sample has been studied in a temperature range 50^0C to 95^0C. **Methods:** The material was procured from Merck, Germany and was used as such without any further purification, and studied for the measurement of optical rotation and transmittance. The Polarizing Optical Microscopy (POM) technique has been used and the different phases existing in the sample were observed by placing the sample having planar alignment under crossed polarizer arrangement. **Findings:** The sharp variation in the values of optical rotation and transmittance at the phase transition points clearly indicates that the different phases exist in the experimental sample. From the LDR vs Temperature and Optical Rotation vs Temperature study, four different phases for the sample were obtained. The SmC* phase exists in the temperature range 30^0C – 62^0C and at 62^0C, the SmA* occurs. The sample shows SmA* phase in the temperature range 62^0C – 76^0C and at 76^0C sample transit to Nematic phase which occurs in the temperature range 76^0C – 86^0C and lastly, Isotropic phase appears at 86^0C. **Novelty:** Some researchers have studied the same sample but in the temperature range 30^0C to 62^0C where they were able to observe only two initial phases namely SmC* and SmA* whereas the present study reports the four different phases (SmC*, SmA*, nematic and isotropic) of the Ferroelectric Liquid Crystal (FLC). The same study can also be carried out using the other technique like Differential Scanning Calorimetry (DSC) but the technique used in the present study is simpler and cost-effective. The same technique can also be applied to other liquid crystal samples to study their phase transition behaviour.

Keywords: Ferroelectric Liquid Crystal; Optical Rotation; Optical Transmittance; Polarizing Microscope; Phase Transition

1 Introduction

The remarkable physical and chemical behaviour such as spontaneous polarization, relaxation time, rotational viscosity etc. shown by the Ferroelectric Liquid Crystals

(FLCs) makes them suitable for the further investigative research and their applications in various technical fields. The remarkable electro-optical behaviour of Ferroelectric Liquid Crystals (FLCs) makes them a potential candidate for the display industry. It is very important for these materials to be in the mesogenic phase for a wide temperature range. Thus, it becomes essential to investigate the phase transition behaviour of these materials.

The most investigated phase of FLCs is SmC* phase because of its fast electro-optical switching response [1]. This property also leads to its most important application i.e. electro-optical displays giving it a clear advantage over Nematic Liquid Crystals (NLCs) which has a rather slower response to the applied field. Also, another feather in the cap of FLCs is that they behave as a memory element when kept in a properly aligned thin sample cell [2]. These two properties alone have invoked considerable scientific research interest in these crystals. Recently, the lensing effect of FLCs in Panchratnam – Berry (PB) phase has also been reported by some researches [3].

Further, when the molecules of FLCs are subjected to homogeneous (planar) arrangement, their chiral Smectic C* phase extends over a wide range of temperature. The alignment of FLC molecules plays a very important role in the display quality and for that matter, the different method such as nanoparticle doping or nano-structure growth techniques are used for alignment of FLC molecules [4].

It is a well-known fact today that the behaviour of different properties of liquid crystalline materials is temperature dependent indicating that temperature studies are an important indicator for their applications. A lot of studies are already going on across the globe by the different groups of researchers to validate the temperature behaviour of different types of liquid crystals. In fact, when the properties of liquid crystals are altered by dispersing with different types of materials such as nanomaterials, polymers etc., then also the temperature behaviour is a key factor to be studied first [5]. The different techniques which are employed to perform this task include Differential Scanning Calorimetry (which make use of change in enthalpy at transition points) [6], Dielectric Measurement Techniques (which make use of change in dielectric parameters at transition points) to name a few [1]. Though these are highly advanced techniques, but they require highly sophisticated, special types of machines which can perform these tasks. Also, these machines are costly and not easily and readily available.

The present study is an attempt to provide an alternative method using optical studies to find the various phase transition temperatures of Ferroelectric Liquid Crystals (FLCs) with the distinct advantage that the experimental techniques used in this study are not only simple, cost effective and easy to operate but also they provide the results which are in good agreement with the literature values. Another reason for taking up the technique of optical transmittance and optical rotation is that this technique provides the most precise and accurate information about the transition temperatures of different phases shown by the liquid crystals. Further, the study of optical rotation also provides valuable information about the viewing angle of FLC displays [1].

In the present study phase transition behaviour of FLC sample ZLI 3654 has been reported using optical rotation and optical transmittance techniques. The material was procured from Merck, Germany and was used as such without any further purification.

2 Methodology

The optical rotation was calculated from the results obtained through the light transmitted through a homeotropic liquid crystal sample cell. For this purpose, a sample cell consisting of two glass plates with an electrode on each plate was used. The Mylar thin-film strip was used as a spacer. After filling the cell with the sample, it was cooled gradually and slowly to SmA* phase. The variation in temperature in continuous cooling process was done at a rate of 0.1^0C/min. The occurrence of different phases was observed with a polarizing microscope (**Model No. CENSICO-7626**).

To calculate the optical rotatory power (ORP), first the light was passed through the homeotropic liquid crystal sample filled cell when the polarizers were in crossed position and then again when the polarizers were parallel to each other. Then the ratio of the amount of light transmitted in two cases was calculated [7–9]. In the case of pure optical rotation when the light transmitted through the cell is linearly polarized, the ratio of these transmissions R_T is given by

$$R_T = \tan^2 \varnothing$$

where ϕ is the angle of rotation of light transmitted through the cell with respect to the transmission plane of polarizer.

The method used here, provides the absolute value of Optical Rotatory Power (ORP). To validate this, the analyzer was rotated until the minimum amount of light transmission is achieved in the various Smectic phases. The clockwise turn was considered as positive while anti-clockwise turn was considered to be negative.

Due to change in order parameter, the physical properties of liquid crystals changes with temperature. These changes are most significant at transition temperatures. A simple and interesting method of finding these transitions is visual phase identification method [10–14]. For this purpose a research polarizing microscope (**Model No. CENSICO-7626**) is used.

The setup for measurement of optical transmittance to visualize these phase changes is shown in Figure 1. An auto bulb fitted in the base of polarizing microscope and run by variable auto transformer is used as a white light source. A light dependent resistance (LDR), fixed in a cap, is fitted on one of the eye-piece holder of microscope. The two terminals of LDR are connected to a digital multimeter to continuously monitor the change in resistance of LDR with the change in intensity of light. The second eye-piece is used to see these beautiful phase transitions. On the third eye-piece holder, a camera (**YASHICA make**) is fitted to take the photographs of these phase transitions. The sample holder is constructed using a glass slide and cover slip combination which is surrounded by a thick thermo-col sheet to attain thermal equilibrium and maintain it. To achieve the homogeneous alignment of sample, the glass slide and the cover slip both are unidirectionally PVA aligned.

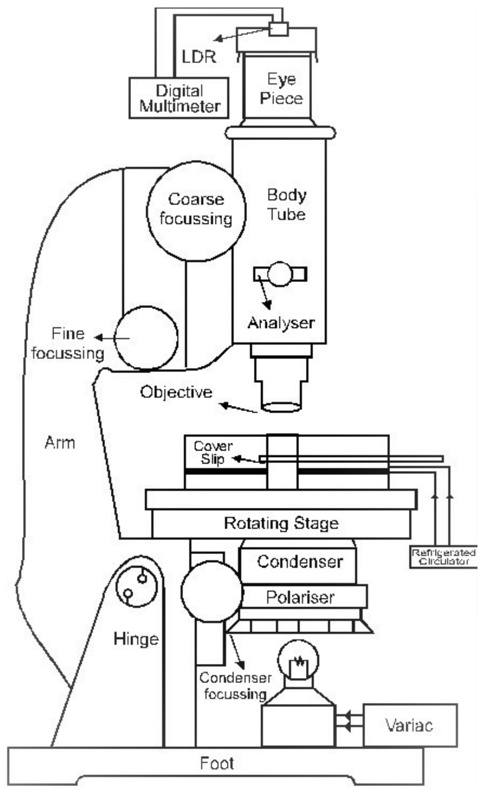

Fig 1. Experimental Setup

Initially, the polarizer-analyzer combination is adjusted for minimum transmission of light. Then after filling the sample holder with sample, its temperature variation is achieved by a refrigerated circulator of Julabo (Model No. F-25). Different phases occur with the variation in temperature of the sample. Depending upon the occurrence of different phases, the light of different intensity passes through the sample and consequently incident on LDR, whose resistance changes accordingly and can be read on digital multi-meter.

3 Results and Discussion

Earlier, Chandel et. al. have studied the dielectric and optical behaviour of the same FLC sample ZLI 3654 in a temperature range of 30°C to 62°C using same technique but their study was limited to two initial phases occurring upto 62°C[1]. In present work, the four phases namely SmC*, SmA*, Nematic and Isotropic of FLC sample ZLI 3654 have been successfully observed.

In the optical rotation measurements, the variation of angle of rotation of light transmitted through the cell with temperature is given in Table 1 and the corresponding graphical behaviour is shown in Figure 2. Various phase transitions are represented as a function of the angle of rotation (in radians).

Table 1. Temperature (^oC) and corresponding Angle of Rotation (ϕ)

S. No.	Temperature (^{o} C)	Angle of Rotation (Radians)	S. No.	Temperature (^{o} C)	Angle of Rotation (Radians)
1	51.0	0.678331	35	75.5	0.533976
2	52.0	0.678693	36	76.0	0.537505
3	53.0	0.678693	37	76.7	0.541415
4	54.0	0.690225	38	77.0	0.538219
5	55.0	0.700776	39	77.2	0.541834
6	56.0	0.683530	40	77.5	0.553136
7	56.5	0.673817	41	79.0	0.563531
8	57.0	0.641472	42	79.5	0.568322
9	57.5	0.629040	43	79.7	0.569804
10	58.0	0.619772	44	80.5	0.588448
11	59.0	0.598677	45	81.0	0.605546
12	60.5	0.587862	46	81.2	0.602293
13	61.0	0.580298	47	81.7	0.587582
14	61.5	0.577398	48	82.0	0.636350
15	62.0	0.571513	49	82.2	0.659844
16	62.5	0.555483	50	82.5	0.646097
17	64.0	0.552554	51	83.0	0.659279
18	64.5	0.550052	52	83.2	0.666770
19	65.0	0.549861	53	83.5	0.667767
20	65.5	0.546833	54	83.7	0.664992
21	67.0	0.547962	55	84.0	0.662621
22	67.7	0.550435	56	84.2	0.647976
23	68.0	0.553525	57	84.7	0.616639
24	68.5	0.557065	58	85.0	0.596393
25	69.0	0.546457	59	85.2	0.585077
26	70.0	0.551203	60	85.5	0.565183
27	70.5	0.545523	61	85.7	0.532931
28	71.0	0.548151	62	86.0	0.514181
29	71.5	0.547397	63	86.2	0.506415
30	72.0	0.536439	64	86.5	0.492161
31	72.5	0.535203	65	86.7	0.473975
32	73.0	0.543669	66	87.0	0.482488
33	73.5	0.540198	67	87.2	0.477301
34	75.0	0.537683	68	87.5	0.475937

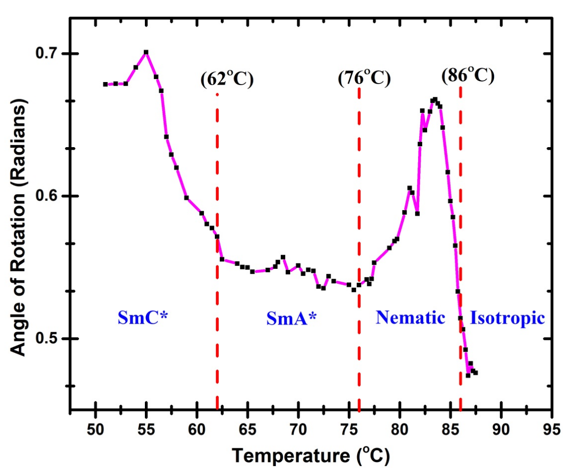

Fig 2. Graph between Angle of Rotation (radian) and Temperature (^{o} C)

In the optical transmittance measurements, the intensity of light passing through the cell has been measured as a function of resistance (in kΩ) of light dependent resistance (LDR) as given in Table 2. The resistance of LDR has been plotted against the temperature as shown in Figure 3.

According to the results obtained for optical rotation for the sample ZLI 3654, the following phase transition sequence is observed

$$SmC^* \xleftrightarrow{62^\circ C} SmA^* \xleftrightarrow{76^\circ C} N \xleftrightarrow{86^\circ C} \text{Isotropic}$$

Table 2. Temperature (°C) and corresponding resistance of LDR (kΩ)

S. No.	Temperature (° C)	Resistance (kΩ)	S. No.	Temperature (° C)	Resistance (kΩ)	S. No.	Temperature (° C)	Resistance (kΩ)
1	43.6	0.525	40	69.5	2.524	79	86.7	1.235
2	44.0	0.394	41	70.0	2.459	80	87.0	1.398
3	47.0	0.405	42	71.0	2.988	81	87.2	1.538
4	49.0	0.409	43	71.5	2.535	82	87.5	2.425
5	50.0	0.425	44	72.0	2.288	83	87.6	1.546
6	51.0	0.446	45	72.5	2.286	84	87.7	2.439
7	52.0	0.495	46	73.0	2.395	85	88.0	2.851
8	53.0	0.499	47	73.5	2.388	86	88.1	3.310
9	53.5	0.566	48	74.0	2.372	87	88.2	4.197
10	54.0	0.553	49	75.0	2.211	88	88.2	4.394
11	54.5	0.565	50	75.2	2.207	89	88.3	4.880
12	55.0	0.557	51	75.5	2.000	90	88.4	5.688
13	55.5	0.559	52	76.5	1.957	91	88.5	6.200
14	56.0	0.601	53	76.7	1.892	92	88.6	4.862
15	56.5	0.709	54	77.0	1.878	93	88.7	6.199
16	57.0	0.712	55	77.5	1.832	94	88.9	6.974
17	57.5	0.844	56	78.0	1.580	95	89.0	7.825
18	58.0	1.094	57	78.5	1.494	96	89.1	8.210
19	58.2	1.034	58	78.7	1.498	97	89.2	8.516
20	58.5	1.372	59	79.0	1.500	98	89.2	9.986
21	58.7	1.899	60	79.5	1.423	99	89.4	10.154
22	59.0	2.230	61	80.0	1.388	100	89.5	10.233
23	59.7	2.009	62	80.5	1.232	101	90.0	11.604
24	60.0	2.092	63	81.0	1.198	102	91.0	11.039
25	60.5	2.090	64	81.2	1.134	103	92.0	11.340
26	61.0	2.052	65	81.5	1.156			
27	61.5	2.062	66	82.0	1.047			
28	62.0	2.155	67	82.5	1.022			
29	62.5	2.135	68	82.7	1.010			
30	63.0	2.144	69	83.0	0.941			
31	63.5	2.174	70	83.2	0.920			
32	64.0	2.189	71	83.5	0.912			
33	64.5	2.128	72	83.7	0.907			
34	65.0	2.12	73	84.0	0.875			
35	66.0	2.133	74	84.5	0.890			
36	67.0	2.15	75	85.0	0.971			
37	67.5	2.158	76	85.2	0.984			
38	68.0	2.443	77	85.5	0.996			
39	69.0	2.519	78	85.7	0.998			

The above phases can also be seen visually with the help of Polarizing Microscope and their optical micrographs can be captured at any temperature [5,15]

The graph for the optical rotation is shown in Figure 2. It represents the change in angle of rotation with temperature. From the graph it can be seen that SmC^* exists up to 62^0C. At 62^0C, a phase transition occurs from SmC^* to SmA^* phase. The SmA^* phase runs up to 76^0C. At 76^0C another phase transition occurs, this time from SmA^* phase to nematic phase. This nematic

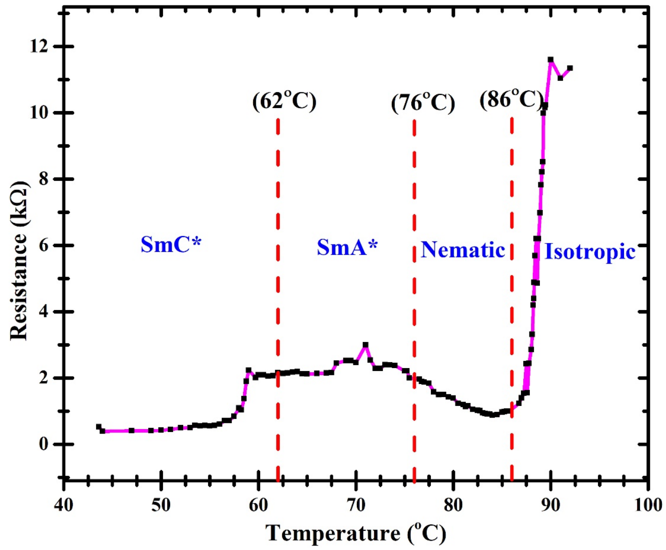

Fig 3. Graph between Resistance of LDR (kΩ) and Temperature (° C)

phase survives for a very small temperature range, from 76^0C to 86^0C and at 86^0C, again a phase transition occurs and the liquid crystalline phase changes to isotropic phase.

With the increase in temperature of sample, the helical director unwinds itself resulting in the decrease in ORP which in turns results in the decrease in the angle of rotation upto SmA* phase. In the nematic phase, the positional ordering of molecules dominates resulting in the increase in angle of rotation again upto isotropic phase. Once the isotropic phase is reached, the disordered state of molecules starts dominating resulting in the fall in angle of rotation.

According to the result obtained for optical transmittance for the above sample, a similar phase transition sequence is observed i.e.

$$\mathrm{SmC}^* \overset{62^\circ C}{\longleftrightarrow} \mathrm{SmA}^* \overset{76^\circ C}{\longleftrightarrow} \mathrm{N} \overset{86^\circ C}{\longleftrightarrow} \text{ Isotropic}$$

The graph for optical transmittance is shown in Figure 3. It shows the variation of resistance of LDR as a function of temperature because the phase transitions have been studied in terms of resistance of LDR.

The SmC^* phase exists up to 62^0C and at 62^0C a phase transition occurs and the SmC^* phase is converted into SmA^* phase. This phase transition can also be seen from the sudden rise in resistance value. At 76^0C, another phase transition occurs and the SmA^* phase changes to nematic phase. This phase transition can also be seen by a drop in the peak. After this phase transition the value of resistance goes on decreasing up to 86^0C and at 86^0C it suddenly rises to a very high value indicating that the liquid crystalline phase has changed to an isotropic phase.

The value of resistance of LDR does not follow any definite trend which may be attributed to the different colours arising due to different molecular structure. This molecular structure changes with the temperature and permits different amount of light to fall on LDR and hence its resistance changes accordingly.

For a thin sample, the boundary conditions of the sample holder may affect the values of phase transition temperatures leading to the small differences in their experimental and literature values.

4 Conclusion

From the present study, we can conclude that the four different different mesogenic phases i.e. SmC*, SmA*, Nematic and Isotropic exist in the FLC sample ZLI 3654. The SmC* phase exists upto 62°C, SmA* phase in the range 62°C - 76°C, Nematic phase in the temperature range 76°C - 86°C and after 86°C liquid crystalline phase changes to isotropic liquid.

The simple techniques used here for the study of optical rotation and optical transmittance of the FLC sample ZLI 3654 provide the critical information about the phase transition behaviour of Ferroelectric Liquid Crystals. This fact is supported by the Temperature versus Angle of Rotation behaviour and also by the Temperature versus Resistance behaviour. The close agreement of the experimental values of transition temperatures with theoretical values establishes the validity of the techniques used. Another advantage of using this technique over other existing techniques is the 'visual phase identification' of different phases that takes place with the change in temperature. By capturing the optical micrographs, one can actually see the different types of phases existing in the sample as well as their mutual transitions. Further, these techniques are not only restricted to FLCs but can also be applied to the study the phase transition behaviour of other types of liquid crystals and their mixtures. These techniques can also be used in those studies where phase transition behaviour with the change in temperature becomes crucial in deciding the type of liquid crystals for a particular application.

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