CHAPTER III

ROLE OF POLYMER COATING ON THE MEMORY EFFECT OF FERROELECTRIC LIQUID CRYSTALS

In this chapter, the discussion is related to the memory behavior of the ferroelectric liquid crystal (FLC) material which has been described by textural, electro-optical and dielectric methods. It has been seen that the memory effect appears in the studied FLC material in nylon (6/6) polymer coated surfaces near transition temperature of Sm C* to Sm A phase and it can be enhanced if a conducting polymer \[\text{poly(3-hexylthiophene)}(P3HT)\], is used instead of nylon(6/6) which is non-conducting in nature. By using P3HT one can achieve a good memory effect even at room temperature. Memory effect was observed in the cells having thickness greater than the pitch value of the material, which is in contrast to the memory effect observed in conventional surface stabilized ferroelectric liquid crystals (SSFLCs). The mechanism behind the long-lasting memory effect is also discussed in the present chapter.

3.1 INTRODUCTION

Liquid crystals (LCs) are unique materials that exhibit the optical properties like solids and fluid properties like liquids. Most of the electro-optical display devices based on LC materials have utilized their simplest form, \textit{i.e.}, nematic LCs \([1]\). The application of sufficient electric field across the nematic LC sample cells can change the orientation of the LC molecules due to the coupling between applied electric field and the dielectric anisotropy ($\Delta\varepsilon$) of the LC material. The assumption of the display devices based on LCs having faster switching time and low threshold, lead to an invention of a promising concept of inclusion of ferroelectricity in LC materials. Ferroelectricity in LC was explained on the basis of symmetry argument by Meyer \textit{et al.} (Chapter I) \([2]\). Ferroelectric liquid crystals (FLCs) have been found to be more advantageous over nematic LCs as the electro-optical switching in these materials occurs due to the
coupling of electric field with that of spontaneous polarization \( (P_s) \). The coupling of the polarization \( (P_s) \) to applied fields is linear, hence, FLCs can be made to switch quickly (typically within a few microseconds) and in a bipolar manner. Owing to their characteristic features such as good optical contrast, fast response, and low threshold voltage, FLCs have been put to various applications such as flat panel displays, spatial light modulators, optical antennas [3, 4], etc. Besides above promising characteristics, some FLC materials have been found enriched with the property of memory effect. However, the memory behavior in most of the FLCs, was found transient (of short duration) in nature [5-7]. Now the main question is how one can define the memory effect.

Basically, memory is one’s ability to store, retain, and subsequently recover information. Techniques of remembering the things have been the subject of much discussion during the last few years and significant efforts have been undertaken in order to understand physical principles and to realize and implement the memory effect. A universal non-volatile memory with fast switching, long retention time, low power, high endurance, random access, and high density has not been created to date. Now a days, several techniques based on magnetic materials, solid ferroelectrics and FLCs, are being used to store the data in computers and other electronic devices. This chapter deals with the long lasting memory effect in FLC material coated with polymers either conducting or non-conducting. It is essential to discuss some earlier studies based on the memory effect of FLCs.

In 1980, Clark and Lagerwall proposed a way to get bistable switching in FLCs by imposing some boundary conditions at the time of fabrication of the FLC sample cells [8]. Clark and Lagerwall succeeded in suppressing the helicoidal structure completely by making the sample cells of thickness less than the pitch of the FLC material, \( i.e., d < p \). Thus, surface constraints the molecules into the geometry so called surface stabilized ferroelectric liquid crystals (SSFLCs), in which spontaneous polarization \( (P_s) \) orientation possesses only two possible states either up or down in the direction of field and thus making the device bistable as shown in Fig. 3.1. Thus bistability is consequence of broken symmetry and is an inherent feature of the SSFLC geometry. It will be there, as long as there are energy maxima (activation energy) between two states 1 and 2 that correspond to the two tilt directions. But this maximum always exists, in
principle, because even a slight elastic distortion involved in turning around all molecular axis inward amounts to such a thing. This bistability is more pronounced in thin samples. For good bistability, a very careful surface treatment along with a sophisticated layer alignment procedure is necessary. The SSFLCs have been described in detail in the section 1.3.3 of Chapter I.

Figure 3.1: Schematic diagram demonstrating stable states of SSFLC device.

Many researchers have contributed to different aspects of the Clark-Lagerwall effect, such as operational speed and contrast dependence on physical parameters of Sm C* and boundary treatment [9-11], occurrence of bistable and memory states due to the boundary conditions [12-15], etc. The occurrence of memory effect in FLCs has rarely been used in devices, however, the memory based on FLCs is more suitable with high write speeds, low-power operation, and high stamina.

In the present chapter, the detailed dynamics of the observed long lasting memory effect in FLC sample cells having the coating of different polymers, *i.e.*, conducting [poly(3-hexylthiophene), *i.e.* (P3HT)] and non-conducting (nylon (6/6)) over the surfaces has been presented by dielectric, textural, and electro-optical methods within a temperature range from room temperature to ferro to para electric (Sm C* to Sm A*) phase transition. Thickness of the sample cells kept more than the pitch value of studied FLC material to avoid the surface stabilization effect. The experimental results also
confirmed that the memory effect in FLC samples having P3HT layer, is much pronounced then the samples having nylon (6/6) layer. The observed memory effect has been attributed to minimization of depolarization field and ionic charges because the depolarizing field tends to cancel out the applied field inside the material and hence affects the stability of permanent dipole moments.

3.2 EXPERIMENTAL DETAILS

Sample cells for the present study were prepared using transparent and highly conducting (10-18 Ω/□) indium tin oxide (ITO) coated optically flat glass substrates. The electrodes in the form of square pattern (4.5 mm x 4.5 mm) were designed using photolithographic technique. Two types of FLC sample cells were prepared to study the memory effect. In first type, the electrodes were treated with adhesion promoter (phenyl trichlorosilane in toluene) followed by the coating of polymer (nylon 6/6) with the rotational speed around 3000 rpm for 50 second and then unidirectionally rubbed to get planar alignment of LC molecules. In second type, the electrodes were treated with adhesion promoter (phenyl trichlorosilane in toluene) followed by the coating the conducting polymer (P3HT) film over the surface of substrates. Layer of P3HT was coated with the rotational speed around 3000 ~ 3500 rpm for 30 seconds and then unidirectionally rubbed. The thickness of P3HT film was tuned by using various concentrations of P3HT in solvent [0.05 to 0.5 % (wt./vol.)] [16]. Here, chloroform (CHCl₃) is used as a solvent for P3HT. The rubbing was done by a buffing machine (Parker Automation, U.S.A.) using velvet cloth on a drum roller under fixed rubbing parameters. A uniform thickness of around 4 μm was maintained between the two plates by using Mylar spacers [17], which is more than the pitch (p) value (2 μm) of the studied FLC material.

The phase sequence of the studied FLC material (Felix 17/100) is as follows:

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Cryst. -28°C → Sm C* 73°C → Sm A* 77°C → N 84 - 87°C → Iso.
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where, Cryst. is the crystalline phase, Sm C* is chiral smectic C phase, Sm A* is the chiral smectic A phase, N is nematic phase, and Iso. is the isotropic phase, respectively.
The material was introduced into the cell by means of capillary action at elevated temperature (~95°C) to ensure that filling takes place in isotropic phase of the used FLC material.

The dielectric measurements were carried out in a shielded parallel plate capacitor using impedance analyzer 6540 A (Wayne Kerr, U. K.) in the frequency range of 20 Hz to 1 MHz. A temperature controller (JULABO F-25 HE) was used for controlling the temperature with a temperature stability of ±0.01°C. The sample holder is set aside thermally isolated from exterior sources. For the electrical and optical response, a triangular or square delayed wave pulse of desired amplitude and frequency generated from a function generator was applied across the electrodes of sample cell and the output response was recorded using a storage oscilloscope (HM 1507–3, HAMEG) interfaced with a computer via SP-107 software. The dc conductivity was measured using an electrometer (Keithley 617). The optical micrographs of the material were recorded using an optical polarizing microscope (AX-40, Carl Zeiss, Germany) (OPM) fitted with a charge coupled device (CCD) camera and interfaced with the computer (Chapter II).

3.3 RESULTS AND DISCUSSION

In the present study, the memory effect has been achieved in FLCs by the coating of polymers either conducting or non-conducting over the ITO surface of substrates [18, 19]. On comparing the results, we found that in case of non-conducting polymer (nylon (6/6)) coated FLC sample, the memory effect appears only at higher temperature range (near transition temperature) while the coating of conducting polymer (P3HT) over the surfaces of FLC sample, enhanced the memory effect and in this case, one can achieved a good memory effect even at room temperature also. In this chapter, we are comparing the memory effect observed in both types of sample cells on the basis of textural, dielectric and electro-optical results.

3.3.1 Effect of polymer coating on the alignment in FLCs

Alignment of LC molecules plays an important role to control the physical parameters and achieve the memory effect in LCs. The planar or homogeneous (HMG) alignment
is required in FLCs to achieve good optical contrast, low threshold voltage, and memory effect [20–22], etc. In the first section of our study, we used a simple but effective method to get a planar alignment. In this method, the glass substrates coated with polyimide [such as nylon (6/6)] and followed by unidirectional rubbing with velvet cloth [23]. The rubbing process creates elongated stress/strain on the polymer and facilitates the alignment of the long axis of the LC molecules along the rubbed direction.

![Figure 3.2: (a) Berreman model of alignment and (b) molecular alignment by polyimide coating.](image)

The foundations of the theory of elastic continuum were laid by Berreman in 1972, according to which, molecular interactions between the alignment layer and LC molecules may not play a role in the alignment mechanism as shown in Fig. 3.2(a), [24]. Instead, the LC molecules orient themselves parallel to the microgrooves, which are formed as a result of the rubbing [Fig. 3.2(b)]. This means that the alignment of LC molecules in and around the microgrooves, with their director parallel to the direction of the groove, results in the lowest surface energy and hence the most stable conformation [25, 26].

In the second part of our study, we used the layer of P3HT coating over the substrate to achieve HMG configuration. P3HT is an important conducting polymer because of its
excellent electrical conductivity, electroluminescence, nonlinear optical properties, and low cost [27]. The conducting and optical properties of a conducting polymer depend mainly on the arrangement of its chains [Fig. 3.3] and thiophene-thiophene interaction in adjacent layers has a strong influence to arrange the molecules of FLC in a HMG manner [28, 29].

Figure 3.3: Schematic model of poly(3-hexylthiophene) [P3HT].

Figure 3.4 shows the optical micrographs of FLC sample cells with rubbed, polyimide (Nylon 6/6) and conducting polymer (P3HT) coated surfaces, respectively. We observed HMG alignment in conducting polymer-coated surface of FLCs like in rubbed polyimide surfaces. The HMG configuration was confirmed by change in the transmission as seen by the rotation of the cell under the crossed polarizers. The good alignment in P3HT coated surface could be due the fact that when the glass surface coated with P3HT were rubbed then the molecules of P3HT get stretched and the LC molecules trapped in between these stretched molecules in the rubbing direction.

In our case, we took measurements for many samples having different concentrations of P3HT in CHCl₃ solvent but only 0.1 to 0.3 % (wt. /vol.) of P3HT in CHCl₃ solvent was found to be the best for achieving good alignment and memory effect.
Figure 3.4: Optical micrographs of (a) rubbed polyimide surfaces and (b) gently rubbed P3HT coated surfaces of Felix 17/100 sample cells.

Low molecular weight P3HT exhibited the strongest correlation with surface treatment while high molecular weight P3HT showed very little dependence on the surface treatment [30].

3.3.2 Observance of memory effect in polymer coated FLC samples by dielectric method

The memory behavior of the present FLC material has been investigated by using dielectric spectroscopy in the cells of thickness greater than the pitch (p) of the FLC material. It is well known that the dielectric relaxation in Sm C* phase arises mainly due to collective dielectric processes contributed by the Goldstone mode and soft mode [31, 32]. The Goldstone mode arises due to the phase fluctuations in the azimuthal orientations of the director and the soft mode which is dominant near the transition temperature of Sm C* to Sm A*, arises due to the fluctuations in the amplitude of the tilt angle. The Goldstone mode is the dominant contributor to the dielectric permittivity (ε’) in the Sm C* phase due to which ε’ is higher in magnitude at lower frequencies [31]. It is known that the application of a strong external bias field unwinds the helicoidal structure and effectively suppresses the contribution from the Goldstone mode to the dielectric permittivity (ε’) [33].
Figure 3.5 shows the curve of dielectric permittivity ($\varepsilon'$) as a function of frequency in nylon (6/6) coated [Fig. 3.5(a)] and P3HT coated [Fig. 3.5(b)] FLCs, respectively, with different bias voltages (0, 20, and again 0 V) in deep Sm C* phase (30°C). At 0 V bias, the high value of dielectric permittivity ($\varepsilon'$) in the Sm C* phase in both cases, is due to the Goldstone or phason mode contribution. The value of dielectric permittivity ($\varepsilon'$) drops to minimum as we changed the bias field from 0 V to 20 V. This decrease in dielectric permittivity ($\varepsilon'$) on the application of strong bias field is due to the suppression of phason mode.

After removing the bias, in case of nylon (6/6) coated FLC samples, the dielectric permittivity ($\varepsilon'$) value regains the previous value, which was at 0 V initially while in case of P3HT coated FLC samples the value of dielectric permittivity ($\varepsilon'$) does not change and remained as it was in the presence of bias of 20 V. This confirms that the nylon (6/6) coated FLC sample does not show any memory effect at room temperature while the FLC sample cell having P3HT coating remains in stable state and shows a good memory effect in deep Sm C* phase also.

Figure 3.5: Behavior of memory effect of FLC material using dielectric method at room temperature of gently rubbed, (a) nylon (6/6) coated and (b) P3HT coated surfaces.
In contrast to the behavior at room temperature, the FLC material coated with nylon (6/6) shows a remarkably different variation near transition temperature (69°C) as shown in Fig. 3.6(a). After removing the bias at 69°C, it shows almost similar dielectric permittivity ($\varepsilon^\prime$) values as with the respective bias voltages. This confirms that the cell remained in its stable state, otherwise it would have shown the previous value of dielectric permittivity ($\varepsilon^\prime$) which was at 0 V initially.

![Figure 3.6](image)

**Figure 3.6:** Behavior of memory effect of FLC material using dielectric method near transition temperature (69°C) of gently rubbed, (a) nylon (6/6) coated and (b) P3HT coated surfaces.

Hence it can be inferred that, on applying a bias voltage (20 V), the molecules are clamped to one side of the cone and after removing the bias, they do not return back to their scattered state. The molecules remain almost in the same state as they were under the bias showing that the cell is in memory state [34, 35]. These observations reveal that the memory effect appears in the FLC material at a higher temperature in nylon (6/6) coated surfaces while the effect was completely absent at room temperature. This is in contrast to the memory effect which was observed in deep Sm C* phase for the cell having P3HT coating. Therefore, it can be said that P3HT layers help to enhance the memory effect in Felix 17/100 which can persist in a wide temperature range.
The occurrence of memory in FLC material has also been confirmed by the textural and electro-optical response, which is discussed in next sections.

3.3.3 Observance of memory effect in polymer coated FLC samples by textural studies

Out of all the methods to check the memory effect in a FLC material, the most sophisticated method is to look at the textures of FLC material under OPM. Figure 3.7 shows the optical micrographs of nylon (6/6) coated surfaces of FLC material which were observed in deep Sm C* phase (room temperature).

Figure 3.7: Optical micrographs of rubbed nylon (6/6) coated surfaces of Felix 17/100 cell at room temperature at (a) 0 V (b) 20 V bias, and (c) just after removal of bias.
Figure 3.7(a) shows the optical micrograph of scattered state (under no bias) of the material. On applying 20 V bias, a completely switched bright/dark state was achieved as shown in Fig. 3.7(b). Now, after removing the bias, FLC samples regain its initial scattered state as shown in Fig. 3.7(c), which means memory effect is absent. From this, one can confirm that the FLC sample does not show any memory effect at room temperature. Figure 3.8 shows the optical micrographs observations at a higher temperature (69°C) of nylon (6/6) coated surfaces of FLC material.

![Optical micrographs](image)

**Figure 3.8:** Optical micrographs of rubbed nylon (6/6) coated surfaces of Felix 17/100 cell near transition temperature (69°C) at (a) 0 V (b) 20 V bias (c) just after removal of bias, and (d) 45 minutes after removal of bias.

Figure 3.8(a) shows the optical micrograph of the scattered state which can be completely switched in to bright state on applying 20 V bias, as shown in Fig. 3.8(b). It is clear from Fig. 3.8(c), that almost same state was retained after removing the bias and
this memory state was retained even after a time gap of 45 minutes as shown in Fig. 3.8(d). Hence, from above micrographs, one can conclude that the memory effect in the FLC material in nylon (6/6) coated surfaces appears only at very high temperature (near transition) and there is no memory at room temperature.

Figure 3.9 shows the polarizing optical micrographs of P3HT coated samples of FLC material which were observed in deep Sm C* phase (room temperature), from which one can get a clear picture of the memory effect. Figure 3.9(a) shows the optical micrograph of the material when no bias was applied across the cell, which is called scattering state.

![Figure 3.9: Optical micrographs of gently rubbed P3HT coated surfaces of Felix 17/100 cell at room temperature at (a) 0 V (b) 20 V bias (c) just after removal of bias, and (d) 45 minutes after removal of bias.](image)

A completely switched bright/dark state was achieved on applying 20 V bias, as shown in Fig. 3.9(b), depending upon the polarity. It is clear from Fig. 3.9(c), that the same
state was retained after removing the bias and this memory state was retained even after a time gap of 45 minutes as shown in Fig. 3.9(d).

Hence, on comparing the results based on optical micrographs of nylon (6/6) coated and P3HT coated surfaces of FLC sample cells, it is clear that nylon (6/6) coated sample cell does not show memory effect at room temperature but the memory effect increases as the temperature is increased while the P3HT coated sample cell shows a good memory even at room temperature (in deep Sm C* phase).

3.3.4 Observance of memory effect in polymer coated FLC samples by electro-optical methods

Bistability in FLCs has also been confirmed by applying time delayed positive and negative square pulses to the sample and by studying the electro-optical response using the POM fitted with a photodiode [36, 37]. Figure 3.10 shows the optical response of the FLC sample coated with nylon (6/6) at two different temperatures (28°C and 69°C), under a bias voltage of 10 V peak to peak and at 20 Hz frequency.

![Figure 3.10: Optical response of the FLC (Felix 17/100) sample coated with nylon (6/6) at 69°C and 28°C, where CH I and CH II show driving square voltage pulse (± 5 V and 20 Hz) and its optical response, respectively.](image-url)

- Ch II: Response pulse
- Ch I: Applied square delayed pulse
- Time (TB A: 20.00 ms)
- 28°C
- 69°C

Figure 3.10: Optical response of the FLC (Felix 17/100) sample coated with nylon (6/6) at 69°C and 28°C, where CH I and CH II show driving square voltage pulse (± 5 V and 20 Hz) and its optical response, respectively.
The absence of memory effect in the sample at room temperature (28°C) is clearly observed in Fig. 3.10. The optical transmission is changing in accordance with the applied inputtime delayed square pulse, thereby showing absence of bistability in the sample at 28°C.

It is worth mentioning here that the helical pitch (p) value in Sm C* phase of the studied material does not change much at room temperature and near the transition temperature of Sm C* to Sm A phase which suggesting that the bistability is not due to the surface effect at higher temperature in nylon (6/6) coated samples.

Figure 3.11 plots the change in transmittance of the cell as monitored by photodiode (along the y-axis) with respect to the applied voltage (along x-axis), which is a growing pulse of triangular shape with 20 V peak to peak and at frequency of 20 Hz for nylon (6/6) coated surfaces of FLC sample cells.

**Figure 3.11:** Optical hysteresis on application of symmetric triangular wave (±10 V and 20 Hz) of the FLC material (Felix 17/100) coated with nylon (6/6) at 28°C (inset) and 69°C where CH I: [1.0 V/DIV] on x-axis is the applied triangular wave and CH II: [0.020 V/DIV] on y-axis is its optical response.
The observance of a square electro-optical hysteresis loop exhibits the presence of memory effect in nylon (6/6) coated FLCs. It is observed that the loop obtained at 28°C as shown in Fig. 3.11(inset), is saturated at higher voltage in the increasing part of the applied pulse, while during decreasing the applied pulse, the optical contrast (response) also decreases confirming the decrease in optical tilt angle. Also, at zero field, the optical contrast is low and decreases further as one goes into the negative half cycle of the applied pulse. Whereas, the transmission characteristic at 69°C is perfectly nonlinear, displaying saturation and the memory behavior as shown in Fig. 3.11.

The shape of hysteresis loop also shows that bistable operation is symmetric with regard to the positive and negative pulse [38, 39]. The optical contrast saturates at lower threshold than that observed at 28°C and during the decreasing part of the positive cycle of the applied voltage, the optical contrast does not decrease and retains the same contrast as it were at the saturation state. Moreover, the optical contrast does not drop even in the absence of applied field that further confirms the perfect memory effect. Hence, these electro-optical observations further corroborate the presence of memory effect in nylon (6/6) coated FLC at higher temperature near the ferro to paraelectric phase transition temperature (Sm C* to Sm A*).

Figure 3.12 shows the optical response in P3HT coated surfaces of FLC material, for different frequencies \(^{i.e.}, 500\) mHz \(\{\text{Fig. 3.12(a)}\}\) and \(100\) Hz \(\{\text{Fig. 3.12(b)}\}\) at a fixed voltage \(20\) Vpp on the application of time-delayed square wave pulses. As seen in the figure, the optical transmission changes from maximum to minimum as the applied field reverses its polarity and there is a little change when the applied field attains its 0 V state. These observations confirm the presence of memory in the entire frequency range of FLC material having the layers of P3HT over the surfaces of substrates. We also prepared a cell of CS 1016 material, which is also a FLC, using rubbed P3HT surfaces. We found memory effect up to some extent in this cell too, whereas no memory effect was observed in rubbed polyimide surfaces of CS 1016 materials.
Figure 3.12: Optical response of gently rubbed P3HT coated surfaces of Felix 17/100 at room temperature at 20 Vpp and at (a) 500 mHz (Time: 500 ms/div), and (b) 100 Hz (Time: 2 ms/div). The voltage on the y-axis for channel Ch 1 and Ch 2 are 10 V/div and 0.05 V/div, respectively.

These observations confirm that P3HT coating on ITO substrates helps in achieving memory effect not only in Felix 17/100 but also in CS 1016 material. We choose only CS 1016 material for comparison because it has most of the physical parameters similar to Felix-17/100 material.

The observation of long lasting memory in P3HT coated surfaces of FLCs ensures that the depolarization field is almost absent in FLC samples. The absence of the depolarization field can also be confirmed by the fact that even after shortening of sample cell we were not able to find the original or scattered state. For the confirmation of the absence of depolarization field, we studied the electrical response of P3HT coated surfaces of FLC cells at a fixed voltage on the application of triangular wave pulses to the sample cell.

Figure 3.13 shows the electrical response of polyimide (nylon (6/6)) coated and P3HT coated FLC samples, respectively, at a fixed voltage (10V) and at a fixed frequency (1 Hz). As one can see from Fig. 3.13(a), that there is no symmetric polarization peak observed in case of rubbed nylon (6/6) surfaces FLC cells. There is nonlinearity in the output response of the rubbed polyimide surfaces FLC samples. Such type of
nonlinearity is due to the generation of depolarization field to reverse the direction of spontaneous polarization ($P_s$) [19, 40].

Figure 3.13: Electrical response of gently rubbed, (a) polyimide (nylon (6/6)) coated (Ch 1: 10 V/div, Ch 2: 0.10 V/div, and Time: 200 ms) and (b) P3HT coated surfaces (Ch 1: 10 V/div, Ch 2: 0.20 V/div, and Time: 50 ms) of Felix 17/100 sample cells at room temperature. The oscillographs have been taken at frequency of 1 Hz and 20 Vpp.

Moreover, it has been observed earlier that if the pulse width of the external voltage is larger than approximately a few hundred µs, then accumulation of excess ions at the interface between the FLC medium and the alignment layer takes place [41]. These excess ions generate an external field, which enhances the depolarization field that is also responsible for the nonlinearity in the output response of rubbed polyimide FLC samples. On the other hand, a symmetric polarization peak was observed in P3HT coated FLC samples, which is clearly reflected in Fig. 3.13(b). There is a perfect linearity, hence no depolarization effect present in such type of samples. The presence of conducting polymer layers (which helps to align the samples) inject free charges to the interface, which also screen or neutralize the interfacial charges and causes the minimization of depolarization field and ionic charges. The memory effect in P3HT coated FLC samples having thicknesses greater than their pitch value ($p$) (~2 µm) could be due to the absence of a depolarization field and the perfect alignment. Secondly, it
can be said that SSFLC effect is not the only factor to get the bistability but surface energy of the cells also play a dominant role for the memory effect in FLC materials. In order to understand the observance of memory effect at higher temperature in nylon (6/6) coated FLC samples, the conductivity of the material was studied as a function of temperature. Figure 3.14 shows the dc conductivity variation as a function of temperature for the studied material.

![Figure 3.14: Temperature dependence of log of dc conductivity \[\log (\sigma)\] in rubbed polyimide (nylon (6/6) coated surfaces of Felix 17/100 sample cell.](image)

It is observed that the conductivity increases with temperature showing a steep increase near \(-63^\circ\)C since it is near the transition from Sm C* to Sm A phase. It is known that the polarization and ionic charges, accumulated on the interfaces between the FLC medium and alignment layers, tend to partially screen the external applied field and generate a depolarization field that reverses the spontaneous polarization when the external field is switched off. There are two sources of free charges/ions in liquid crystals: the LC itself and the alignment layer [1]. In nylon (6/6) coated samples, the conductivity near room temperature is low which causes the charges to accumulate on the interfaces between the FLC and the alignment layer. At room temperature,
saturation in conductivity follows from the gradually increasing depolarization field that effectively counteracts the applied field and hampers the movement of the ionic charges which degrades memory effect, and hence no memory effect was observed at room temperature. But at a higher temperature, increased conductivity allows the free charges to drift back into the bulk thereby reducing accumulation near the interfaces. This reduces the depolarization field and thus memory is observed near transition temperature (i.e., 69°C).

In the cells having thickness more than the pitch value, the surface stabilization effect becomes weaker and bulk conductivity plays a major role for the memory effect in FLC materials with temperature. In addition to the weak surface effect, the low bulk conductivity at room temperature is not sufficient to minimize the accumulated charge so that depolarizing field can be reduced. At higher temperature in rubbed polyimide coated surfaces of Felix 17/100 samples, surface stabilization effect weakens further but the increased bulk conductivity reduces the accumulated charges that decrease the depolarizing field. The magnitude of depolarizing field is negligible or very weak to reorient the dipoles in the absence of external field and the stressed state is preserved and as a result memory effect is observed. Such memory effect near transition temperature has been observed in other two FLC materials as well, i.e., CS 1016 and Felix 17/00. The thickness of the FLC sample has been taken into account by Iwasaki et al. [42], where they studied the color switching in FLC. However, the mechanism of the memory effect in FLC materials is quite unclear and leaves further scope for LC researchers to think in this direction.

3.4 CONCLUSIONS

We have investigated the memory effect in sample cells having the coating of non-conducting polymer [nylon (6/6)] and conducting polymer [poly(3-hexylthiophene) (P3HT)] over the surfaces of substrates and the sample cells having thickness greater than the pitch value (p) of the studied material. A long-lasting memory effect was observed by textural, dielectric and electro optical measurements in used FLC material. The effect of temperature on the memory effect has been demonstrated. FLC material used in the present study, does not show memory effect at room temperature in nylon (6/6) coated sample cells but the memory effect increases as the temperature is
increased while the same material coated having P3HT layer over the surfaces, shows a good memory even at room temperature (in deep Sm C* phase). The observed memory effect has been attributed to the absence of depolarization field and ionic charges in P3HT coated surfaces while in nylon (6/6) coated surface of FLC material the most probable reason behind the memory is dc conductivity, which increases with temperature and minimizes the effect of depolarizing field as well.
References


