CHAPTER 10

OPTICAL SHUTTERING AND FILTERING STUDIES

The response of liquid crystalline molecules with the applied stimulus is to be considered of more importance as it determines the electrooptic properties exhibited by the mesogen. Less ordered nematic molecules have a good response to the applied electric stimulus. In optical shuttering, the mesogens either completely or partially inhibit the passage of light. Thus these mesogens can be used as light shutters or light modulators in a variety of applications. The profile of intensity of light with external stimulus is also discussed.

In an optical filter the passage of light is varied with the mesogenic phase and temperature. Thus various kinds of optical filter can be realized such as notch filter, low pass, band pass and high pass studied by Adams (1972). In the present investigation filtering action is carried out in less ordered nematic phase. The results obtained from the measurement makes the phase to be utilized as desirable filters depending upon the wavelength absorbed.
Table 10.1 Optical shuttering and filtering action observed in HBLC complexes

<table>
<thead>
<tr>
<th>Phenomena</th>
<th>HBLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical shuttering and</td>
<td>ClBAO+nBAO (n = 7 to 11)</td>
</tr>
<tr>
<td>Optical filtering action</td>
<td>CBA+10BAO</td>
</tr>
<tr>
<td></td>
<td>HQ+nBAO (n = 10 to 12)</td>
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<tr>
<td></td>
<td>nBAO+mBAO, (m and n varies from 5 to 12)</td>
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</tbody>
</table>

10.1 INTRODUCTION

As well known, LC molecules respond to the external stimuli applied over it. Response of the molecules depends on anchoring energy of the molecules to a considerable extent. As the applied field is increased, the mesogenic molecules get loosely bounded by the substrate surface. To define it scientifically, LC molecules tends to behave as a light modulator. Increase in the field further leads to the extinction of light passed through the LC molecules which may be referred to as optical shuttering (OS) action. This parameter sounds the response of nature of the mesogen prepared towards the field applied, which frames the utility of LC in advanced display device applications.

It is not surprise to note that molecules under the influence of external stimuli prefer homeotropic like alignment when the strength of the field is gradually increased to the maximum value, where the molecules inhibit light and act as optical shutters. This is due to the applied field exceeding surface anchoring resulting the LC molecules geometry an orientation which resembles homeotropic alignment leading to exhibit OS action. In the present investigation optical shuttering action, output light intensity profiles and optical filtering action of various mesogens in nematic phase are discussed. The complexes investigated are listed in table 10.1.
In the entire thermal span of nematic phase of the complexes considered, when an applied dc bias voltage of both polarities exceeds a particular threshold value \( E_1 \), the light from the liquid crystal is observed to be extinct which is referred as optical shuttering action. This transition is classified as \( E_0 \) to \( E_1 \) which is referred as OS and is given by

\[
E_0 \leftrightarrow E_1 (\text{Optical Shutter})
\]

Light intensity profiles as a function of applied stimulus in nematic phase is also manifested from the OS study. \( E_0 \) represents the absence of applied field to the mesogen. The bias voltages of both polarities are drawn from impedance analyzer HP 4192A and the intensity of the light from the liquid crystal sample is measured by a photo diode TSL 252.

Generally optical filters are capable of substantially transmitting light at all wave lengths while reflecting light over a single, generally narrow, wavelength band. This principle is incorporated for the first time to the LC mesogenic phase, in particular to the orientational ordered nematic phase. From the results it is inferred that the unique optical properties of liquid crystal elements can be exploited to provide a wide variety of narrow band filtering functions extending over a wide wavelength range from the near ultraviolet to the far infrared spectra.

**10.2 OPTICAL SHUTTERING ACTION, INTENSITY PROFILE: CIBAO+nBAO**

CIBAO+nBAO complexes viz., \((n=7 \text{ to } 11)\) when subjected to various strengths of external dc bias voltage, optical shuttering (OS) action is observed. These complexes in entire thermal span of nematic phase when an applied dc bias voltage exceeds a particular threshold value \( E_1 \), the light
from the liquid crystal is observed to be extinct which is referred as OS action.

As a representative case, OS action in ClBAO+11BAO is discussed. Figure 10.1 depicts clearly the nematic phase observed in ClBAO+11BAO complex, while Figure 10.2 represents the OS action in the nematic phase with influence of applied field. From Figure 10.2, the OS action is observed in the conducting while nematic texture is seen in the non-conducting area. Immediately after withdrawing the bias voltage the original texture of the nematic phase is retained.

Thus this process is reversible with both polarities applied bias voltage. In the entire thermal span of nematic phase of these complexes this phenomenon is observed. While in the other phases succeeding nematic phase no such transition is found. Table 10.2 depicts the various HB complexes along with their threshold field values obtained for both the polarities.

ClBAO+8BAO complex is filled in a 4 micron commercially available buffered cell (Instec) and silver leads are drawn for contact. The sample is cooled from isotropic to nematic phase at a cooling rate of 0.5°C /min. Light intensity profile experiment is conducted at 80.5°C in the nematic phase of the sample. The external bias voltage from the impedance analyzer (4192A) is incremented in small predetermined steps of 1 volt, this in turn varied the intensity of the light passing through the nematic texture.

The variation of the intensity of the texture is noted at each step of the applied bias voltage and plotted as shown in Figure 10.3. It is not surprising to note that the magnitude of the light is similar in both the polarities indicating a similar type of molecular orientation. During the transition from \( E_0 \) to \( E_1 \) there is a steep sudden decrement of the intensity of light manifesting the OS of light.
These voltage values of both polarities are referred as threshold values of the complexes and are tabulated in table 10.2 for various complexes. This phenomenon is referred as OS action where the light intensity is completely vanished. Thus the liquid crystal behaved as an optical shutter (Figure 10.2). Hence this HBLC may be used as a light modulator. Similar trend of results are obtained for other complexes with the variation in the corresponding threshold values in the nematic phase.

It is remarkable to note that the threshold voltage magnitudes follows an odd-even pattern with respect to the variation in the alkyloxy carbon number. The odd homologues follow one pattern while the even exhibit another. As the chain length increases the conjugation is also enhanced. The conjugative interactions between alkyloxy groups on the aromatic ring increases the anisotropy of the polarizabilities and inter molecular attraction for the systems. This leads to the above observed odd-even effect discussed in section 6.5 of chapter 6.

Table 10.2 HB complexes exhibiting OS action along with threshold field values

<table>
<thead>
<tr>
<th>Hydrogen bonded Complexes</th>
<th>Threshold field values (Volts/µ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClBAO+11BAO</td>
<td>2.0 and -2.0</td>
</tr>
<tr>
<td>ClBAO+10BAO</td>
<td>1.5 and -1.5</td>
</tr>
<tr>
<td>ClBAO+9BAO</td>
<td>3.0 and -3.0</td>
</tr>
<tr>
<td>ClBAO+8BAO</td>
<td>2.5 and -2.5</td>
</tr>
<tr>
<td>ClBAO+7BAO</td>
<td>2.75 and -2.75</td>
</tr>
</tbody>
</table>
Figure 10.1 Optical texture of nematic phase of ClBAO+11BAO complex

Figure 10.2 OS action in nematic phase of ClBAO+11BAO complex
Figure 10.3  Light intensity profile as a function of applied stimulus for ClBAO+8BAO complex

Figure 10.4  Variation of polarized transmitted light with wavelength
10.2.1 Optical Filtering Action in ClBAO+10BAO Nematic Phase

Figure 10.4 presents the variation of percentage polarized transmission with wavelength for the homologue ClBAO+10BAO in its nematic phase. From the Figure 10.4, it can be observed that the visible region is allowed to pass, while the ultraviolet radiation is blocked. Thus these liquid crystals can be used as an effective filter for ultraviolet region of the spectrum.

10.3 OPTICAL SHUTTERING ACTION IN CBA+10BAO

In nematic phase of CBA+10BAO complex, under investigation, when an applied dc bias voltage exceeds a particular threshold value, the phase of the complex is observed to prefer homeotropic like alignment with light being optically extinct which is referred as OS action. Figure 10.5 and 10.6 refers to the nematic texture and OS action observed in CBA+10BAO complex respectively. It is also interesting to note that immediately after withdrawing the bias voltage from the induced transition the original texture of the nematic phase is retained (Figure 10.5). Thus this process is reversible with bias voltage. In the entire thermal span of nematic phase (~137°C to ~112°C) this is observed. While in the other phases preceding and succeeding nematic phase no such transition is found.

A meticulous investigation has been made to study the light intensity profile measurement in CBA+10BAO complex. Nematic phase of CBA+10BAO is applied with a bias voltage (both polarities) less than or equal to ±4.20 v/µ, which is referred as E₀ where there is no change in the texture of the nematic phase (Figure 10.5). As the voltage is increased in small steps the intensity of the light from the texture drops. An important observation is that when a dc bias voltage of ±4.60 v/µ is applied, the optical extinction is observed with the optical texture of the compound suddenly disappears, this new phase is designated as OS (E₁) given as Figure 10.6.
Figure 10.5 Optical texture of nematic phase of CBA+10BAO complex

Figure 10.6 OS action in nematic phase of CBA+10BAO complex
The above explanation is clearly depicted in Figure 10.7. One of the possible reasons for this interesting phenomenon may be the realignment of the molecules to form a homeotropic like alignment.

### 10.4 OPTICAL SHUTTERING ACTION, INTENSITY PROFILE IN HQ+nBAO

Three HB complexes, viz., HQ+10BAO, HQ+11BAO and HQ+12BAO in nematic phase, when subjected to an external bias field exhibits light modulation. It is worth mentioning that when the external bias field is withdrawn, the original nematic texture is instantaneously retained, thus this light modulation action is reversible. Furthermore, this light modulation i.e., OS action is noticed in the entire nematic thermal span of the respective complexes. Figure 10.8 and 10.9 refers to the nematic texture and OS action observed in HQ+11BAO complex respectively.
The various threshold voltage values corresponding to HQ+10BAO, HQ+11BAO and HQ+12BAO complexes are given in Table 10.3. The maximum threshold field value is 3.5 V/μ for HQ+10BAO and the minimum threshold is 1.4 V/μ for HQ+11BAO complex, their percentage of light modulation along with nematic thermal range are depicted in Table 10.3. The decrease in the magnitude of the threshold values can be justified by correlating it to the anchoring energy.

**Table 10.3** HB complexes exhibiting OS action along with nematic thermal range, threshold field values and percentage of light modulation

<table>
<thead>
<tr>
<th>Complex</th>
<th>Nematic thermal range (°C)</th>
<th>Threshold field value (V/μ)</th>
<th>Field induced transitions</th>
<th>Percentage of light modulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>HQ+10BAO</td>
<td>13.1</td>
<td>3.5</td>
<td>$E_0 \rightarrow E_1$</td>
<td>79</td>
</tr>
<tr>
<td>HQ+11BAO</td>
<td>6.5</td>
<td>1.4</td>
<td>$E_0 \rightarrow E_1$</td>
<td>51</td>
</tr>
<tr>
<td>HQ+12BAO</td>
<td>5.3</td>
<td>2.0</td>
<td>$E_0 \rightarrow E_1$</td>
<td>63</td>
</tr>
</tbody>
</table>

The optical intensity in the nematic phase exhibited by all the three complexes under the influence of external stimulus at a constant temperature are studied. Figures 10.10, 10.11 and 10.12 illustrate the light intensity profile with applied external field for HQ+10BAO, HQ+11BAO and HQ+12BAO complexes respectively. In all the complexes, at the respective threshold value the light intensity steeply falls indicating the onset of $E_1$ phase (Figure 10.9) which is referred as OS action.
Figure 10.8 Nematic four brush texture of HQ+11BAO complex

Figure 10.9 OS action in nematic texture of HQ+11BAO complex
Figure 10.10  Light intensity profile as a function of applied stimulus in HQ+10BAO

Figure 10.11  Light intensity profile as a function of applied stimulus in HQ+11BAO
Figure 10.12 Light intensity profile as a function of applied stimulus in HQ+12BAO

The alignment of the molecules with the external stimulus and the anchoring energy of the molecules to the glass substrate of the liquid crystal cell containing the respective complexes are responsible for the above behavior. The percentage of the light inhibited at the threshold value is tabulated in table 10.3.

10.5 nBAO+mBAO HOMOLOGOUS SERIES

An interesting attempt is made in forming HBLC series between two mesogenic chemical moieties of same structure with the change in carbon number to one of the moiety, while the other remains fixed. Alkylxy benzoic acids referred as (nBAO) with carbon number pentyl to dodecyl formed hydrogen bond with another set of alkylxy benzoic acids referred as (mBAO) yielding eight hydrogen bonded homologous series represented as 5BAO+mBAO, 6BAO+mBAO, 7BAO+mBAO, 8BAO+mBAO,
9BAO+mBAO, 10BAO+mBAO, 11BAO+mBAO and 12BAO+mBAO, with 56 complexes. Reported synthetic procedure, as discussed in section 3.3 of chapter 3 is adopted for synthesizing the present homologous series. However in the complexes the structural isomers like 5BAO+10BAO, 10BAO+5BAO result in only one complex with similar properties.

Furthermore, synthesis of identical complexes like nBAO+nBAO is not possible. In all, there are 8 such identical complexes namely 12BAO+12BAO, 11BAO+11BAO, 10BAO +10BAO, 9BAO +9 BAO, 8BAO +8BAO, 7BAO +7BAO, 6BAO +6BAO and 5 BAO +5BAO. On scrutinizing and eliminating these structural isomers and identical complexes the total number of complexes reduces to 28 which is half of the expected 56 complexes.

10.5.1 Optical Shuttering Action in nBAO+mBAO Series

The present complexes viz. nBAO+mBAO (m and n varies from 5 to 12) when subjected to various strengths of external dc bias voltage, optical shuttering action is observed. As a representative case, optical shuttering action in 12BAO+11BAO is discussed. Figures 10.13 10.14, and 10.15 depicted, clearly indicates the nematic phase, light modulation and OS action observed in 10BAO+6BAO complex respectively. At a lower threshold value, light modulation (Figure 10.14) is observed and on further increase of the field, OS (Figure 10.15) is observed. From Figure 10.15, the OS action is observed in the conducting area, while nematic texture is seen in the non conducting area.

The threshold values of all the HBLC are tabulated in the Table 10.4. It is remarkable to note that the threshold voltage values are symmetric with respect to polarities with an exception of 10BAO+6BAO complex. As the chain length increases the conjugation is also enhanced. The l/d ratio plays a vital role in determining the threshold voltage.
Table 10.4 nBAO+mBAO series threshold field values

<table>
<thead>
<tr>
<th>Hydrogen bonded Complexes</th>
<th>Threshold values (Volts/micron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12BAO+6BAO</td>
<td>1.75 and -1.75</td>
</tr>
<tr>
<td>12BAO+8BAO</td>
<td>2.0 and -2.0</td>
</tr>
<tr>
<td>12BAO+11BAO</td>
<td>2.75 and -2.75</td>
</tr>
<tr>
<td>10BAO+5BAO</td>
<td>3.25 and -3.25</td>
</tr>
<tr>
<td>10BAO+6BAO</td>
<td>4.25 and -3.25</td>
</tr>
<tr>
<td>10BAO+9BAO</td>
<td>2.5 and -2.5</td>
</tr>
</tbody>
</table>

10.5.2 Optical Intensity Profile Observed in nBAO+mBAO series

In order to study the molecular orientation, intensity profile in the nematic phase of various complexes of nBAO+mBAO homologous series is experimentally analyzed by applying external bias voltage of both polarities. As a representative case, intensity profile of the 9BAO+5BAO complex is discussed.

9BAO+5BAO complex is filled in a 4 micron commercially available buffed cell (Instec) and silver leads are drawn for contact. The sample is cooled from isotropic to nematic phase (133.7°C) at a cooling rate of 0.5°C /min. The external bias voltage from the impedance analyzer (4192A) is incremented in small predetermined steps of 1 volt, this in turn varied the intensity of the light passing through the nematic texture. The variation of the intensity of the texture is noted at each step of the applied bias voltage and plotted as shown in Figure 10.16. It is not surprising to note that the magnitude of the light is similar in both the polarities indicating a similar type molecular orientation.

At the threshold field sudden decrement of the intensity of light is noticed which manifests the OS of light. These voltage values of both polarities are referred as threshold field values. This action is referred as OS
where the optical profile is completely vanished. Thus the liquid crystal behaves as an optical shutter (Figure 10.15). Hence it may be used as a light modulator.

### 10.5.3 Light Filtering Action in nBAO+mBAO Series

From the literature of nematic liquid crystals by Adams (1972) it can be inferred that the unique optical properties of liquid crystal elements can be exploited to provide a wide variety of narrow band filtering functions extending over a wide wavelength range from the near ultraviolet to the far infrared. As a representative case, optical filtering action exhibited by 12BAO+mBAO homologous series are discussed.

The liquid crystal sample is filled in 4 micron commercially available polyimide coated homogeneous aligned anti parallel cell. The LC sample is mounted on circular graduated stage of polarizing microscope which is sandwiched between crossed analyzer and polarizer. It may be recalled that the vector n representing the direction of preferred orientation of the molecules in the neighborhood of any point is termed as director.

Its orientation can change continuously and in a systematic manner from point to point in the medium. So, the external forces and fields acting on the liquid crystal can result in a translational motion of the fluid as also in an orientational motion of the director. The director is parallel to the molecules and perpendicular to the transmitted light. The normalization is done with respect to the maximum percentage of light transmitted from the LC cell.

Figure 10.17, represents the application of 12BAO+5BAO and 12BAO+7BAO complexes as band pass filters while the variation of percentage polarized transmission with wavelength for the 12BAO+8BAO complex indicates the usage of it as notch filters in its nematic phase which is clearly portrayed in Figure 10.18.
Figure 10.13 Optical texture of nematic phase of 10BAO+6BAO complex

Figure 10.14 Light modulation of nematic phase of 10BAO+6BAO complex
Figure 10.15 OS action in nematic phase of 10BAO+6BAO complex

Figure 10.16 Light intensity profile as a function of applied stimulus for 9BAO+5BAO complex
Figure 10.17 Filtering action in 12BAO+mBAO complexes (m = 5 and 7)

Figure 10.18 Filtering action in 12BAO+8BAO complex
From Figure 10.19, it is observed that the higher homologues viz., 12BAO+9BAO, 12BAO+10BAO and 12BAO+11BAO complexes show a similar trend of transmission of polarized light which clearly indicates that the visible region is allowed to pass, while the ultraviolet radiation is blocked. Thus these liquid crystal complexes can be used as an effective filter for ultraviolet region of the spectrum.

10.6 CONCLUSION

a) Optical shuttering and field induced transition studies of the mesogenic complexes provides valuable information regarding the influence of applied electric field on micro structural transitions of LC.
b) The threshold voltages obtained for the individual complexes paves way for the better understanding of optical modulation and optical shuttering actions and their corresponding device applications.

c) Filtering action carried out in nematogens makes the phase to be utilized as desirable filter which depends on the magnitude of the wavelength absorbed.