DIVERSIFIED APPLICATIONS OF HYDROGEN BOND LIQUID CRYSTALS

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Abstract: Liquid crystals are extensively utilized in display device technology. Apart from display applications, they can also be used in various optical, electrical applications. Liquid Crystal capacitors can easily replace conventional electrolyte capacitors. Optical data storage is evinced through textural evidence while electrical storage is established by dielectric studies. Optical light filters plays a pivotal role in many electronic applications. Optical filters in visible and infrared region using liquid crystal are discussed. High pass, low pass, notch and band pass filters are explored. Light modulator application of liquid crystal is detailed.

Keywords: Hydrogen bond liquid crystals, capacitors, data storage, filters

1. Introduction

Liquid crystals are most attractive substances. Many researchers [1-10] across the globe contributed towards the isolation and characterization of these materials. Hydrogen bonded liquid crystal (HBLC) form a branch of the thermotropic liquid crystals. Ease of design, simple synthetic procedure and vast applicational potential are the main reasons for the fast growth of HBLC materials. Many types of HBLC are reported [11-15] with various chemical ingredients. The ultimate aim of these materials is aimed for some applicational use [16-24]. Theoretical studies on these materials are also reported [25]. Liquid crystals in display technologies are still in use but the utility of these materials are not confined to it alone. These organic materials exhibit many other applicational viabilities like luminescent [16], light emitting [26-28] properties. Room temperature HBLC mesogens [29] and photo chemical phase transition in properties [30] are available in literature. Our research group is actively engaged [30-40] in the research of various types of HBLC namely identification and characterization of new sm ordering and investigation of Optical, thermal, dielectric studies.

In the present work applications features in hydrogen bonded liquid crystals are discussed. Various above techniques along with necessary experimentation are discussed. The details of the molecular structure of several liquid crystal used are also explained.

2. Experimental

In each of the application, different types of liquid crystals are used. The design and synthetic details are appended in each section separately. Various specific instruments are used in each of the application which are discussed below. General liquid crystal cell construction is explained below. Liquid crystal is filled in to a 10 micron conducting transparent glass cell under vacuum. Silver leads, which act as electrodes are drawn and the LC cell is placed in Instec hot and cold stage, Instee STC is programmed for precise temperature control to an accuracy of ±0.1°C. Agilent 4192A and Wayne Kerr 6500B impedance analyzers are used for dielectric studies. Nikon polarizing microscope is used for textual observation and Nikon image
software system to record, store and retrieve the liquid crystalline textures. ABB Bomem FTIR is used in tandem with MB3000 software for recording the FTIR spectra. Keithley 61/2 digital multi meter is used to measure current, voltage and resistance. All the chemicals are of Sigma Aldrich grade with high purity.

3. Results and discussion

Thermotropic hydrogen bonded liquid crystals applications can be classified as follows:

1. Liquid Crystal capacitors
2. Liquid Crystal memory storage devices
3. Optical filters in the visible region
4. Optical filters - Infra Red region
5. Liquid Crystal light modulator

Each of the above application is detailed in the forthcoming sections

3.1 Liquid Crystal Capacitors

In electronic circuits various types of capacitors are used. Broadly these are divided into various classifications based on their value. If a capacitor value is above 1 micro farad (1µF), it ought to be electrolytic capacitor. More the value of capacitor more charge it can store. Commercially available electrolyte capacitors have many disadvantages. The limitation of these are based on Working Voltage, (WV), Tolerance, (±%), Leakage Current, Working Temperature, (T) and Temperature Coefficient, (TC).

A liquid crystal can replace an electrolytic capacitor. A liquid crystal in its liquid crystalline phase (nematic or any sm phase) can be used in place of a commercial capacitors. The LC cell when filled with a room temperature liquid crystal with sm C* phase, it acts as a capacitor. The value of the capacitor can be varied by altering (increasing/decreasing) the LC cell size. The LC cell is filled with the reported [41] room temperature FLC (S)-2-chloro-3-(4-benzamido acetophenyl)1-(4'-octadecyloxy benzoyl)-benzoato propionate The variation of a liquid crystal capacitance with frequency is noted using Agilent 4192A impedance analyzer. Figure 1 illustrates the variation frequency from 100 KHz to 100 KHz.

![Molecular diagram of a FLC](image)

The variation is noticed to be extremely minimal compared to a commercially available capacitor. The advantages of LC capacitor compared to its conventional electrolytic capacitor are

i. LC capacitors are not bulky and require less physical space
ii. LC capacitors working voltage is very high, it is the dielectric breakdown of the LC material which is always extremely high. Dielectric breakdown of the present liquid crystal occurs approximately at a field of $\pm 35V/\mu m$

iii. Tolerance, the percentage variation of the given value to the experimental value, is almost less than 1%. The commercial counterparts possess tolerance rating from -20% to +80%.

iv. In LC capacitors the variation in capacitance with frequency is as low as 1 to 2%. In the present case the capacitance at 30°C is approximately 0.23nF and is almost invariant within a frequency range of 100 KHz to 200 KHz.

v. The normal working temperature range for most of the LC capacitors is the phase width of the particular phase it is used. In the present case it from 55°C to -10°C.

3.2 Liquid Crystal memory storage devices

Liquid crystals are capable of storing and retrieving data and thus are referred as memory store devices. Conventional electronic devices uses optical, magnetic and semiconductor techniques for memory storage. Liquid crystal uses electrical and optical signal to store data.

3.2.1 Optical storage of data

Reported [42] ferroelectric liquid crystal material composed of ingredients acid dextro tartaric and benzoic acid alkylxy referred as ADT+nBAO (where n varied between 8 to 12) are experimented, the ball and stick models of ADT+12BAO is represented in figure 2.

![Fig. 2. Ball and stick model of ADT+12BAO](image)

The process of memory storage will be discussed for ADT+9BAO. All the other four liquid crystalline complexes namely ADT+8BAO, ADT+10BAO, ADT+11BAO and ADT+12BAO follow the same procedure. ADT+9BAO compound sealed in 10 micron space cell (Instec, USA) by capillary action in its isotropic state. In the all the five liquid crystals, sm X* phase is detected. ADT+8BAO has the onset of sm X* phase at 109.8°C, and the end set is 109.3°C with a total thermal range of 0.6°C. Similarly ADT+9BAO exhibits the onset of sm X* phase at 117.5°C, and the end set is 166.6°C with a total thermal range of 0.9°C. ADT+10BAO possess the onset of sm X* phase at 125.4°C, and the end set is 123.6°C with a total thermal range of 1.8°C. For ADT+11BAO the onset of sm X* phase is observed at 131.2°C, and the end set is 130.6°C with a total thermal range of 0.6°C. For ADT+12BAO the onset of sm X* phase at 125.2°C, and the end set is 120.4°C with a total thermal range of 4.8°C.

The cell filled with liquid crystal is mounted on an Instec HCS-402 and the temperature is controlled by an Instec STC to an accuracy of $\pm 0.1°C$. This is mounted between polar of Nikon polarizing microscope. Two electrical wires are drawn from the liquid crystal cell for electrical contact. It may be noted that the incident light and the applied field both are at right angles to the cell.
The liquid crystal is taken to isotropic state and is observed through eye piece of the microscope for conformation. It is held at isotropic state for 2 minutes for the sample to attain thermal stability. The sample is then slowly cooled at the rate of 0.1°C till a clear Sm X* texture is observed.

External field is applied to the liquid crystal sample in steps of 0.1 volts per micron and the resultant texture is recorded. At a threshold field the memory storage is observed in the sense that the continuous long striations are noticed. Interesting observation is, on withdrawal of the field the original Sm X* texture does not appear. In either polarities same profile of the Sm X* texture are observed and hence both polarities influence the liquid crystal molecules to act as memory storage device. Figure 3a and figure 3b gives the OFF and ON states of the optical memory storage device.

3.2.2 Electrical storage of data

The process of memory storage will be discussed for a reported [43] FLC. The LC cell is filled with RTFLC (figure 1) in a LC cell. This compound exhibit sm C* phase, the onset and end set temperatures are 65°C and -20°C with a thermal span of 85°C. The cell filled with liquid crystal compound is placed in an instec HCS-402 and the temperature is controlled by an Instec STC to an accuracy of ± 0.1°C. Under crossed polar of Nikon polarizing microscope observations are recorded. Two electrical conducting silver wires are drawn from the liquid crystal cell for electrical contact. It may be noted that the incident light and the applied field both are at right angles to the cell.

The liquid crystal is taken to its isotropic state and is detected through eye piece of the microscope for conformation. It is held at isotropic state for 2 minutes for the sample to attain thermal stability. The sample is then slowly cooled at the rate of 0.1°C till a clear sm C* texture is observed.
External stimulus is given to the ferroelectric liquid crystal in steps of 0.1 volts per micron and the resultant permittivity is noted. In either polarities same profile of the permittivity versus field is observed and hence both polarities influence the liquid crystal molecules to act as memory storage device. Dielectric hysteresis as a function of field obtained for electrical memory storage is depicted as figure 4.

3.3 Optical filters in the visible region

The concept of optical filtering action by liquid crystal materials is novel and accurate. Thermotropic liquid crystalline materials are reliable. These materials exhibit various phases and the phase chosen for the optical filtering action is nematic.

Nematic phase is widely used for applicational aspects because the molecules can be easily oriented with applied field.

As reported [44,45] by us alkyloxy benzoic acids are found to exhibit liquid crystal property and hence are mesogenic. When carboxylic acids are reacted with alkyloxy benzoic acids, the resultant yields a liquid crystal with reduced temperatures and enhanced polymorphism. In the present case, various alkyloxy benzoic acids are reacted and compounds with mBAO+nBAO (where m and n varied from 5 to 12) are isolated. The generalized chemical structure is given in figure 5.

![Fig. 5. Generalized chemical structure of mBAO+nBAO](image)

In all the twenty eight HBLC nematic phase is observed, the onset and end set temperatures and the thermal ranges of the nematic phase are discussed below:

For 5BAO+6BAO the onset of nematic phase is 149.5°C and the end set is 93.5°C with a total thermal range of 56°C. Similarly 5BAO+7BAO has the onset of nematic phase at 149.6°C and the end set is 81.3°C with a total thermal range of 68.3°C.5BAO+8BAO exhibits the onset of nematic phase at 145.7°C and the end set at 75.4°C with a total thermal range of 70.3°C. 5BAO+9BAO possess the onset of nematic phase at 142.9°C
and the end set at 136.2°C with a total thermal range of 6.7°C. For 5BAO+10BAO the onset of nematic phase is observed at 140.7°C and the end set at 70.4°C with a total thermal range of 70.3°C. For 5BAO +11BAO and 5BAO+12BAO the onset of nematic phase is at 139.2°C and 135.3°C while the end set is at 62.8°C and 83.4°C with a total thermal range of 76.4°C and 51.9°C respectively.

For 6BAO+7BAO the onset of nematic phase is 148.1°C and the end set is 87.9°C with a total thermal range of 60.2°C. Similarly 6BAO+8BAO has the onset of nematic phase at 145.6°C and the end set is 89.1°C with a total thermal range of 56.5°C. 6BAO +9BAO exhibits the onset of nematic phase at 142°C and the end set at 130.8°C with a total thermal range of 11.2°C. 6BAO+10BAO possess the onset of nematic phase at 142.8°C and the end set at 89.3°C with a total thermal range of 53.5°C. For 6BAO+11BAO the onset of nematic phase is observed at 140.7°C and the end set at 99.5°C with a total thermal range of 41.2°C. For 6BAO +12BAO the onset of nematic phase is at 138.1°C and the end set is observed at 109.2°C with a total thermal range of 28.9°C.

For 7BAO+8BAO the onset of nematic phase is 144.5°C and the end set is 100.5°C with a total thermal range of 44°C. Similarly 7BAO+9BAO has the onset of nematic phase at 139°C and the end set is 130.6°C with a total thermal range of 8.4°C. 7BAO +10BAO exhibits the onset of nematic phase at 141°C and the end set at 102.9°C with a total thermal range of 38.1°C. 7BAO+11BAO possess the onset of nematic phase at 139.9°C and the end set at 107.9°C with a total thermal range of 32°C. For 7BAO+12BAO the onset of nematic phase is observed at 135.6°C and the end set at 119.1°C with a total thermal range of 16.5°C.

For 8BAO+9BAO the onset of nematic phase is 139.8°C and the end set is 133.1°C with a total thermal range of 6.7°C. Similarly 8BAO+10BAO has the onset of nematic phase at 138.8°C and the end set is 119°C with a total thermal range of 19.8°C. 8BAO +11BAO exhibits the onset of nematic phase at 138.9°C and the end set at 115.9°C with a total thermal range of 23°C. 8BAO+12BAO possess the onset of nematic phase at 133.6°C and the end set at 116.3°C with a total thermal range of 17.3°C.

For 9BAO+10BAO the onset of nematic phase is 138.2°C and the end set is 129.3°C with a total thermal range of 8.9°C. Similarly 9BAO+11BAO has the onset of nematic phase at 136.5°C and the end set is 127.9°C with a total thermal range of 8.6°C. 9BAO +12BAO exhibits the onset of nematic phase at 133.3°C and the end set at 122.4°C with a total thermal range of 10.9°C.

10BAO+11BAO has the onset of nematic phase at 138.2°C and the end set is 123°C with a total thermal range of 15.2°C. 10BAO +12BAO exhibits the onset of nematic phase at 135.5°C and the end set at 124.5°C with a total thermal range of 11°C.

11BAO +12BAO exhibits the onset of nematic phase at 135.1°C and the end set at 127.8°C with a total thermal range of 7.3°C.

The cell filled with liquid crystal compound nBAO+mBAO and temperature is mentored by Instec STC to an accuracy of ± 0.1°C. This arrangement is observed under crossed polar of polarizing microscope.

High pass filter is observed in HBLC, 5BAO+6BAO, is shown in figure 6a. X axis is the wavelength while y axis is the normalized intensity of light. Light is filtered up to 5500Å, there by light is allowed to pass. Thus this action is refereed as high pass filtering action.
In figure 6b low pass filter is observed in hydrogen bonded liquid crystal, 6BAO+7BAO, is depicted. X axis is the wavelength while y axis is the normalized intensity of light. Light is allowed to pass up to 5750 Å, thereby light is not allowed to pass. Thus this action is refereed as low pass filtering action.

Figure 6c illustrates notch filter is observed in hydrogen bonded liquid crystal, 8BAO+9BAO. X axis is the wavelength while y axis is the normalized intensity of light. Wavelengths between 4750 Å to 5750 Å are allowed while all other wavelengths are not allowed.

### 3.4 Optical filters in the Infra Red region

Conventional method of filtering action is obtained using solid state integrated circuits comprising of passive and active components. A key difference is that liquid crystal based filters are versatile as there is no internal switching of the transistors. Hence it is understood that the liquid crystal filters does not require any power supply hence power consumption is eliminated and reduced to zero, while the conventional solid state integrated circuits require an additional power supplying component. In the present case filtering action in reported mesogen [42] viz., undecyloxy benzoic acid abbreviated as 11BAO mixed with dextro tartaric acid abbreviated as ADT in 2:1 molar ratio to form a FLC ADT+10BAO is discussed.

#### 3.4.1 Spectra analysis: Band pass filter

The spectra recorded and retrieved from FTIR is a plot between the wave number and percentage of transmission. The ordinate and the abscissa of the plot are converted to frequency and gain. From this plot various types of filters namely, band pass, high pass, low pass and notch filters can be observed. As a representative case the bandpass filter is discussed. Figure 7 illustrates band pass filter obtained through ferroelectric liquid crystal with high frequency (f_H) and low frequency (f_L) cut off along with the stop and pass bands. The band width of filter is observed to be 204±8 GHz with low frequency (f_L) and high frequency (f_H) cut off as 504±4 GHz, to 708±4 GHz respectively.
3.5 Liquid Crystal light modulator

Light modulation is a special property of liquid crystals possessing vast device applications. Light modulation refers to the change in wavelength of the incident light which follows the energy difference pattern. Output devices depending on change in color which dependent on field.

Alkyloxy benzoic acids are found to exhibit liquid crystal property and hence are mesogenic. When carboxylic acids are reacted with alkyloxy benzoic acids, the resultant yields a liquid crystal with reduced temperatures and enhanced polymorphism. In the present case, various alkyloxy benzoic acids are reacted with Malic acid and six HBFLC namely MA+7BAO, MA+8BAO, MA+9BAO, MA+10BAO, MA+11BAO and MA+12BAO are formed as reported by us earlier [46]. The general molecular structure this series is shown in figure 8.

In all the six HBFLC cholesteric phase is observed, the onset and end set temperatures of the cholesteric phase for all the six homologous series along with the optical texture of the cholesteric phase are discussed below: For MA+7BAO the onset of cholesteric phase is 130.3°C and the end set is 84.5°C with a total thermal range of 45.8°C. Similarly MA+8BAO has the onset of cholesteric phase at 140.9°C and the end set is 137.3°C with a total thermal range of 3.6°C. MA+9BAO exhibits the onset of cholesteric phase at 134.5°C and the end set at 124.5°C with a total thermal range of 10.0°C. MA+10BAO possess the onset of cholesteric phase at 134.5°C and the end set at 131.7°C with a total thermal range of 2.8°C. For MA+11BAO the onset of cholesteric phase is observed at 133.1°C and the end set at 130.6°C with a total thermal range of 2.5°C. For MA+12BAO the onset of cholesteric phase is at 131.0°C while the end set is at 126.2°C with a total thermal range of 4.9°C.

The process of light modulation will be discussed for MA+7BAO. All the other five liquid crystalline complexes namely MA+8BAO, MA+9BAO, MA+10BAO, MA+11BAO and MA+12BAO follow the same procedure. MA+7BAO compound is used. This compound exhibit cholesteric phase, the onset and end set temperatures are 130.3°C and 84.5°C with a thermal span of 45.8°C. The cell filled with liquid crystal compound MA+7BAO, the temperature is controlled by an Instec STC. It may be noted that the incident light and the applied field both are at right angles to the cell.
Fig. 8. Variation of wavelength with applied field

The LC in the cell is taken to cholesteric phase and an electric field of strength between 1 to 5 volts/ micron is applied to the cell. The direction of the light as well as the applied electric field to the cell is at right angles. The modulation of the light is observed with increasing applied field and at a threshold value, the light modulation is clearly noticed. External field is applied to the liquid crystal sample in steps of 0.1 volts per micron and the resultant texture is recorded. At a threshold field the light modulation is observed in the sense that the green color of the texture abruptly changes to red color. Interesting observation is, on withdrawal of the field the original color of the cholesteric texture reappears. In either polarities sample profile of the cholesteric texture are observed and hence both polarities influence the light through liquid crystal cell evenly. Figure 8 is a graphical illustration of the variation of wavelength of the light from the LC cell with applied field for MA+7BAO.

4. Conclusion

Utility of thermotropic hydrogen bonded light crystals in various applications is demonstrated. Liquid crystals can be used as capacitors, memory storage devices, Optical filters in the visible region and infrared region and light modulators.

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