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Field induced Optical anisotropy of Nematic Liquid Crystals from Image analysis

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Abstract:- This paper presents the investigation on Electric field induced optical anisotropy of the planar alignment of nematic liquid crystals: 4-n alkyl benzoic acids (nBA, where n = 6,7,8) towards the electro optic device applications. Analysis of microscopic textures of liquid crystals under the application of DC electric field is used for this investigation. It includes the computation of optical anisotropic properties from the textures of samples. As a function DC applied field, textures of the samples in the mesophase region of constant temperature are recorded in three monochromatic image planes. Optical anisotropic properties: Normalized transmittance, Absorption coefficient, Birefringence, Kerr constant and Figure of Merit are computed from the intensities of liquid crystal textures using MATLAB software. Results obtained from this investigation shows that Nematic liquid crystal: heptyl benzoic acid (nBA where n= 7) has high value of birefringence, Kerr constant, FOM and is more suitable material for the various electro optic device applications.

Keywords:- *Optical Anisotropy, Nematic Liquid Crystals, Image Analysis, Fredericksz Transition And Birefringence.*

I. INTRODUCTION

Optical anisotropy is a very important physical property of liquid crystal and plays a vital role in various applications of liquid crystal devices. Liquid crystals exhibit the anisotropy as a function of thermal, electrical ,mechanical and magnetic fields which makes them as a promising materials for device fabrications. Among different types of liquid crystals [1-3], Nematic liquid crystals (NLCs) are of great interest due to their molecular alignment and high anisotropic nature [4],[5]. There were many authors reported the temperature and electric field induced optical anisotropy of nematic liquid crystals from the different experimental set ups and techniques. [6-9]. Still, there is a great research interest to investigate the field induced optical anisotropy of NLCs due to their immensive applications in different electro optic devices besides thermometric devices [10-12]. Such devices: optical shutters, modulators, switches, optical storage devices, displays, mobile phones and temperature sensors. In such devices, as a function of applied field optical anisotropy controls the performance and functioning of material [13-15]. Here in this paper, electric field induced optical anisotropy of NLCs: 4-*n* alkyl benzoic acids (*n*BA, where *n* = 6,7,8) was studied using microscopic texture analysis.

Optical microscopic textures of samples are recorded as a function of DC voltage in the mesophase region of constant temperature. As a function of applied DC voltage, Molecular reorientation causes changes in the sample's textural characteristics. The variations in such textural characteristics are roughness, randomness color, bands or stripes, size, and shape etc. Such features are key points for understanding NLCs ' anis otropic behavior [9],[16],[17] and are useful to compute the optical anisotropic properties : Normalized transmittance, Absorption coefficient, Birefringence, Kerr constant and Figure of Merit (FOM). Qualitative evaluation of liquid crystal material performance towards the device applications is done by the parameters of Birefringence, Kerr constant and FOM. A computational tool MATLAB is used for the purpose of analyzing texture intensity values. As a function of DC applied filed parameters are computed from the microscopic textures of liquid crystals. Obtained results tell the material utilization towards the fabrication of electro optic devices.

II. MATERAILS AND METHOD

Liquid crystals: 4-*n* alkyl benzoic acids (*n*BA where *n* = 6, 8) were purchased from Frinton laboratory, New Jersy, USA. Homogeneous (planar) alignment Indium Tin Oxide coated liquid crystal cell with thickness 5µm are imported from INSTEC company, USA[18]. For measurements, the liquid crystal sample is filled in cell through capillary action. The sample cell is placed on the hot stage of POM for experimental observations. Methodology for sample preparation and recording of the s ample textures as a function of DC voltage has been given in [9],[16],[19]. Here, Meopta Polarizing Microscope (POM) with hot stage and camera attachment was used to record the textures of the samples. Canon EOS Digital REBEL XS/ EOS1000D is a digital single lens reflex camera is used to record the texture images of the samples through the crossed polarizer's of the POM. The recorded color image has a resolution of 3888 x 2592 pixels with 24bit true color pixel tone. The pixel intensities of the each image ranges from 0 to 255 in R, G, and B color tones with wavelengths 635nm, 540nm, and 470nm. On the MATLAB platform [20],[21], computational analy sis of liquid crystal textures which are recorded as function of applied field was performed.

III. THEORY

As a function applied DC field and wavelength, computation of optical anisotropic properties: Normalized transmittance, Absorption coefficient, Birefringence of liquid crystals is defined in terms of textural intensity values in [9],[19],[22]. Other optical anisotropic properties: Kerr constant, Figure of Merit defined from birefringence of the liquid crystals are explained below.

Liquid crystal texture *I(i, j)* is of size m-by-n, of the samples are recorded as function of DC electric field on cooling. *I(i, j)* composed of 'm' pixels in the vertical direction and 'n' pixels in the horizontal direction. Here, *i, j* are horizontal and vertical co-ordinates of the texture image. The total number of pixels in the image is $m * n = N$, $0 \leq i \leq m$, $0 \leq j \leq n$. *N* is total number of pixels of the recorded texture image. The defined properties are

A. Kerr constant

Kerr constant is a measure of strength of the kerr effect in a material. It is defined as ratio of Birefringence of the material to the product of wavelength and the square of the electric field and is given by the equation [23],[24]

$$\Delta n = kE^2\lambda \qquad (1)$$

Where k is kerr constant, Δn is Birefringence, E is applied electric field (in volts) and λ is wavelength.

B. Figure of Merit

Liquid crystal material performance is given by the Figure of Merit (FOM). There are two factors accounts the measurement of FOM. Such as absorption coefficient (α) and Birefringence (Δn) which depends on the wavelength, thickness of the cell [25],[26].

$$\text{Figure of Merit} \quad \text{FOM} = \left[\frac{\Delta n}{\alpha}\right] \qquad (2)$$

IV. RESULTS AND DISCUSSION

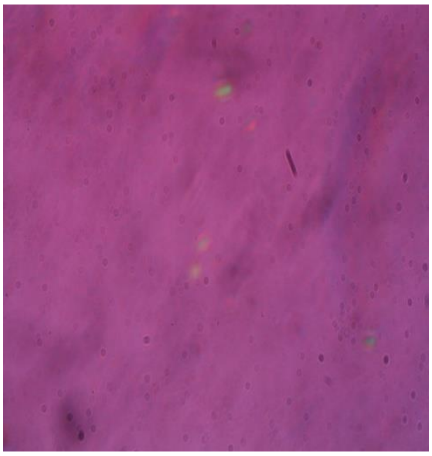
Nematic liquid crystals: 4-*n* alkyl benzoic acids, *n*BA (where *n* =6,7,8) exhibit the Planar textures of Nematic phases on cooling and heating. Textures of the NLC are shown in Fig 1. Mesophase transition scheme on heating is

Hexyl benzoic acid (6BA) $Cr \xrightarrow{100.0^0C} N \xrightarrow{114.8^0C} I$

Heptyl benzoic acid (7BA) $Cr \xrightarrow{104.0^0C} N \xrightarrow{123.0^0C} I$

Octyl benzoic acid (8BA) $Cr \xrightarrow{100.0^0C} N \xrightarrow{111.0^0C} I$

(Cr – Crystal, N-Nematic, I- Isotropic)



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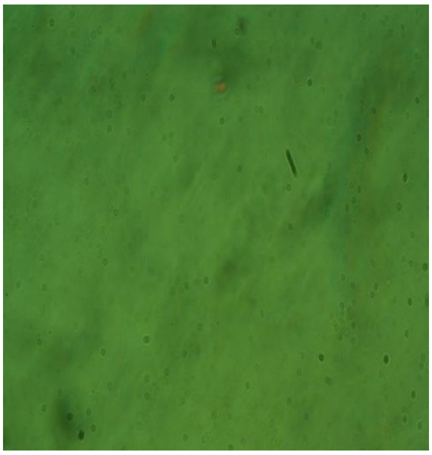

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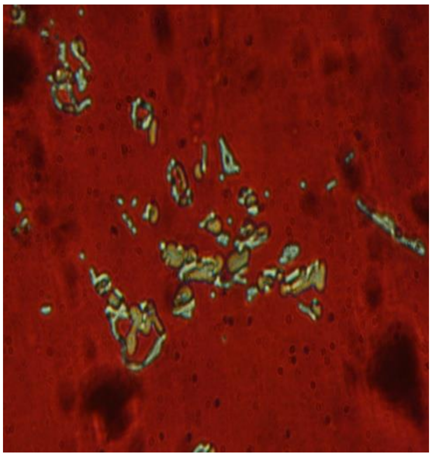

(c)

Fig 1:- Planar Nematic textures of *n*BAs (a) 6BA; (b)7BA;(c) 8BA.

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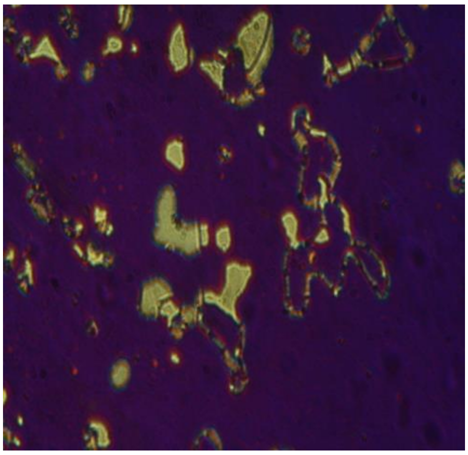
For the given homogeneous alignment of NLCs, DC field was applied perpendicular to the molecular alignment. Field induced optical anisotropic properties of NLCs: *n*BA, are computed in the mesophase region of constant temperature 102^0C for hexyl benzoic acid (6BA), 106^0C for heptyl benzoic acid (7BA) and 104^0C for octyl benzoic acid (8BA) on cooling . As a function of DC voltage, Optical textures of the samples are recorded in monochromatic image planes of Red (635nm), Green(540nm) and Blue(470nm) wavelengths and in true color form. In the field on state, the mesophase order (here nematic phase alignment) of the sample changed in three steps. Such as initiation, orientation and saturation**.** In initial stage or field on stage, the electrical energy is not sufficient to rotate the molecules and there is no change in the textural features of samples. It appears same as textures like when there is no field. After reaching certain voltage, electrical energy is sufficient to rotate the molecules and the molecules are trying to orient along the field direction. This voltage is called threshold voltage (V_{th}) and this effect is known as Fredericksz transition effect [9],[19],[27]. Fredericksz transition is an important phenomenon for homogeneous aligned liquid crystals with positive dielectric anisotropy. Below the threshold voltage(V_{th}), there is no change in the textures of the samples and was shown in Figs 2(a),3(a),4(a). As the field strength is increased from the threshold voltage, orientation of molecules along the field direction takes place [28-30]. On further increasing the field strength, all the molecules are aligned completely in the field direction and get saturates. This was clearly depicted in Figs 2, 3 and 4. From Figs 2,3 and 4, it was observed that, as a function of voltage orientation of the molecules brings the variations in the textural features and these variations can be observed as textural intensity value changes. Analysis of these textural intensity values is useful for computing the field induced optical anisotropic properties of liquid crystals.



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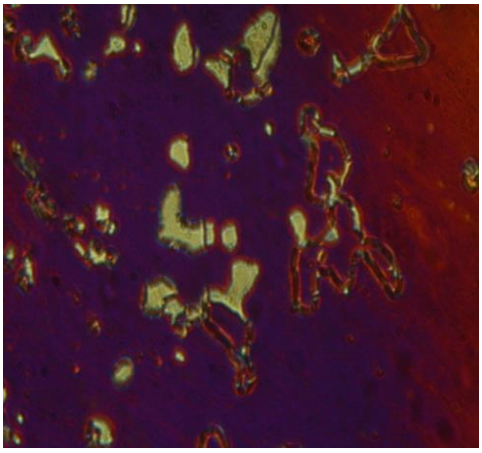

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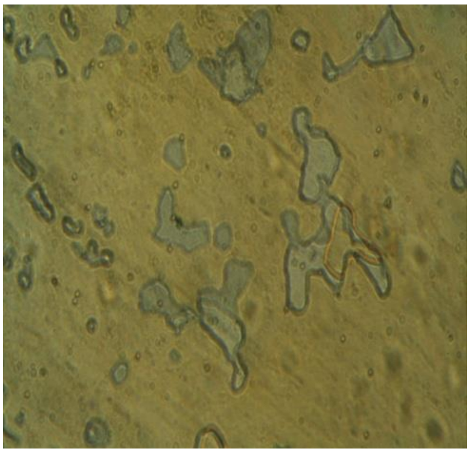

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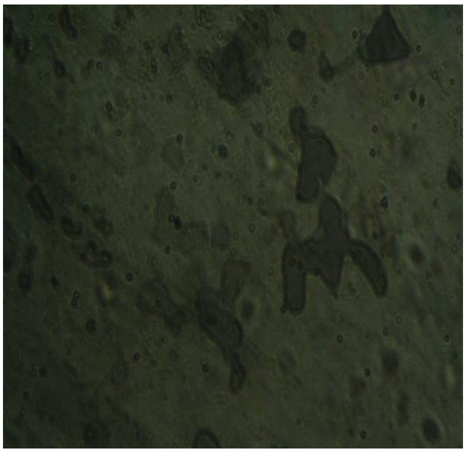

(d)

Fig 2:- Optical textures of homogeneous alignment of nematic liquid crystal *p*-*n* alkyl benzoic acid, where *n* = 6 at temperature 102^0C at (a) 2V, (b) 13V, (c) 15V, (d) 22V.

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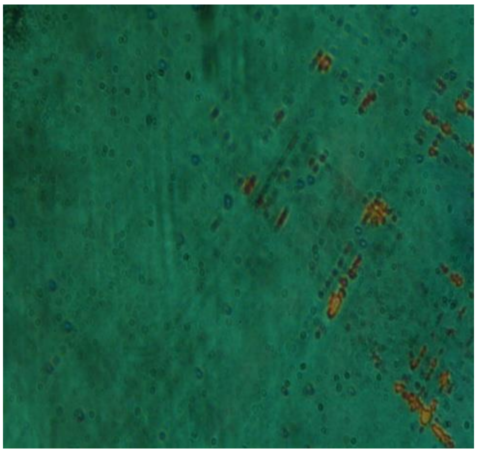

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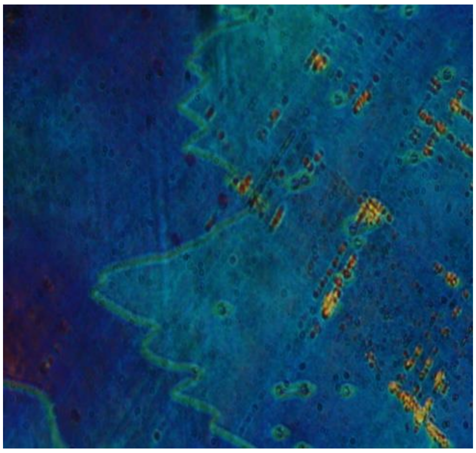

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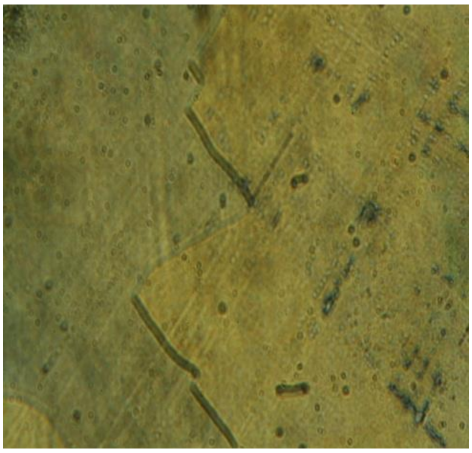

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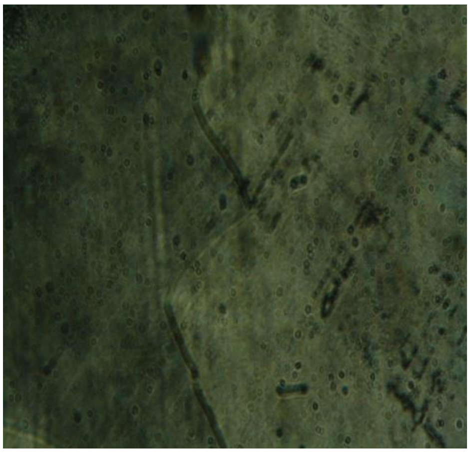
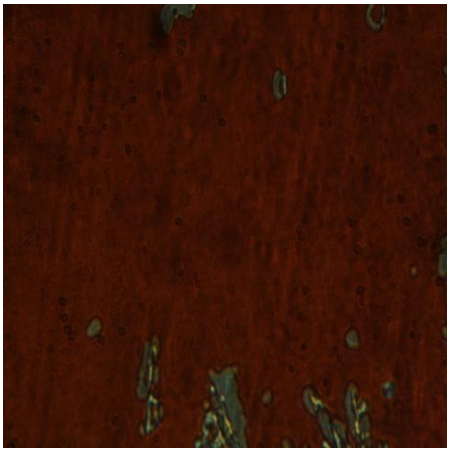


(d)

Fig 3:- Optical textures of homogeneous alignment of nematic liquid crystal *p-n* alkyl benzoic acid, where $n = 7$ at temperature 106^0C at (a) 2V, (b) 11V, (c) 15V, (d) 22V.



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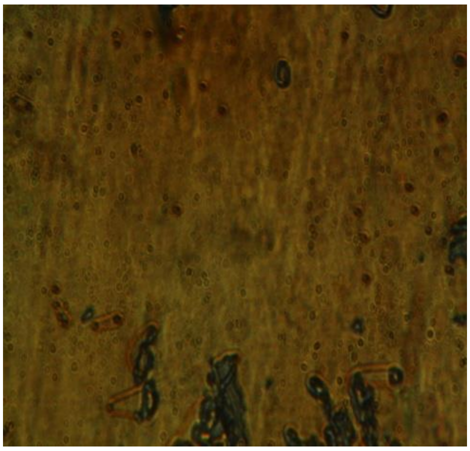

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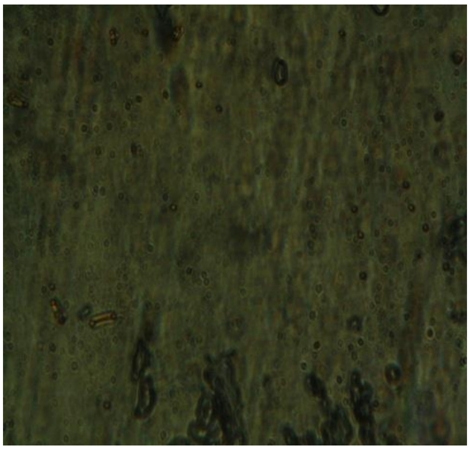
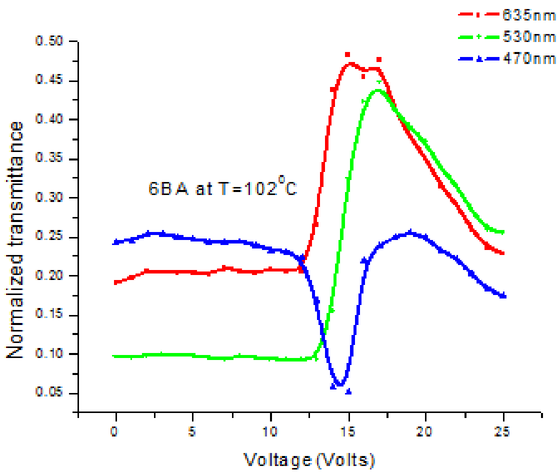


(d)

Fig 4:- Optical textures of homogeneous alignment of nematic liquid crystal *p-n* alkyl benzoic acid, where $n = 8$ at temperature 104^{0}C at (a) 2V, (b) 11V,(c) 15V, (d) 22V.

In mesophasic region of constant temperature, optical anisotropic properties of the NLCs are drawn against the DC voltage and are shown in Figs 5, 6, 7. In all plots, the behaviors of the anisotropic properties vary based on their threshold voltages and wavelengths. They may be similar in some properties of three wavelengths. But they are different for different compounds.



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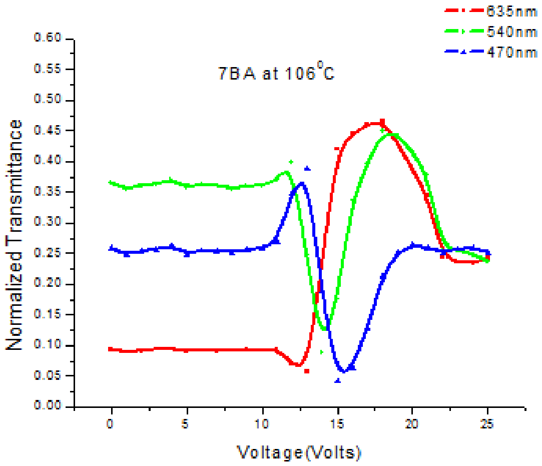

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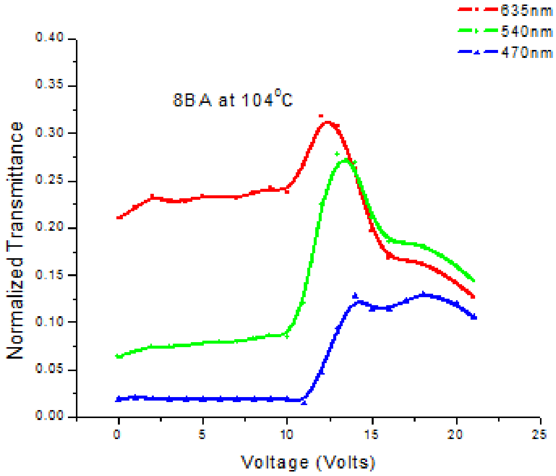

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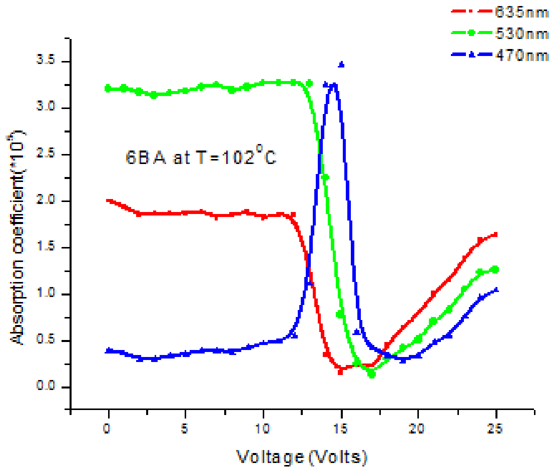
Fig 5:- Normalized transmittance of *n*BAs as a function of voltage (a) 6BA; (b) 7BA; (c) 8BA.



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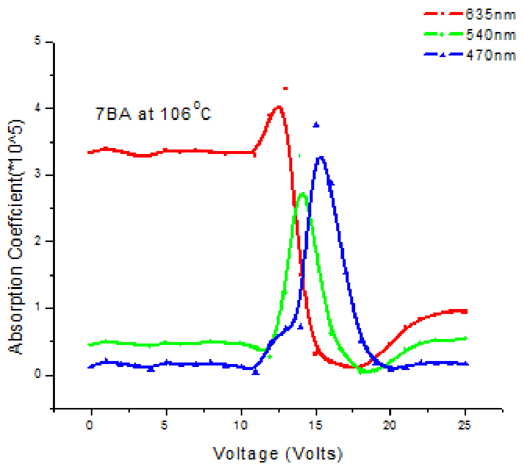

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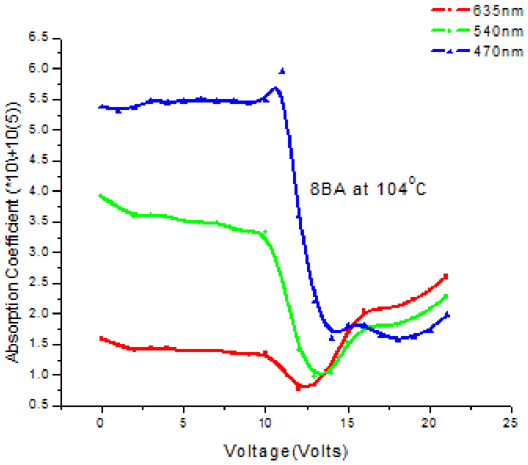
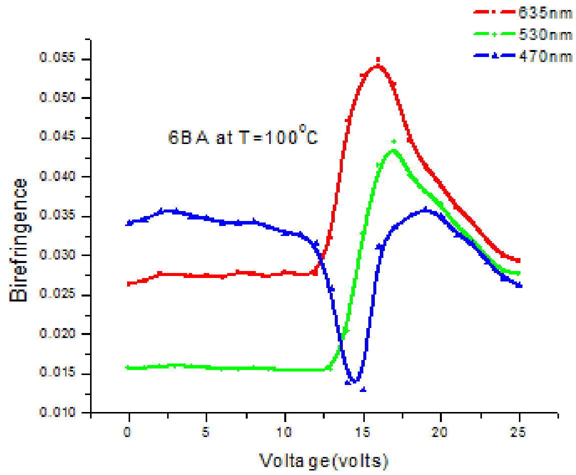


(c)

Fig 6:- Absorpion coefficient of *n*BAs as a function of voltage (a) 6BA; (b) 7BA; (c)8BA.

From Figs 5 and 6, it was observed that Fredericksz Transition (FT) voltage of samples 6BA is 13V, 7BA is 10V, 8BA is 11V. Before Fredericksz Transition (FT) voltage, the values of the normalized transmittance and Absorption Coefficient (AC) of the samples remain same and show the abrupt changes from the FT voltage. In high voltage region, they get saturated to a certain value. The same can be observed wavelengths of Red, Green and Blue color wavelengths. Fig 5 shows that, as function of applied field normalized transmittance increases to its maximum value for Red and Green color wavelengths and get saturated. But, for Blue color wavelength it decreases abruptly to a minimum value, increases to its maximum and then saturated. Similarly, AC of the liquid crystal samples show the vice versa behavior for three wavelengths since AC measures the loss of light. As a function of temperature or voltage transmittance of the samples are inversely proportional to the AC [9],[22]. This was clearly shown in Figs 5, 6. If the voltage exceeds Fredericksz Transition (FT) voltage ($V > V_{th}$), the sample molecules in the liquid crystal cell are tend to align in the direction of field i.e. the planar alignment to the homeotropic alignment transmittance is reduced. Consequently, texture would appear dark in color (not perfect black) [23], [31].This can be observed from Figs 2(d), 3(d) and 4(d).



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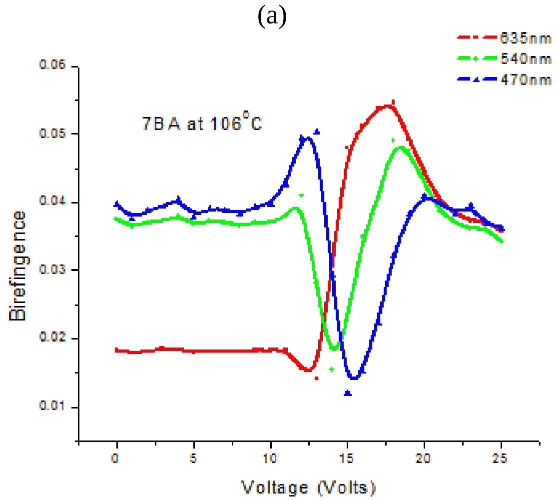

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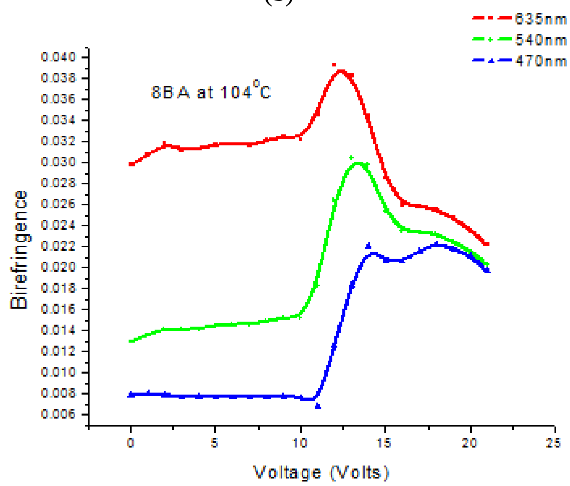
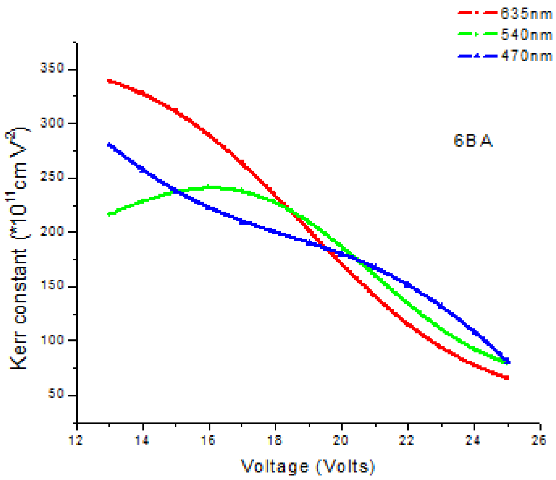


(c)

Fig 7:- Birefringence of *n*BAs as a function of voltage (a) 6BA; (b) 7BA; (c) 8BA.

Birefringence of the given NLCs as a function of voltage was shown in Fig 7. It shows that, there is no change in the value of birefringence before the threshold voltage and shows the sudden changes from the Fredericksz transition voltage. At higher voltages ($V>V_{th}$) birefringence decreases linearly and reaches its steady state value for all three wavelengths. The rate of decrement is less in the high voltage region. Birefringence variations with respect to voltage are different for different wavelengths. From the Fredericksz transition birefringence value increases for Red and Green color wavelengths and get saturated for higher voltages. But, for Blue color wavelength it decreases abruptly to a minimum value, increases to its maximum and then saturated. This can be observed from Fig 7. The variations plotted for birefringence of NLCs are high and linear for all three wavelengths. Therefore NLCs exhibit the tunable birefringence by showing more variations in the birefringence values of each wavelength with linearity. So, the compounds *n*BAs *n*=6, 7, 8 are more suitable for electro optic device applications. Other optical anisotropic properties given in (1),(2) derived from the birefringence values and they are Kerr constant and Figure of merit.



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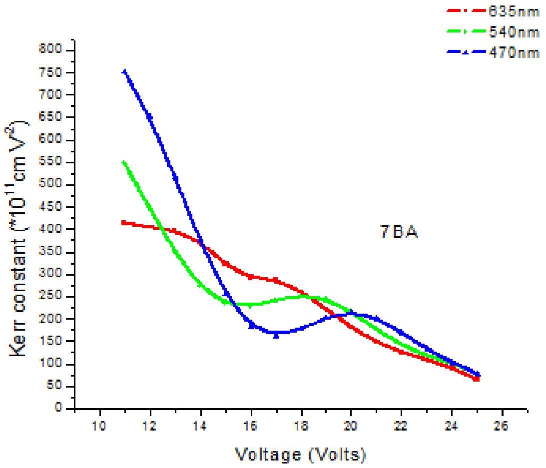

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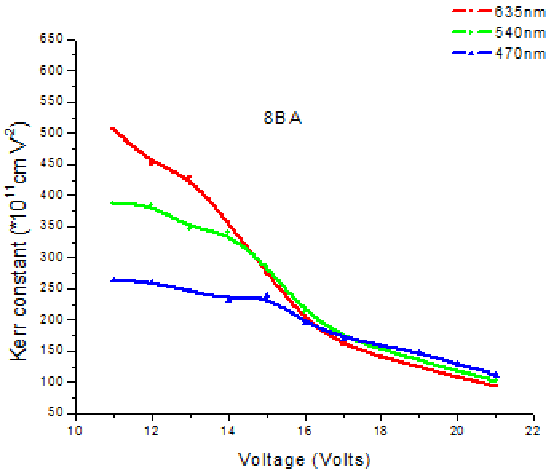
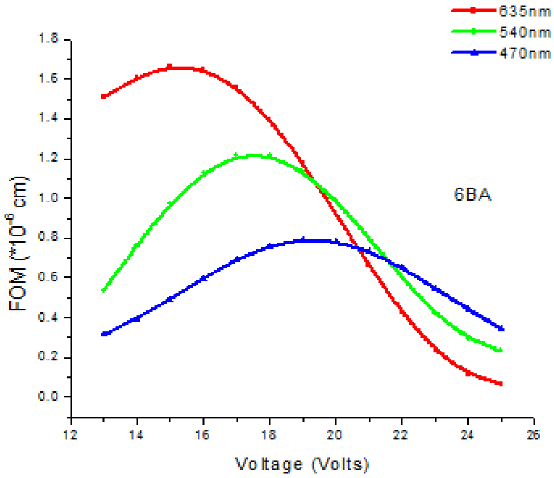


(c)

Fig 8:- Kerr constant of *n*BAs as a function of voltage (a) 6BA; (b) 7BA; (c) 8BA.



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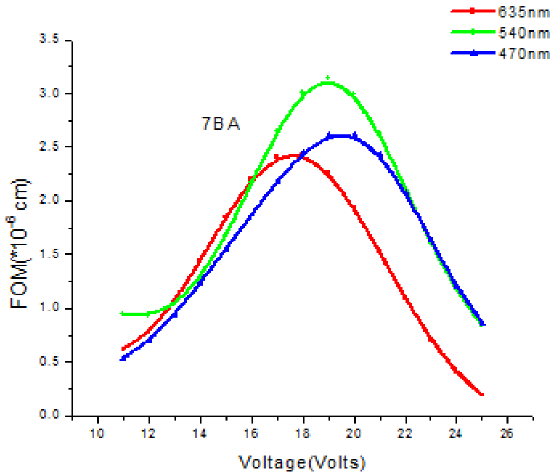

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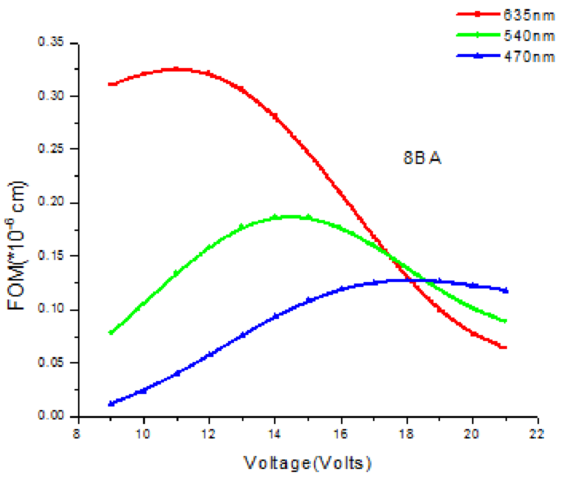

(c)

Fig 9:- Figure of Merit of *n*BAs as a function of voltage (a) 6BA; (b) 7BA; (c) 8BA.

The plots of the Kerr constant and Figure of merit are shown in Figs 8 and 9. Fig 8 shows the Kerr constants of NLC samples at three wavelengths. In low field region, the value of Kerr constant is high and decreases linearly with increasing voltage ($V>V_{th}$) for all three wavelengths. Generally, in low voltage region birefringence of the samples give the higher values of kerr constant and allows maximum transmission. In high voltage region all the molecules tend to align in the field direction (i.e. homogeneous alignment to homeotropic alignment) and allow less transmission of light from the sample which results the lower values of birefringence (pictorically shown in Figs 2,3,4 and Figs 5,7). Therefore the values of Kerr constant are also less in high voltage region. Fig 9 shows the FOM of the NLCs sample as a function of voltage. For all three wavelengths the values of FOM decreases with increasing voltage get saturated to minimum value at higher voltages. The rate of decrement is less in the high voltage region.

Obtained results show that, NLC 7BA has lower threshold voltage, high value of birefringence, Kerr constant and FOM value compared to the compounds 6BA,8BA. Large induced birefringence, higher values of Kerr constant and FOM play a key role for lowering the operation voltage and for reducing the response time of the devices. Low operational voltage and Fast response time are the attractive features of the material for device fabrication. Therefore compound heptyl benzoic acid (nBA where *n*= 7) is more suitable material for the fabrication of electro optic devices like displays, optical switches and modulators.

V. CONCLUSION

Field induced optical anisotropic properties of the nematic liquid crystals: 4-*n* alkyl benzoic acids (*n*BA, where *n* = 6,7,8) are successfully investigated using image analysis technique. Nematic liquid crystal: heptyl benzoic acid has larger induced birefringence, high values of Kerr constant and FOM. Compound heptyl benzoic acid (nBA where *n*= 7) is more suitable material for the fabrication of electro optic devices compared to the compounds hexyl benzoic acid(6BA) and octyl benzoic acid(8BA).

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