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Effect of Ferroelectric Nanopowder on Electrical and Acoustical Properties of Cholesteric Liquid Crystal

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ABSTRACT

The composite materials based on nanopowder dispersed liquid crystals are important both from fundamental research and device applications due to their unique properties such as improvement in various properties like electrical, optical, thermal, energy storage and spontaneous polarization etc. The proper selection of nanoparticle and its size which to be dispersed in particular liquid crystals is very important for a particular application. In the present study, a ferroelectric nanopowder of Barium Titanate (BaTiO₃) was dispersed in cholesteric liquid crystal and the same was confirmed by Fourier Transform Infrared (FTIR) Spectroscopy. The various acoustical properties like ultrasonic velocity, density, Adiabatic Compressibility, Rao Constant, Wada Constant and Acoustic Impedance were investigated by ultrasonic interferometer at room temperature at fixed frequency. The dielectric constant was determined by Precision Impedance Analyzer. In addition to these investigations, particle size and surface area were also measured. Our investigation shows enhanced in dielectric and acoustical properties which may be useful for device applications extensively in microelectronics, low cost- photovoltaic devices, and custom-shaped containers possibly applied as a coating.

1. Introduction

Liquid Crystals (LCs) are soft condensed matters which can flow like conventional liquids and also have properties of crystalline solids. They play vital role in modern technology due to their photonics and display applications like optical imaging, organic light emitting diodes, erasable optical disks, light modulators, full color electronic slides for computer aided design, optical antenna etc. [1-4]. However, drawbacks such as limited temperature range, slow response to external stimuli and degradation over longer periods prevent LCs from utilization to their full potential, for various applications. In order to overcome or minimize these drawbacks, different approaches were explored by scientific community based on technological applications. Out of all these approaches, it was found that when a nanomaterial is dispersed in LC, there are no significant structural distortions as these materials combine order and mobility at nanoscale scale and hence appear as a perfect candi-
date for functional composites[5-13].

The investigation performed by scientific community confirms that the dispersion of nanoparticle into LC has improved properties like polarization, response time, operating voltage and conductivity. The composite material also exhibits property of strong surface plasmon resonance due to the collective oscillation of conduction electrons. Therefore, dispersion of nanoparticles in liquid crystals can give rise to the tuning various properties[14-19].

The advantage of dispersing ferroelectric nanoparticle over other nanoparticle is that they show more alignment in the direction of LC molecules for better electrical, optical, acoustical response. In addition with this, the anisotropic nature of these nanoparticle make them suitable candidate for variety of applications. The idea of dispersing ferroelectric nano-particles to LC emerges by the work by de-Gennes and Brochard. They found that the sensitivity to a magnetic field could theoretically be increased by adding ferromagnetic nanoparticles to nematic liquid crystals [20-24]. The ferroelectric particles have a strong permanent dipole which will align the LC molecules locally with the particles which will be transmitted to the rest of the bulk via weak inter-particle. Various researchers have reported enhancement in optical, structural and thermal properties of liquid crystal after dispersing nanoparticles, however the effect of ferroelectric nanopowder on cholesteric LC is rarely reported [9,10,19-31].

In the present study we have dispersed ferroelectric nanopowder of Barium Titanate (BaTiO3) in cholesteric liquid crystal and its electrical and acoustical properties were investigated. We have also examined particle size and surface area of pure and nono-particle dispersed LC. The materials used in this work were procured from Sigma Aldrich and no further purification was performed. The ferroelectric nanopowder of Barium Titanate (BaTiO3) was dispersed in cholesteric liquid crystal by ultrasonication a technique which is reported earlier [32].

2. Results and Discussion

2.1 Dielectric Measurements

Dielectric properties of pure LC and composite material were studied in terms of frequency using Precision Impendence Analyser (Wayne Kerr 6500B,) by applying AC voltage at constant amplitude [35]. The variation of dielectric constant with frequency for pure and nanopowder dispersed LC is shown in Figure 1.

![Figure 1. Variation of Dielectric Constant with frequency for pure and nanopowder dispersed LC](image)

The dielectric constant increases when nanopowder of BaTiO3 is dispersed in LC, which indicates in increase in electric flux density and conductivity. The dielectric constant increases due to the increase of space polarization. The enables the composite material to hold large quantity of electric charge for longer period of time and as also increases the capacity to store energy.

2.2 Determination of Specific Surface Area and Particle Size

The specific surface area and particle size were measured by BET Nitrogen adsorption. The specific surface area gives information about porosity, pore size distribution, shape, size, and roughness of the material under investigation. The specific surface area of pure LC was found 0.685 m³gm whereas for manpowder dispersed LC it was found as 0.725 m³gm. The particle size plays an important role in various physical properties such as viscosity, heat and mechanical behavior and provides information about dispersion, solubility, nucleating efficiency, and optical properties of materials. The particle size of pure LC was found as 9.73 micron whereas for manpowder dispersed LC it was found 6.13 micron. The particle size reduction may be due to increasing the exposure of weak soluble by increasing surface area which improves the dissolution rate.

2.3 Measurement of Acoustical Parameter

These investigations were performed by Ultrasonic Interferometer (Mittal Enterprises) at room temperature with accuracy ±0.1ms⁻¹. For these investigations, ultrasonic wave of frequency 2MHz are generated by quartz crystal and allowed to reflect by another metallic plate which is kept parallel to it. The separation between these two plates is adjusted such that it is integral multiple of the waves formed in the medium which gives acoustic resonance.
Due to this, the current of anode becomes maximum and readings were recorded \[7,23-24,31-33\]. The various acoustic parameters were investigated which are shown in Table-2.

**Table 2. The Different Acoustic Parameters for Pure and nanopowder dispersed LC**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Density ( \rho ) ( \text{gm/ml} )</th>
<th>Velocity ( \text{m/s} )</th>
<th>Adiabatic Compressibility ( \beta )</th>
<th>Rao Constant ( R )</th>
<th>Wada Constant ( W )</th>
<th>Acoustic Impedance ( Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toluene</td>
<td>0.87</td>
<td>1310</td>
<td>6.62 x 10^{-10}</td>
<td>1.14</td>
<td>2.18</td>
<td>1.14 x 10^{6}</td>
</tr>
<tr>
<td>Pure LC</td>
<td>0.91</td>
<td>1260</td>
<td>6.49 x 10^{-10}</td>
<td>5.85</td>
<td>11.7</td>
<td>1.22 x 10^{6}</td>
</tr>
<tr>
<td>Nanopowder Dispersed LC</td>
<td>2.14</td>
<td>1280</td>
<td>2.85 x 10^{-10}</td>
<td>1.18</td>
<td>2.18</td>
<td>2.74 x 10^{6}</td>
</tr>
</tbody>
</table>

The Rao Constant and Wada constant changes due to increase in velocity of nanopowder dispersed LC sample. The increasing in acoustical parameters suggests the increase in molecular density. The decrease in Adiabatic Compressibility indicates enhancement in degree of association among a liquid crystal and the significant structural after dispersing ferroelectric nanopowder in cholesteric liquid crystal. The increase in Acoustic Impedance suggests that molecular interactions after dispersing ferroelectric nanopowder in cholesteric liquid crystal are associative in the nature \[34\].

### 2.4 Fourier Transform Infrared Spectroscopy

**Figure 2. FTIR Spectrum of Pure LC**

**Figure 3. FTIR Spectrum of nanopowder dispersed LC**

FTIR study indicates that the absorptions intensities in doped liquid crystals are reduced due to strong interaction of nanopowder with LC particles and new peaks emerging at 1400 cm\(^{-1}\) - COO group, 3000 cm\(^{-1}\) - 3100 cm\(^{-1}\) indicating C-H stretching 3478 cm\(^{-1}\) indicating C=O stretching due to strong presence of BaTiO\(_3\). Thus confirms the formation of nano composites of LC with BaTiO\(_3\).

### 3. Conclusions

(1) The effect of dispersing ferroelectric nanopowder of BaTiO\(_3\) into cholesteric LC has been studied using acoustical and electrical measurements. The sensitivity of LC is enhanced after dispersing ferroelectric nanopowder which increases the performance of the LC.

(2) We observed that the ultrasonic velocities are lower in pure LC solution and increases after dispersing ferroelectric nanopowder which confirm greater association of molecules. Ultrasonic velocity and hence adiabatic compressibility are structure depended properties which in turn are related to interlayer compelling and molecular orientation in the layer.

(3) This indicates that nanopowder dispersed LC are very useful in futuristic applications like device applications extensively in microelectronics, low cost- photovoltaic devices, and custom-shaped containers possibly applied as a coating.

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