Ultrasonic Study of Polymer Dispersed Liquid Crystal

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Abstract: Polymer dispersed liquid crystals (PDLCs) are composite materials in which liquid crystalline material is dispersed with a polymer matrix to form micron-sized droplets. PDLCs have variety of electro optic applications ranging from display to light shutters. In the present study we have dispersed two different monomers in the Cholesteric liquid crystal (CLC). We have measured the velocity of ultrasonic wave of 2MHz for CLC as well as both PDLCs as a function of temperature. We have also measured density at those temperatures. From the experimental data various thermo acoustical parameters such as acoustic impedance (Z) and adiabatic compressibility (β) have been evaluated. The comparison of the results of CLC and PDLCs is used for understanding the change in the molecular structure of CLC after doping.

Keywords: Polymer dispersed liquid crystals (PDLCs), Cholesteric Liquid Crystal (CLC), ultrasonic velocity (V), acoustic impedance (Z), adiabatic compressibility (β).

1. Introduction

Liquid crystals are compounds that display order in the liquid state above the melting temperature and below the mesogenic isotropic temperature. Polymer dispersed liquid crystal (PDLC) systems are promising novel materials for their potential applications as reflective displays, electrically controllable light shutters and holographic gratings [1–7]. PDLCs are usually composed of micronized domains of liquid crystals randomly dispersed in a polymer matrix and the LC domains are usually in the form of droplets. The sizes of the LC domains are usually comparable to the wavelength of visible light and this special feature enables PDLC films to be used as light control devices. The morphology of PDLCs is quite diverse and depends on the LC concentration, the cure temperature, the properties of the polymer and the liquid crystals and other experimental conditions [8–10]. PDLC films can be prepared by four different techniques namely Microencapsulation, Thermally Induced Phase Separation (TIPS), Solvent Induced Phase Separation (SIPS) and Polymerization Induced Phase Separation (PIPS) [7, 8, and 9]. Related work shows that the liquid crystal doped with polymer as well as monomer enhances physical as well as optical properties of the material which improves the thermal and mechanical stability of thermo optical devices [10, 11]. The ultrasonic waves are waves of frequencies more than 20 KHz. These waves have many applications in various fields such as basic science, medical science, forensic science, space research etc. The previous study shows that the study of molecular interactions using ultrasonic wave provides valuable information regarding internal structure, molecular association etc [12,13,14,]. In the present study thermo acoustical parameters of pure Cholesteric liquid crystal and PDLC have been studied. The comparison of results is useful for understanding the change in the molecular structure of CLC after doping.

2. List of Chemicals and sample preparation

In the present study Cholesteric liquid crystal (CLC) was dispersed with two different monomers to form polymer dispersed liquid crystal. The CLC in the present study, Cholesteryl Myristate (LC) is a thermotropic liquid crystal whose properties change with the change in temperature. The monomer M₁, Ethylene Glycol Dimethacrylate (EGDMA) is a water-insoluble difunctional methacrylic monomer employed as a cross-linking agent or a low viscosity reactive diluent. The monomer M₂, 2-ethyl hexyl acrylate(2eha) is an acrylate monomer. It is a clear liquid which is not soluble in water and completely soluble in alcohols and ethers. It is easily miscible with other organic solvents and is readily polymerized with monomer molecules to create polymer chains. Both the monomers were dispersed in Cholesteryl Myristate (LC) by encapsulation method.

3. Experimental Techniques

Measurement of velocity of an ultrasonic wave is done using multifrequency interferometer by Mittal enterprises. The temperature range of this instrument is from room temperature to 200°C. The arrangement of oil bath and display is as shown in Fig.1. It is provided with digital micrometer to avoid error in the measurement.
For density measurement we used capillary method. The amount of 0.1gm pure CLC or PDLCs was mixed in 10ml of solvent and the height of the solution raised in the capillary tube is measured using travelling microscope. Using the radius of the bore of the tube(r), the volume of the solution was determined at different temperatures. Similarly the mass at different temperatures is measured using analytical microbalance. The digital thermometer (Model 305) with K-type thermocouple as a temperature sensor is used for accurate temperature measurement. The mica-band heater (from HBCSE) along with variac is used for changing the temperature of the solution. The digital thermometer and mica-band are as shown in Fig.2.

4. Results and Discussion

The thermotropic liquid crystals change its phase with change in temperature, the temperatures at which it changes its phase is called phase transition temperature (PTT). The phase transition temperatures of all the samples were measured by Differential Scanning calorimetry. The values of phase transition temperatures for all the three samples are given in table 1.

5. Phase Transition Temperatures:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Heating PTT</th>
<th>ΔH J/g</th>
<th>Cooling PTT</th>
<th>ΔH</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLC</td>
<td>45.19</td>
<td>-8.44</td>
<td>71.49</td>
<td>34.09</td>
</tr>
<tr>
<td></td>
<td>79.12</td>
<td>-0.45</td>
<td>76.05</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>84.59</td>
<td>-0.35</td>
<td>84.59</td>
<td>-0.28</td>
</tr>
<tr>
<td>CLC + M1</td>
<td>44.88</td>
<td>-3.99</td>
<td>71.38</td>
<td>-18.28</td>
</tr>
<tr>
<td></td>
<td>78.61</td>
<td>-0.59</td>
<td>77.21</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>84.15</td>
<td>-0.34</td>
<td>83.01</td>
<td>0.28</td>
</tr>
<tr>
<td>CLC + M2</td>
<td>70.84</td>
<td>-63.63</td>
<td>42.61</td>
<td>-0.12</td>
</tr>
<tr>
<td></td>
<td>78.49</td>
<td>-1.86</td>
<td>76.64</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>84.02</td>
<td>-1.23</td>
<td>77.21</td>
<td></td>
</tr>
</tbody>
</table>

The formulae used in the present work:
- The ultrasonic velocity \( U = \frac{2 \times D \times F}{n - 1} \) decay.
Where: \( D \) = Distance of micrometer screw for ‘n’ rotations

\[ F = \text{Frequency of the ultrasonic wave} \]

- Density \( \rho = \frac{\text{Mass}}{\text{Volume}} \)
- \( \text{Acoustic Impedance} = \rho \times U \)
- Adiabatic compressibility \( = (\rho \times U^2)^{-1} \)

The measurements for mass and volume of the solvent are taken. The height of the solvent in the capillary tube remained unchanged for all the temperatures whereas there is negligible change in the mass of the solvent at some temperatures. All the three solutions viz LC, LC+M1 and LC+M2 showed remarkable change in height as well as mass. The readings given in the present study are of the solutions.

The results for ultrasonic Velocity and density are given in table 2.

<table>
<thead>
<tr>
<th>Temp.</th>
<th>Ultrasonic Velocity</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LC</td>
<td>LC+M1</td>
</tr>
<tr>
<td>30</td>
<td>1444</td>
<td>1426</td>
</tr>
<tr>
<td>35</td>
<td>1432</td>
<td>1420</td>
</tr>
<tr>
<td>40</td>
<td>1426</td>
<td>1414</td>
</tr>
<tr>
<td>45</td>
<td>1422</td>
<td>1411</td>
</tr>
<tr>
<td>50</td>
<td>1419</td>
<td>1405</td>
</tr>
<tr>
<td>55</td>
<td>1416</td>
<td>1404</td>
</tr>
<tr>
<td>60</td>
<td>1412</td>
<td>1405</td>
</tr>
<tr>
<td>65</td>
<td>1408</td>
<td>1398</td>
</tr>
<tr>
<td>70</td>
<td>1392</td>
<td>1378</td>
</tr>
</tbody>
</table>
The impedance as well as the adiabatic compressibility for impedance vs. temperature and adiabatic compressibility vs. range of 70°C to 90°C we have concentrated in the range of 70°C to 90°C for the graphical analysis.

The results for ultrasonic Impedance and Adiabatic compressibility are given in table 3.

### Acoustic Impedance and Adiabatic compressibility:

<table>
<thead>
<tr>
<th>Temp.</th>
<th>Ultrasonic Impedance</th>
<th>Adiabatic compressibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LC</td>
<td>LC+M&lt;sub&gt;1&lt;/sub&gt;</td>
</tr>
<tr>
<td>30</td>
<td>524678.0784</td>
<td>535232.0225</td>
</tr>
<tr>
<td>35</td>
<td>545135.7979</td>
<td>53179.7288</td>
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<tr>
<td>40</td>
<td>569554.8485</td>
<td>529311.9197</td>
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<tr>
<td>45</td>
<td>572427.6422</td>
<td>521442.0086</td>
</tr>
<tr>
<td>50</td>
<td>578422.3218</td>
<td>516085.6616</td>
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<tr>
<td>55</td>
<td>585468.0009</td>
<td>512251.0232</td>
</tr>
<tr>
<td>60</td>
<td>607971.8028</td>
<td>503434.4226</td>
</tr>
<tr>
<td>65</td>
<td>613787.8349</td>
<td>505224.0023</td>
</tr>
<tr>
<td>70</td>
<td>613320.074</td>
<td>501339.6414</td>
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<tr>
<td>75</td>
<td>625670.8579</td>
<td>497173.6755</td>
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<tr>
<td>80</td>
<td>624099.4903</td>
<td>491826.1111</td>
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<tr>
<td>85</td>
<td>627372.9957</td>
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<tr>
<td>90</td>
<td>645756.6187</td>
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<td>95</td>
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<tr>
<td>100</td>
<td>644985.9797</td>
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<tr>
<td>105</td>
<td>60856.7984</td>
<td>481632.678</td>
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<tr>
<td>110</td>
<td>606385.1737</td>
<td>497044.4762</td>
</tr>
<tr>
<td>115</td>
<td>592885.623</td>
<td>498550.6193</td>
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<tr>
<td>120</td>
<td>605902.1888</td>
<td>498219.2377</td>
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<tr>
<td>125</td>
<td>628080.6382</td>
<td>498754.7284</td>
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<tr>
<td>130</td>
<td>618046.2108</td>
<td>502733.4445</td>
</tr>
<tr>
<td>135</td>
<td>54612.8246</td>
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<td>140</td>
<td>523486.1847</td>
<td>501736.2634</td>
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<tr>
<td>145</td>
<td>73650.6699</td>
<td>496864.7589</td>
</tr>
<tr>
<td>150</td>
<td>912632.3945</td>
<td>497201.9699</td>
</tr>
<tr>
<td>155</td>
<td>937984.3816</td>
<td>496323.8492</td>
</tr>
</tbody>
</table>

The impedance as well as the adiabatic compressibility for all the samples show change in the behavior near phase transition temperatures. Though the temperature range starts from the room temperature we have concentrated in the range of 70°C to 90°C for the graphical analysis. The graph of ultrasonic velocity vs temperature, acoustic impedance vs. temperature and adiabatic compressibility vs. temperature are as given in Fig.3, Fig.4 and Fig.5 respectively.
From Fig.3, Fig.4 and Fig.5 it is clearly evident that all the three samples show change in behavior near PTT. Also, the change in the ultrasonic velocity, acoustic impedance and adiabatic compressibility is more for PDLC-LC+M1. With change in temperature, the translational and orientational orders of the constituent molecules of LC and PDLCs change. These changes are affected by many factors. One of them can be the specific forces between the molecules viz hydrogen bonds. The physical intermolecular forces including electrostatic forces between charged particles and between a permanent dipole and so on also may change the order. Also the induction forces between a permanent dipole and induced dipole, the forces of attraction and repulsion between nonpolar molecules may affect the order. Similarly the structural characteristics of the composition arising from geometrical fitting of one component into other structure due to difference in shape and size also may change the order. These microscopic changes change the internal pressure. As Adiabatic compressibility of a fluid is a measure of the relative volume change of the fluid as a response to a pressure change, the change in the structural arrangement in the neighborhood of constituent ions affects the value of adiabatic compressibility. In comparison with LC, LC+M2 Adiabatic compressibility of LC+M1 is less indicating more structural changes in it. Also, the resistance to the ultrasonic wave ie acoustic impedance is more in the same sample.

6. Conclusion

We determined the elastic properties of polymer dispersed liquid crystals as a function of external parameter such as temperature using Ultrasound waves. The ultrasonic velocity (V), acoustic impedance (Z), adiabatic compressibility (\(\beta\)) of LC, LC+M1 and LC+M2 were measured in order to understand their molecular dynamics and optical transmission properties. The acoustic waves change the optical axis of a LC system thereby changing the transmitted light intensity. LC realignment based on the acousto-optic effect has many valuable applications such as imaging, medical diagnostics, flat panel displays and in windows as sun-roofs for automobiles.

7. Acknowledgement

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References