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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 thermooptical 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 M_1, Ethylene Glycol Dimethacrylate (EGDMA) is a water-insoluble diffunctional methacrylic monomer employed as a cross-linking agent or a low viscosity reactive diluent. The monomer M_2, 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 200^0C.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.

Figure 1

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.

Figure 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 Scanninig calorimetry. The values of phase transition temperatures for all the three samples are given in table 1.

5. Phase Transition Temperatures:

Table 1

Sample	Heating		Cooling	
	PTT	ΔH J/g	PTT	ΔH
CLC	45.19	-8.44		
	71.49	-13.91	34.09	0.08
	79.12	-0.45	76.05	0.64
	84.59	-0.35	84.59	-0.28
CLC + M1	44.88	-3.99		
	71.38	-18.28	44.88	-0.37
	78.61	-0.59	77.21	0.40
	84.15	-0.34	83.01	0.28
CLC + M2	70.84	-63.63	42.61	-0.12
	78.49	-1.86	76.64	0.31
	84.02	-1.23	77.21	

The formulae used in the present work:

- The ultrasonic velocity $U = \frac{2 \times D \times F}{n-1}$

  Where: D=Distance of micrometer screw for 'n' rotations

  F=Frequency of the ultrasonic wave
- Density $\rho = \frac{\text{Mass}}{\text{Volume}}$

  Where: Volume=$\pi r^2 h$
- 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+M_1 and LC+M_2 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.

Ultrasonic Velocity and Density:

Table 2

Temp.	Ultrasonic velocity			Density		
	LC	LC+M_1	LC+M_2	LC	LC+M_1	LC+M_2
30	1444	1426	1438	327.3179705	367.9369414	374.2921
35	1432	1420	1426	333.2141684	383.9111265	372.875
40	1426	1414	1420	339.6688383	402.7969226	370.3605
45	1422	1411	1416	331.1404477	405.5617592	368.25
50	1419.5	1408.5	1413.5	340.8945786	410.6654752	365.1119
55	1416	1404	1408	348.658088	417.0000007	363.8146
60	1412	1400.5	1402	352.1112591	434.110534	362.5845
65	1408	1398	1400	352.4782394	439.0470922	360.8743
70	1392	1378.5	1394	354.4847569	444.9184432	359.6411

72	1388	1355.5	1384	357.1959214	460.1039158	359.2297
74	1380	1352	1372	359.2566671	461.5824633	358.4738
76	1375	1346.5	1366	359.4578139	466.1960606	357.2376
77	1361	1337	1347	360.1517479	482.9892436	356.4127
78	1359	1332.5	1346	361.5476849	484.654623	356.0671
79	1317	1310.5	1315	362.6683868	492.1671865	357.9623
80	1348	1341	1344	356.3159577	450.3108116	358.3536
81	1356	1360	1352	359.5720145	445.8699807	367.6364
82	1351	1351.5	1351	360.9711274	438.6871055	369.0234
83	1342	1326.5	1336	375.5853431	456.156946	372.9186
84	1303	1342	1325	382.554968	468.0183593	376.4187
85	1339	1338	1337	378.399228	462.1870036	377.9158
86	1332	1330	1335	388.6904204	410.8367102	378.1481
88	1329	1322.5	1326	400.6532127	471.6402153	378.3833
90	1316	1314	1315	410.018913	558.3341476	377.8439
92	1308	1306	1306	423.6211133	698.7996895	380.7059
94	1300	1302	1301	433.557465	720.4181118	381.4941

The ultrasonic Velocity as well as density for all the samples show change in the behavior near phase transition temperatures. Though the temperature range in the measurement is from the room temperature to 94^0 C we have concentrated in the range of 70^0 C to 90^0 C for the graphical analysis.

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

Acoustic Impedance and Adiabatic compressibility:

Table 3

Temp.	Impedance			Adiabatic compressibility		
	LC	LC+M_1	LC+M_2	LC	LC+M_1	LC+M_2
30	472647.1493	524678.0784	538232.0225	1.4652E-09	1.33656E-09	1.29203E-09
35	477162.6891	545153.7997	531719.7288	1.4635E-09	1.29179E-09	1.31886E-09
40	484367.7634	569554.8485	525911.9197	1.4478E-09	1.2417E-09	1.33906E-09
45	470881.7166	572247.6422	521442.0086	1.4934E-09	1.23848E-09	1.35435E-09
50	483899.8543	578422.3218	516085.6616	1.4558E-09	1.22743E-09	1.37083E-09
55	493699.8526	585468.0009	512251.0232	1.4305E-09	1.21655E-09	1.38648E-09
60	497181.0979	607971.8028	508343.4226	1.4245E-09	1.17445E-09	1.40312E-09
65	496289.3611	613787.8349	505224.0023	1.4311E-09	1.1654E-09	1.4138E-09
70	493442.7816	613320.074	501339.6414	1.4559E-09	1.18279E-09	1.43089E-09
72	495787.9389	623670.8579	497173.8755	1.4532E-09	1.18289E-09	1.4533E-09
74	495774.2006	624059.4903	491826.1111	1.4616E-09	1.18522E-09	1.48195E-09
76	494254.4941	627732.9957	487986.6137	1.4715E-09	1.18309E-09	1.50017E-09
77	490166.5289	645756.6187	480087.9429	1.499E-09	1.15824E-09	1.54636E-09
78	491343.3038	645802.2851	479266.2746	1.4976E-09	1.16207E-09	1.55017E-09
79	477634.2654	644985.0979	470720.4867	1.5897E-09	1.18308E-09	1.61552E-09
80	480313.9109	603866.7984	481627.2678	1.5445E-09	1.2349E-09	1.54486E-09
81	487579.6516	606383.1737	497044.4762	1.5125E-09	1.21259E-09	1.48809E-09
82	487671.9931	592885.623	498550.6193	1.5178E-09	1.248E-09	1.48469E-09
83	504035.5304	605092.1888	498219.2377	1.4784E-09	1.24587E-09	1.50236E-09
84	498469.1233	628080.6382	498754.7284	1.5396E-09	1.1864E-09	1.5132E-09
85	506676.5663	618406.2108	505273.4445	1.474E-09	1.20857E-09	1.48027E-09
86	517735.64	546412.8246	504827.7603	1.4501E-09	1.37603E-09	1.4838E-09
88	532468.1197	623744.1847	501736.2634	1.4131E-09	1.21227E-09	1.50308E-09
90	539584.8895	733651.0699	496864.7589	1.4083E-09	1.03733E-09	1.53051E-09
92	554096.4162	912632.3945	497201.9699	1.3798E-09	8.38998E-10	1.54001E-09
94	563624.7045	937984.3816	496323.8492	1.3648E-09	8.18829E-10	1.54867E-09

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 70^0 C to 90^0 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.

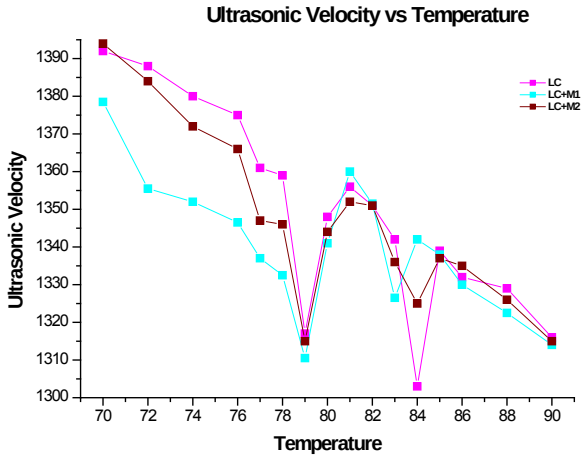

Figure 3

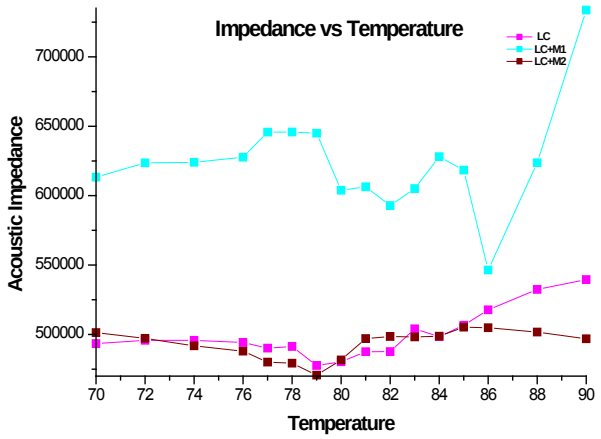

Figure 4:

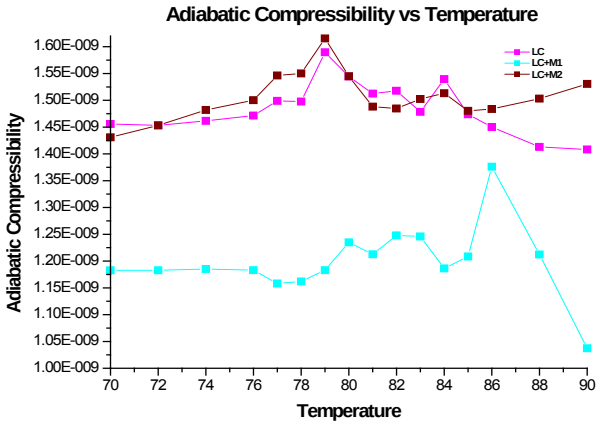

Figure 5:

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+M_1. 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+M_2 Adiabatic compressibility of LC+M_1 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 Ultrasonic waves.The ultrasonic velocity (V), acoustic impedance (Z), adiabatic compressibility (β) of LC, LC+M_1 and LC+M_2 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.

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