Non–Metallic Material Science
https://ojs.bilpublishing.com/index.php/nmms

ARTICLE

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

Santosh Mani[1,2*] Madhavi Pradhan[2] Archana Sharma[1] S..R.Chawade[1] Sameer Hadkar[2] Krishnakant Mishra[2] Jyoti Amare[2] Pradip Sarawade[2]

1. K. J. Somaiya College of Engineering, Vidyavihar (E), Mumbai, 400077, India
2. Department of Physics,University of Mumbai, Santacruz (E), Mumbai, 400098, India

ARTICLE INFO

Article history
Received: 21 April 2020
Accepted: 26 April 2020
Published Online: 30 April 2020

Keywords:
Ferroelectric nanopowder
Cholesteric liquid crystal
Dielectric
Acoustical
Ultrasonic

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 ($BaTiO_3$) 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-

**Corresponding Author:*
Santosh Mani,
K. J. Somaiya College of Engineering, Vidyavihar (E), Mumbai, 400077, India;
Department of Physics, University of Mumbai, Santacruz (E), Mumbai, 400098, India;
Email: santoshmani@somaiya.edu; samphy2013@gmail.com

 Distributed under creative commons license 4.0 DOI: https://doi.org/10.30564/omms.v2i1.1821

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 of 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 ($BaTiO_3$) in cholesteric liquid crystals 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 ($BaTiO_3$) 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 nanpowder dispersed LC is shown in Figure 1.

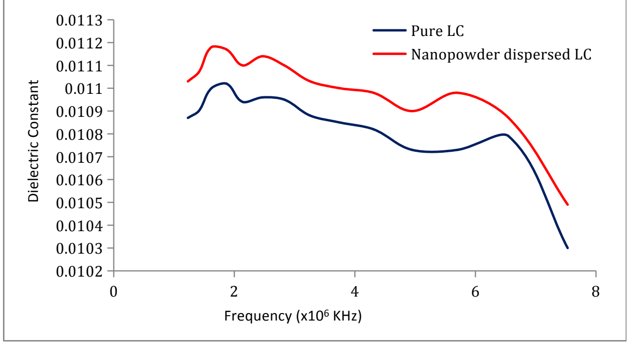

Figure 1. Variation of Dielectric Constant with frequency for pure and nanopowder dispersed LC

The dielectric constant increases when nanopowder of $BaTiO_3$ 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 m^2\gm whereas for manpowder dispersed LC it was found as 0.725 m^2\gm. 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.

Distributed under creative commons license 4.0 DOI: https://doi.org/10.30564/omms.v2i1.1821

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

Sample	Density ρ gm/ ml	Velocity (m/s)	Adiabatic Compressibility β	Rao Constant (R)	Wada Constant (W)	Acoustic Impedance (Z)
Toluene	0.87	1310	6.62×10^{-10}	1.14	2.18	1.14×10^{6}
Pure LC	0.91	1260	6.49×10^{-10}	5.85	11.7	1.22×10^{6}
Nanopowder Dispersed LC	2.14	1280	2.85×10^{-10}	1.18	2.18	2.74×10^{6}

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

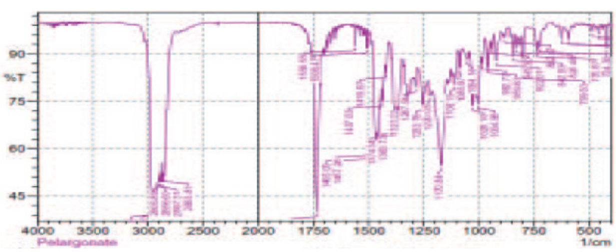

Figure 2. FTIR Spectrum of Pure LC

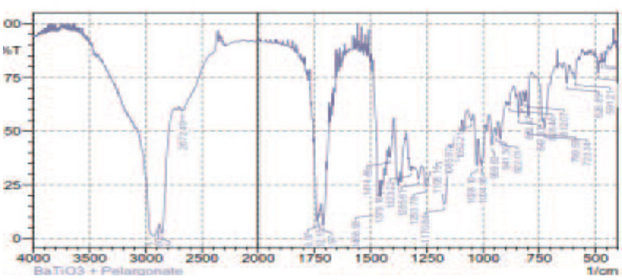

Figure 3. FTIR Spectrum of nanopowder dispersed LC

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 1400cm^{-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 nanpowder 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.

References

[1] P. J. Collings, Liquid Crystals: Nature's Delicate Phase of Matter, Princeton University Press, Princeton, 1990.

[2] P. G. De Gennes, J. Prost. The Physics of Liquid Crystals 2nd Edn.. Oxford University Press, Oxford, 1995.

[3] S. Chandrasekhar. Liquid Crystals 2nd Edn.. Cambridge University Press, Cambridge, 1992.

[4] Krishnakant G. Mishra,S.K. Dubey, Santosh A. Mani, Madhavi S. Pradhan. Comparative study of nanoparticles doped in Liquid Crystal Polymer System. Journal of Molecular Liquids, 2016, 224: 668-671. http://dx.doi.org/10.1016/j.molliq.2016.10.075

[5] Shri Singh. Impact of Dispersion of Nanoscale Particles on the Properties of Nematic Liquid Crystals. Crystals, 2019, 9: 475. https://doi.org/10.3390/cryst9090475

[6] D. Demus,J. Goodby, G. W. Gray, H. W. Handbook of Liquid Crystals. Spiess and V. Vill, eds., Wiley-VCH, Weinheim, 1998, 1: 1-16.

[7] V.K.Syal G.Lal P. Bisht S.Chauhan. Ultrasonic measurements of some 1:1 electrolytes in chlorobenzene + methanol mixtures. Journal of Molecular Liquids, 1995, 63(3): 317-328, https://doi.org/10.1016/0167-7322(94)00795-X

[8] CW Oh, EG Park, HG Park. Enhanced electro-optical properties in titanium silicon oxide nanoparti-

Distributed under creative commons license 4.0
DOI: https://doi.org/10.30564/omms.v2i1.1821

cle doped nematic liquid crystal system Surface and Coatings Technology, 2019, 360(25): 50-55 , https://doi.org /10.1016/j.surfcoat.2019.01.014

[9] S. Kaur, S. P. Singh, A. M. Biradar, A. Choudhary, K. Sreenivas. Enhanced electro-optical properties in gold nanoparticles doped ferroelectric liquid crystals. Applied Physics Letters, 2007, 91: 2, Article ID 023120.

[10] Chinky, Pankaj Kumar, Vandna Sharma, Praveen Malik, K.K. Raina. Nano particles induced vertical alignment of liquid crystal for display devices with augmented morphological and electro-optical characteristics. Journal of Molecular Structure, 2019, 1196: 866-873, https://doi.org/10.1016/j.molstruc .2019.06.045

[11] Praveen Malik, Ashok Chaudhary Rohit Mehra, K. K. Raina. Electrooptic and Dielectric Studies in Cadmium Sulphide Nanorods/Ferroelectric Liquid Crystal Mixtures Advances in Condensed Matter Physics. Hindawi Publishing Corporation, 2012: 8. Article ID 853160. DOI: 10.1155/2012/853160

[12] A. Kumar, A. M. Biradar. Effect of cadmium telluride quantum dots on the dielectric and electro-optical properties of ferroelectric liquid crystals. Physical Review E, 2011, 83(4): 8. Article ID 041708.

[13] Santosh A. Mani, Jyoti R. Amare, Sameer U. Hadkar, Krishnakant G. Mishra, Madhavi S. Pradhan, Hind Al-Johani & Pradip B. Sarawade. Investigations of optical and thermal response of polymer dispersed binary liquid crystals, Molecular Crystals and Liquid Crystals, 2017, 646(1): 183-193. https://doi.org/ 10.1080/15421406

[14] Y. Shiraishi, N. Toshima, K. Maeda, H. Yoshikawa, J. Xu, S. Kobayashi. Frequency modulation response of a liquidcrystal electro-optic device doped with nanoparticles, Applied Physics Letters, 2002, 81(15): 2845-2847.

[15] Y. Reznikov, O. Buchnev, O. Tereshchenko, V. Reshetnyak, A. Glushchenko, J. West. Ferroelectric nematic suspension, Applied Physics Letters, 2003, 82(12): 1917-1919.

[16] C. I. Cheon, L. Li, A. Glushchenko et al. Electro-optics of liquid crystals doped with ferroelectric nano-powder. SID International Symposium Digest of Technical Papers, 2005, 36: 1471-1473.

[17] F. Haraguchi, K. I. Inoue, N. Toshima, S. Kobayashi, K. Takatoh. Reduction of the threshold voltages of nematic liquid crystal electrooptical devices by doping inorganic nanoparticles. Japanese Journal of Applied Physics 2, 2007, 46(33-35): L796-L797.

[18] Prakash, A. Choudhary, A. Kumar, D. S. Mehta, A. M. Biradar. Nonvolatile memory effect based on gold nanoparticles doped ferroelectric liquid crystal. Applied Physics Letters, 2008, 93(11). Article ID 112904.

[19] A. Kumar, J. Prakash, D. S. Mehta, W. Haase, A. M. Biradar. Enhanced photoluminescence in gold nanoparticles doped ferroelectric liquid crystals. Applied Physics Letters, 2009, 95(2). Article ID 023117.

[20] Krishnakant G. Mishra,S.K. Dubey, Santosh A. Mani, Madhavi S. Pradhan. Comparative study of nanoparticles doped in Liquid Crystal Polymer System. Journal of Molecular Liquids, 2016, 224: 668-671. http://dx.doi.org/10.1016/j.molliq 2016.10.075

[21] X. Tong, Y. Zhao. Liquid-crystal gel-dispersed quantum dots: reversible modulation of photoluminescence intensity using an electric field. Journal of the American Chemical Society, 2007, 129(20): 6372-6373.

[22] S.W. Lee, C.Mao, C. E. Flynn, A.M. Belcher. Ordering of quantum dots, using genetically engineered viruses. Science, 2002, 296(5569): 892-895.

[23] V.K.Sayal, S. Chauhan, R. Gautam. Ultrasonic velocity measurements of carbohydrates in binary mixtures of DMSO + H2O at 25°C. Ultrasonics, 1998, 36: 619-623, https://doi.org/10.1016/S0041-624X(97)00104-2

[24] John P. Idoux, Cynthia K. McCurry, Tejraj M. Aminabhavi. Densities, Viscosities, Speeds of Sound, and Water Solubilities of Some Polypropylene Glycol Ether Derivatives in the Temperature Range. 273.15-323.15 K, J. Chem. Eng. Data 1994, 39(2): 261-265, https://doi.org/10.1021/je00014a015

[25] A. S. Pandey, R. Dhar, S. Kumar, R. Dabrowski. Enhancement of the display parameters of 4_-pentyl-4-cyanobiphenyl due to the dispersion of functionalized gold nano particles. Liquid Crystals, 2011, 38(1): 115-120.

[26] F. V. Podgornov, A. M. Suvorova, A. V. Lapanik, W. Haase. Electrooptic and dielectric properties of ferroelectric liquid crystal/single walled carbon nanotubes dispersions confined in thin cells. Chemical Physics Letters, 2009, 479(4-6): 206-210.

[27] A. Chaudhary, P. Malik, R. Mehra, K. K. Raina, Electrooptic and dielectric studies of silica doped ferroelectric liquid crystal in SmC* phase, Phase Transitions, 2012, 85: 244- 254.

[28] P. Malik, A. Chaudhary, R. Mehra, K. K. Raina. Electrooptic, thermo-optic and dielectric response of multiwalled carbon nanotube doped ferroelectric liquid crystal thin films. Journal of Molecular Liquids, 2012, 165: 7-11.

[29] A. Kumar, J. Prakash, M. T. Khan, S. K. Dhawan,

A. M. Biradar. Memory effect in cadmium telluride quantum dots doped ferroelectric liquid crystals. Applied Physics Letters, 2010, 97(16): 3. Article ID 163113.

[30] P.Malik, A. Chaudhary, R. Mehra, K. K. Raina. Dielectric studies and memory effect in nanoparticle doped ferroelectric liquid crystal films. Molecular Crystals and Liquid Crystals, 2011, 541: 243-251.

[31] Manisha G Bhave, Rita Gharde, Radha S. Comparative study of acoustic relaxation time of cholesteric liquid crystal and mixtures. 2016 IOP Conf. Ser.: Mater. Sci. Eng. 149 012202
DOI: 10.1088/1757-899X/149/1/012202

[32] Rita A. Gharde, Madhavi S. Pradhan, Santosh A. Mani, Jyoti R. Amare. Electro-Optical Studies on Nanopowder Doped Liquid Crystal. International Journal of Chemical and Physical Sciences, NCRTSM, 2014, 3(Special Issue). ISSN: 2319-6602

[33] Rita A. Gharde, Manisha G. Bhave. Ultrasonic Behaviour of Cholesteric Liquid Crystal. IJ IJIRSET, 2015, 4(6).
DOI: 10.15680/IJIRSET.2015.0406077

[34] R.Mehra, Brij B. Malav. Ultrasonic, volumetric and viscometric studies of lactose in mixed solvent of DMF-H2O at 298, 308 and 318 K. Arabian Journal of Chemistry, 2017, 10: S1894-S1900.
https://doi.org/10.1016/j.arabjc.2013.07.018

[35] Rajendra R. Deshmukh & Anuja Katariya Jain. The complete morphological, electro-optical and dielectric study of dichroic dye-doped polymer-dispersed liquid crystal. Liquid Crystals, 2014, 41(7): 960+975.
https://doi.org/: 10.1080/02678292.2014.896051

Distributed under creative commons license 4.0
DOI: https://doi.org/10.30564/omms.v2i1.1821