

THE BENEFITS AND APPLICATIONS OF LIQUID CRYSTAL DOPED NANOPARTICLE SYSTEM

Abstract

Research on liquid crystals and its applications has been frequently paying attention on optical and display devices as well as its innovative and assorted relevance in the nanoscience and nanotechnology fields. Alteration in the physical assets of liquid crystals have been mainly made to a major extent by the addition of dopant/foreign entity or functional nanoparticles of varying shape and size like arbitrary spherical wires and discs, rods. Suspension of nanomaterials in liquid crystals with a certain surface anchoring energy induces an orientation deformation in the surrounding environment of liquid crystals, generating topological defects in nanoparticles vicinity. The elastic deformation force on nearby nanomaterials at a distance of up to a few micrometers results in the defect sites surrounding nanoparticles. Thus, the patterning and orientation of liquid crystal molecules is achieved through self-organization of liquid crystal molecules. In the vicinity of isotropic host solvents, lyotropic liquid crystalline phases have been observed to emerge by employing nanoparticles like graphene oxide, nanotubes and rods. These consequences lead to opulence of new applications, some of which will be discussed in this chapter.

Keywords: Quantum dots, Carbon nanomaterials, Liquid Crystals, Applications

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I. INTRODUCTION

In the recent decades the scientists have encouraged their global attention towards the diversity of novel fields away from display applications—for instance, elastomer robots, energy conservation, novel optical devices, telecommunication, nano-/micromanipulation, biotechnologies, sensors, information storage, just to name a few [1-3].

These fascinating innovative applications are moderately singular and distinguish from display world and are further exhilarating and thrilling due to their uniqueness that escorts to a new - fangled episode for liquid crystals, machineries, technology, equipments and materials blueprint. Concurrently, ground-breaking, pioneering and inventive expansions have been developed in the nanotechnology, nanoelectronic and nanoscience fields, accompanying to the nativity of a series of contemporary nanomaterials [1-3]. Incontrovertibly, when these brand new nanomaterials stumble upon liquid crystals, an exceedingly appealing and exceptional synergy will be pragmatic, guiding to a profusion of utterly innovative and prospective applications [4 - 7].

Nano structured materials to liquid crystalline mesogens creates a colloidal dispersion [8, 9] and the fresh materials are predictable to perform in a different way from their specific entities (nanomaterials and liquid crystals) both on the microscopic plus macroscopic level [10, 11]. There are three fundamental motives to process a liquid crystal– nano dispersed system: (a) Alteration of the prime physical, biological, electrical or chemical characteristics of the pure liquid crystals [12]; (b) Controlling and organizing nano structured materials in liquid crystals in order to change the nanomaterials properties [12]; and (c) to achieve additional/supplementary functionalities and characteristics that are accessible from neither the liquid crystalline mesogens nor the nanometer scale materials in their native states [13]. The fast advancement of liquid crystal - nanocomposite system led to recognition of mesophase orientation and interactions which generates sturdy impression of nanomaterials on the liquid crystalline hosts [14, 15] and vice versa i.e., the nanomaterials orientational and positional order rearrangement by liquid crystal matrix [14]. The coupling of long - range orientation order and extraordinary properties of dopant in liquid crystals permit us to modify or even inflict exceptional physical assets on the liquid crystal – nano composites by addition of distinct nanomaterials in it [7].

In this chapter, we discuss about the recent investigations on the liquid crystal nanomaterials interaction which leads to superior physical properties for novel applications in diverse fields [3]. This chapter is also focused on the consequences based on enhanced electro-optical and other physical properties of liquid crystals doped with different nanoparticles. The emphasis is laid on the liquid crystalline materials for the anisotropic nanoparticles self assembly into lyotropic mesophases and biological overview of liquid crystal nanoparticle composites, i.e., biosensors. However, further information may be obtained in a review that Kato et al. [16] just released as well as the book by Li [17].

II. ROLE OF NANOSCALE MATERIALS IN MODIFYING THE PHYSICAL PROPERTIES OF LIQUID CRYSTALS

The recognition of liquid crystals in the commercial display applications has been made by its outstanding electro - optic performance. Consequently, the anisotropic nature of liquid crystal molecules modifies its physical parameters such as optical refractive index, dielectric constant, response to external stimuli and elastic constants. However, conventional liquid crystal mixtures can no longer fulfill the escalating requirement of visual necessity in LCDs with the rapid development in technological field. Hence new materials need to be synthesized in order to meet these demands that provides shorter response times, lower driving voltage and higher color contrast ratio in LCDs. Concurrently, improvement in physical properties which are essential for scientific research, technological and industrial areas can be gained through the synthesization and growth in materials such as sophisticated materials, biosciences, nanotechnologies and novel optical devices. Recently, the introduction of various well developed and well synthesized nanodopants into liquid crystal is one of the chief key in order to transform their physical properties.

Reznikov et al. were the first to describe how dispersing modest percentage of ferroelectric particles Sn₂P₂S₆ in nematic ZLI - 4801 led to decreased operating voltage, improved dielectric response, and an induced linear response to the applied electric field [18]. The argument was made on the improvement in the liquid crystal orientation by the coupling of spontaneous polarization of the ferroelectric nanoparticles and the liquid crystal via an elastic field through the dispersion of ferroelectric nanoparticles that efficiently advances the electro - optical performance of liquid crystals [19].

Just like ferroelectric nanoparticles, the improvement in the electro - optical and other physical parameters of liquid crystals can be potentially made through the modification in the orientation order of liquid crystal which has been anticipated to the electrostatic interactions between liquid crystal molecules and gold nanoparticles [20]. Elkhajji et al. reported the electro-optic response, dielectric permittivity and thermodynamics of a nematic 6CHBT doped with gold nanoparticles [21]. It was found that the first phase transition temperature, dielectric permittivity for the mixtures was raised and the threshold voltage was decreased due to the enhanced nematic ordering. Apart from that, the promotion in the reorganization and orientation of liquid crystal molecules, in the existence of gold nanoparticles dopant was possible by the application of an electric field. Moreover, an increase in ionic conductivity and dielectric constant was noticed in the gold nanoparticle dispersed in columnar discotic HAT4 suspensions [22].

The enhancement in the induced morphological changes by increase in remotely triggered local temperature has been made using the functional nanomaterials liquid crystal composites as reported in [23]. Such materials are driven by light where the light energy is converted into heat energy when photothermal nanomaterial absorbs the light resulting to a local increase in temperature.

1. Quantum dot in liquid crystals [24- 26]: As described in [24- 26], QDs are have distinctive physical characteristics like large absorption cross - section, broad excitation

spectra, fluorescence emission tunability, high quantum yields, excellent stability and long lifetimes with exceptional colour purity. The exceptional photonic properties can be added to liquid crystals as a result of using QDs as a nanodopant in liquid crystal materials such as LC lasers. Nanomaterials with fluorescence emission, surface Plasmon resonance (SPR) effects and other meticulous optical characteristics provides exclusive photonic properties to liquid crystal materials. Conversely, liquid crystals act as dynamic medium for modifying and tuning optical properties of nanoscale materials externally through its long range elastic anisotropies and large refractive index. Such multifunctional mixtures provide the roadmap for the recognition of distinguished new optical devices.

- **Core/Shell quantum dots versus bare quantum dots [27]:** There is increase in dielectric loss, loss factor or $\tan \delta$ and decrease in conductivity due to surface defects on bare core quantum dots. This shows the adverse consequence of surface defects on dielectric properties of quantum dots. Therefore, the formation or deposition of different shells and multishells is necessary on the quantum dots surface to obtain reduce dielectric loss. The reason for the decline of loss factor in core/shell quantum dots is the surface defects passivation that results easiness in charge carrier tunneling. The fabrication of electronic devices and nano circuits that attracted the attention of global community involves the implementation of nano - composite matrices with CdSe based QDs. For the design and manufacturing of more efficient devices the study and evaluation of QDs dielectric properties is very much significant in order to find the best candidate in prevailing conditions. As described in [27], the introduction of first and second layer of shells or multishell structures on CdSe QDs decreases the dielectric permittivity, loss, $\tan \delta$ and enhances the ac conductivity of QDs which has been due to the surface passivation that has a vital role in conductivity enhancement and accordingly suppresses dielectric losses and dissipation factor. These properties are mainly influenced by charge tunneling phenomenon i.e., reduce trapping of charge carriers with better charge tunneling to outer layers.
2. **Graphene and its derivatives in liquid crystals [28- 32]:** Carbon nanomaterials are another kind of nanomaterials for manipulating the physical parameters of liquid crystal materials. Carbon nanotube, carbon nanospheres, fullerene, graphene oxides and graphene have fascinated the consideration due to their striking physical and chemical properties. Graphene oxide (GO), synthesized by oxidation of graphene is voluntarily dispersible in water due to its hydrophilic nature. In several solvents in addition to water, GO does in fact crystallize as a lyotropic phase. Chemical or thermal reduction techniques can transform it into conductive reduced graphene oxide (rGO) and partly retrieving the conductivity of neat graphene. A large number of reports have shown progress in the electro - optic performance of thermotropic liquid crystal doped with graphene oxide (GO) [28 - 32]. As described in [33], a small amount of nanomaterials can make composites with customized physical properties and improved electro - optical performance for instance, a higher birefringence, a shorter response time, a larger dielectric anisotropy, enhanced nonlinear - optical properties, better contrast, etc., which has immense potential for the devise of next generation liquid crystals instruments and tools involving tunable lasers, liquid crystals displays, nonlinear - optical valves for photonic information processing systems, telecommunication and filters, electro - optical switchers and shutters and various other features of modern technology. Presently,

experimental results are still open to doubts, lacking reliability and are inconclusive. Therefore, both theoretical and experimental approaches require more study for the near future in order to recognize the foremost fundamental features that are directed to the variation of liquid crystal based composite properties. Uplifting an understanding of the later will provide the path for an optimized improvement of new equipments for enhanced future machineries.

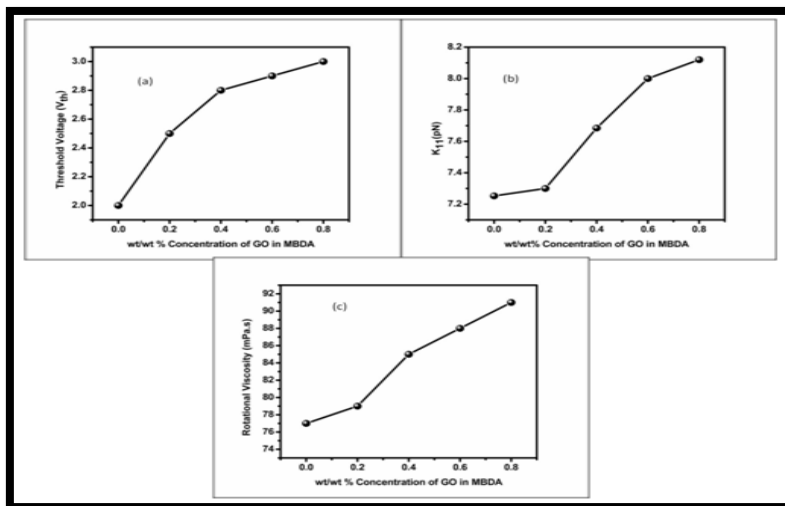


Figure 1: Dependence of (A) Threshold Voltage, (B) Splay Elastic Constant and (C) Rotational Viscosity on Concentration of Graphene Oxide in Nematic Liquid Crystal at 54 Oc in Aligned Sample Cells. Reproduced from Ref. [31].

The key idea of using liquid crystal materials for biosensing approach is using nematic liquid crystal with a definite alignment either planar or homeotropic at an aqueous phase interface [34, 35]. One of the advantages of using oil palm leaf (OPL) nanosphere is its application in supercapacitors. The large surface area, improves charge holding capacity, and low cost [36] makes activated carbon nanospheres (ACNs) most popular among carbonaceous materials [37, 38] as shown in table 1. The pore size of activated carbon nanoparticles include; macropores (> 50 nm), mesopores (2 –50 nm) and micropores (< 2 nm) [36- 38]. The most important role is played by the involvement of micropore in the internal surface area. The porosity and large surface area makes ACNs applicable in supercapacitors. Oil palm leaf based nanoparticles doped E 48 liquid crystal find its potential application in biosensors, supercapacitors, display as well as non display devices.

Table 1: Comparison of the Average Pore Size, Surface Area, Specific Capacity, and Pore Volume for Activated Carbons [36].

Carbon	(F g ⁻¹)	(F cm ⁻²)	(m ² g ⁻¹)	(cc g ⁻¹)	(Å)
M-10	55.95	0.041	1370	0.500	9.12
M-14	57.20	0.0047	1223	0.561	9.60
M-15A	78.10	0.043	1800	0.629	9.17
M-15B	55.80	0.034	1624	0.563	9.37
M-15C	63.34	0.042	1518	0.600	9.79
M-20	100	0.046	2130	0.709	14.73

M-30	62.9	0.024	2571	1.230	14.95
A-10	35.3	0.031	1150	0.424	-
A-20	41.20	0.020	2012	0.902	14.23
SACF-20	48.8	0.027	1839	0.699	9.74
SACF-25	27.9	0.011	2371	0.977	11.93

- 3. Tin oxide nanoparticles in ferroelectric liquid crystal [39]:** The stability of tin oxide (SnO_2) towards atmospheric environment is moderate. It is perfunctorily hard and can resist elevated temperature. For optoelectronic point of view, the material properties possess the combination of high electrical conductivity with optical transparency. As cited in reference [39], the significant alteration in the alignment properties of composites is made through the self assembled 2D array by ferroelectric liquid crystal (FLC) molecules and tin oxide nanoparticles interactions. Phase transition temperature varied with the dispersion of nanoparticles in FLCs system. The capability of tin oxide nanoparticles to trap the ionic impurities in pure FLC consequently results in reduced relative permittivity, ac conductivity and dielectric loss for the mixtures. The reduction in UV absorbance with quenched PL emission of the neat FLC system was observed hence tin oxide nanoparticles behave as luminescence quencher.

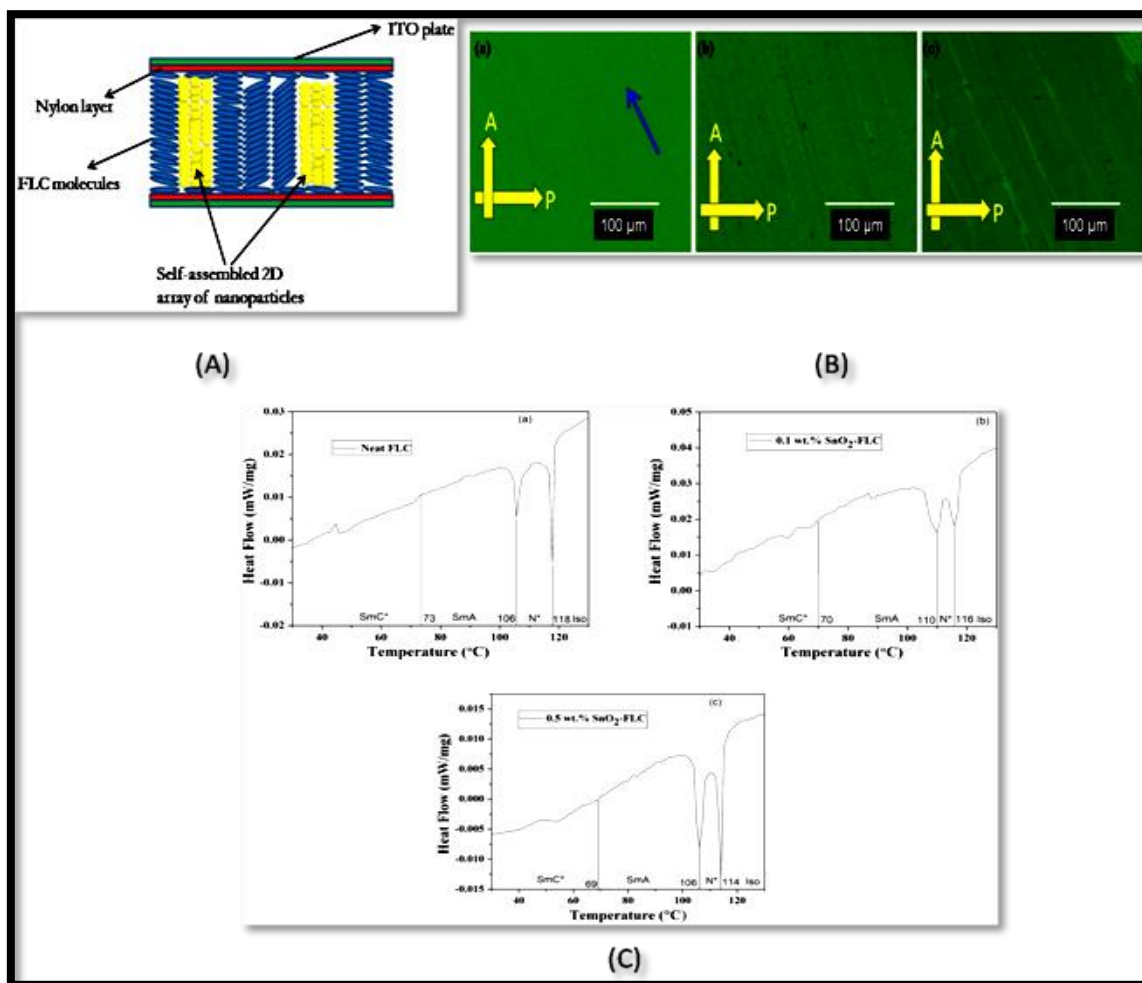


Figure 2: (A) Schematic model to represent the formation of 2 - D arrays of nanoparticles by the dispersion of SnO₂ nanoparticles in FLC system. (B) Optical micrographs/POM of (a) neat FLC (b) 0.1 weight percent, and (c) 0.5 weight percent SnO₂-FLC composite in the SmC* phase. (C) Differential scanning calorimetry (DSC) curves of (a) neat FLC, (b) 0.1 weight percent, and (c) 0.5 weight percent SnO₂-FLC composite. The DSC scan rate was 2 oC/min for all the samples. (Reproduced with permission from Mater. Chem. & Phy. Elsevier) [39].

- 4. Zinc ferrite nanoparticles in nematic liquid crystal [40]:** In zinc ferrite nanoparticles iron on the Zn surface behaves as surfactant molecules absorbing the mobile ions present in liquid crystals medium. Consequently, dispersion of ZnFe₂O₄ NPs in host liquid crystal matrix has potential to tailor the properties of pure liquid crystal such that the dispersed system becomes suitable for the use in liquid crystal based devices. Variation in the surface topology with ferronematics droplets have been observed after dispersion of ZnFe₂O₄ nanoparticles in 7CB [40]. Birefringence enhancement was revealed. Remarkable increase in dielectric constant was revealed on the basis of ZnFe₂O₄ nanoparticles and nematic liquid crystal interaction. Non monotonous dependence with decreased dissipation factor was observed with dopant concentration. Loading of dopant leads to shift in the high relaxation frequency to lower frequency regime. Improvement in the ac conductivity was found. The aim of this work was to purify pure nematics from impurity ions. The existence of memory was observed. The charge trapping capability of ZnFe₂O₄ nanoparticles had been explained on the basis of super paramagnetic nature of these magnetic nanoparticles. The increased magnetization of nanoparticles was attributed to small size of these particles causing increase in the inversion parameter. The ZnFe₂O₄ nanoparticles showed S- formed hysteresis loops and non cancelled magnetic moments which indicated its super paramagnetic nature [40]. It exhibited coexistence of ferromagnetic and anti - ferromagnetic phases. The ferromagnetic part saturates when applied field increases but antiferromagnetic part increases linearly and never saturates. S- Like hysteresis loop showed presence of curvature and linear parts [40].

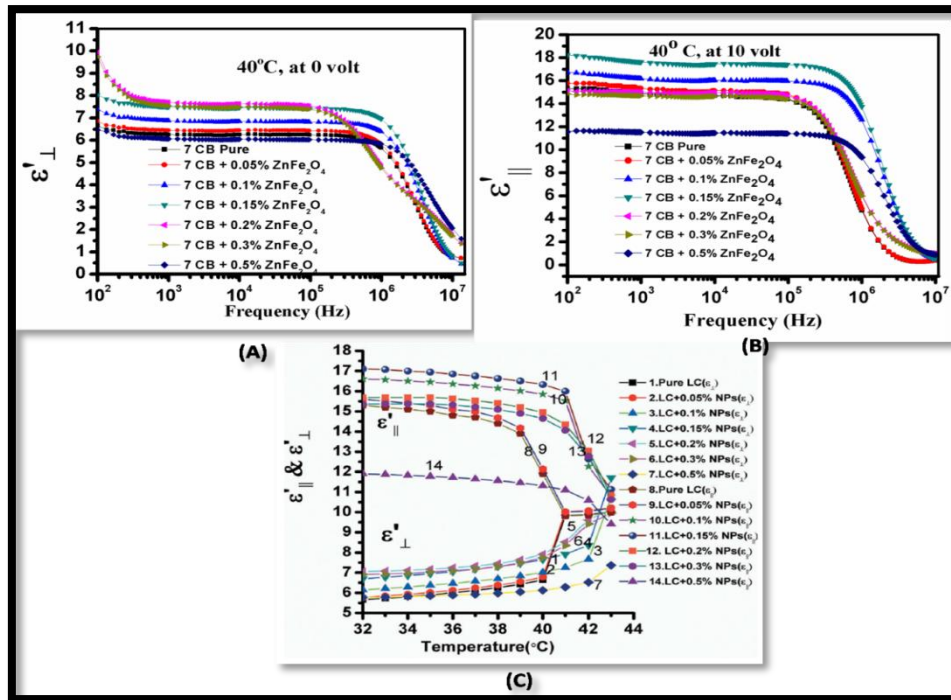
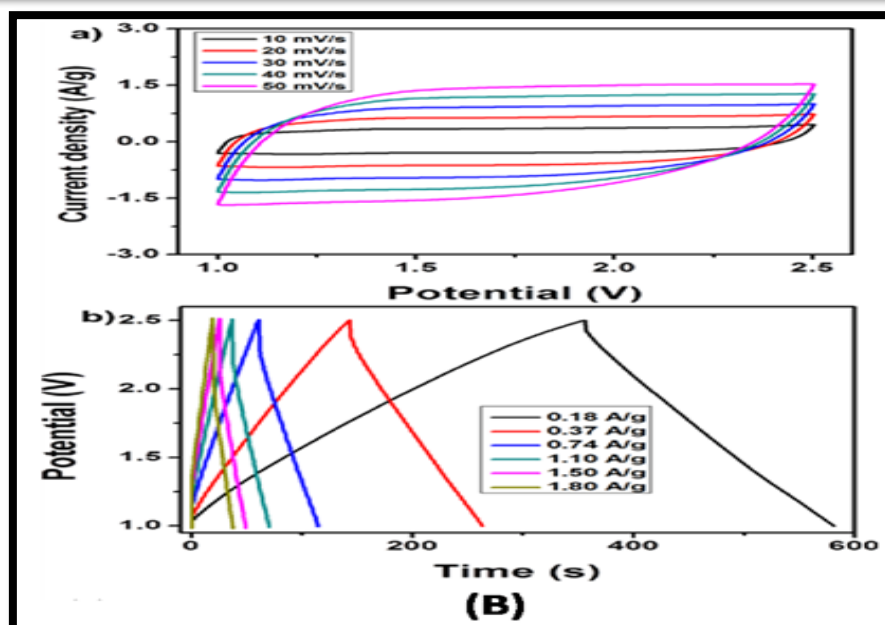
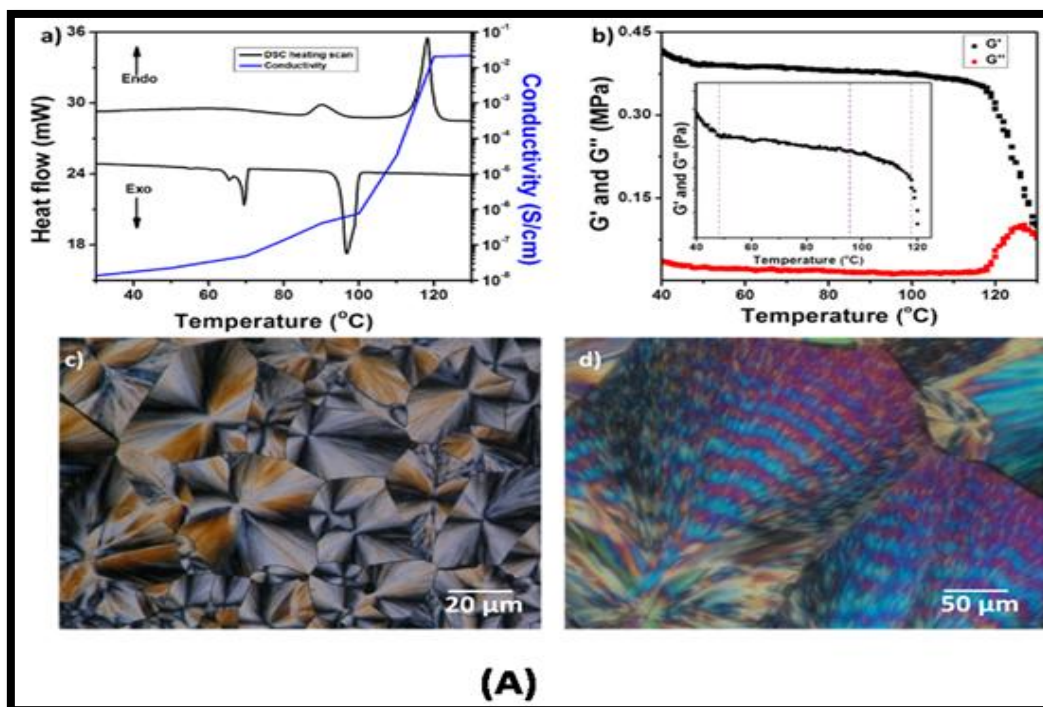


Figure 3: Frequency dependence of the (A) transverse component ϵ_{\perp}' , and (B) parallel component ϵ_{\parallel}' of permittivity, (C) Temperature dependence of ϵ_{\parallel}' and ϵ_{\perp}' at 10 kHz frequency for neat 7 CB and its composites with zinc ferrite nanoparticles. (Reproduced with permission from [40] Liq. Cryst. Taylor & Francis)

5. Novel applications

- Superior and efficient bio based ionic liquid crystal electrolytes for supercapacitors [41 - 49]
 - Sophisticated LCDs with excellent image intrinsic worth [50]
 - Wireless temperature and bio Sensors based on a nematics as variable capacitance [51 - 56]
 - Liquid Crystal based Lens [57]
 - Waveguide application [58 - 60]
 - Textile industries etc. [31]
- **High performance bio based ionic liquid crystal electrolytes for supercapacitors [41- 49]:** In the present century, the ever - increasing requirement in order to tackle the challenges and rising large - scale energy stipulation the extremely proficient and environmentally sustainable production and energy storage is mandatory. Advancement, Design and progression of new materials and manufacturing system that authorize accurate control over the electrochemical performance and electrolytes conductivity is vital for accomplishing such objectives. The reported work of [41- 44], on an exploitation of ionic liquid crystal electrolyte resulting from a non degradable source: cashew nut shell liquid. They studied the structural and mesogenic phase formation by adopting different methods by synthesizing imidazolium-based ionic liquid crystal (PMIMP) derived from cardanol. A current density of 0.37 A/g, 80% capacitance retention after 2000 cycles with outstanding cycle stability and a specific

capacitance of 131.43 F/g measured in a symmetrical supercapacitor made - up of mesoporous carbonaceous electrodes using PMIMP as electrolyte [43]. All these exceptional assets of the synthesized ionic liquid electrolyte recommended its relevance as well-organized, nature sociable and reasonably worth electrolyte for energy harvesting devices.



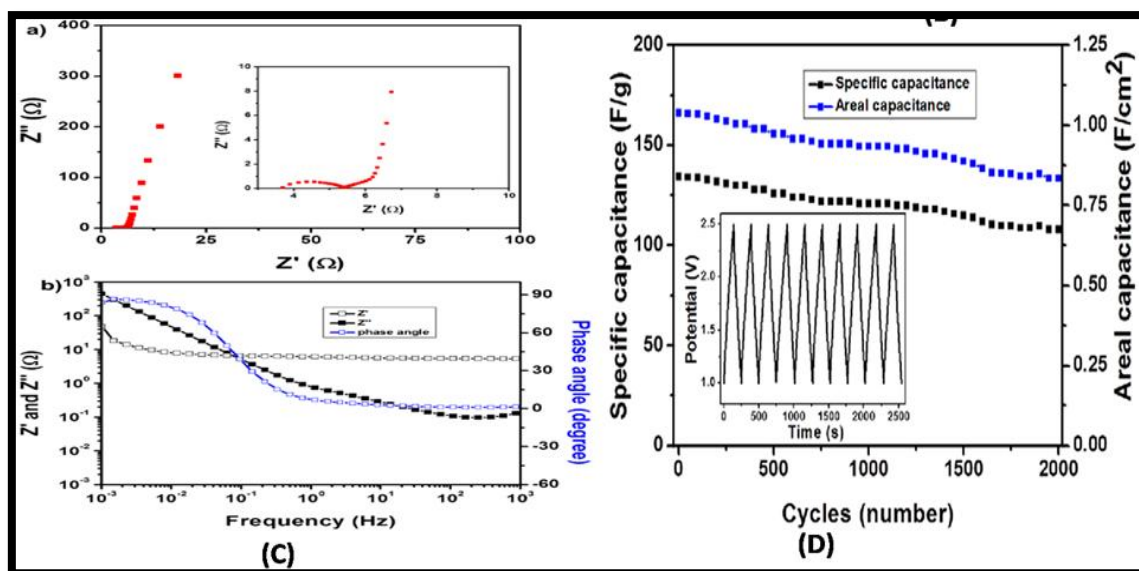


Figure 4: (A) (a) PMIMP's DSC heating and cooling scans demonstrating thermotropic behavior and concomitant conductivity variation, (b) Alteration in PMIMP's viscoelastic moduli due to thermotropism. Optical images of (c) columnar (Col) phase with focal conic domains, and (d) Sm F phase emerged. (B) (a) At various scan rates, the supercapacitor using PMIMP electrolyte exhibits a rectangular current density-potential curve.; (b) Galvanostatic charge– discharge profile. (C) (a) Nyquist and (b) Bode impedance plot, (D) Cycling stability of PMIMP-based supercapacitor. Inset contains the first 10 cycles. Reproduced with permission from ACS sustainable chemistry & engineering [43].

Electrical energy storage is an indispensable methodical spot that demands unfathomable research. A sustainable manner for stable and reliable energy storage is obtainable by electrolytic batteries and capacitors. Batteries offers discharge of energy with high power density. Corresponding to them, electrolytic capacitors are also competent to discharge with elevated energy density [41]. Supercapacitors with characteristics intermediary to electrolytic capacitors and batteries portrays advanced cycle lives, easy, simple and flexible models and foster charge–discharge rates which make them potential contender in military equipments, in hybrid transportation structure, electronic instruments and medical diagnostic appliances [41]. The fabrication and proposal of novel electrode materials, novel electrolytes and novel electrochemical hypothesis lead to the improvement in tuning machinery efficiency and its performance by its energy density [42, 43]. The extortion of superior performance from both organic and aqueous electrolytes by using carbonaceous supercapacitors reported by [44, 45]. The ionic liquid crystal fluids have better electrochemical window and improved conductivity to be appropriate in electrochemical energy devices as competent electrolytes [46, 47]. The improved replacement for conventional electrolytes is considered to be the ionic fluids and ionic mesogenic liquids with mutual properties of both organic and aqueous electrolytes [48, 49].

- Sophisticated LCDs with excellent image intrinsic worth [50]:** The heated debatable question to get answer is ‘LCD vs. OLED: who wins?’ The technological machineries used in scientific areas have own pros and cons. A review work of H. Chen et al., [50] exemplifies current progress in LCDs from following performance parameters: contrast ratio, viewing angle, and response time which conclude the ultimate professed image superiority. Enhancement in LCD efficiency with extremely low viscosity materials, quantum dots and novel machinery structures were investigated, together their operational methods explored. Another round of LCD innovation is around the corner. The improvement in the contrast ratio of vertically aligned LCDs from 5000:1 to 20,000:1 was elaborated by H. Chen et al. [50]. The implementation of local fainted backlight was required to increase contrast ratio to 1,000,000:1. Along with other stupendous features, such as superior resolution density, enhanced peak brightness, low cost and long lifetime, LCD would continue its supremacy in the predictable future.

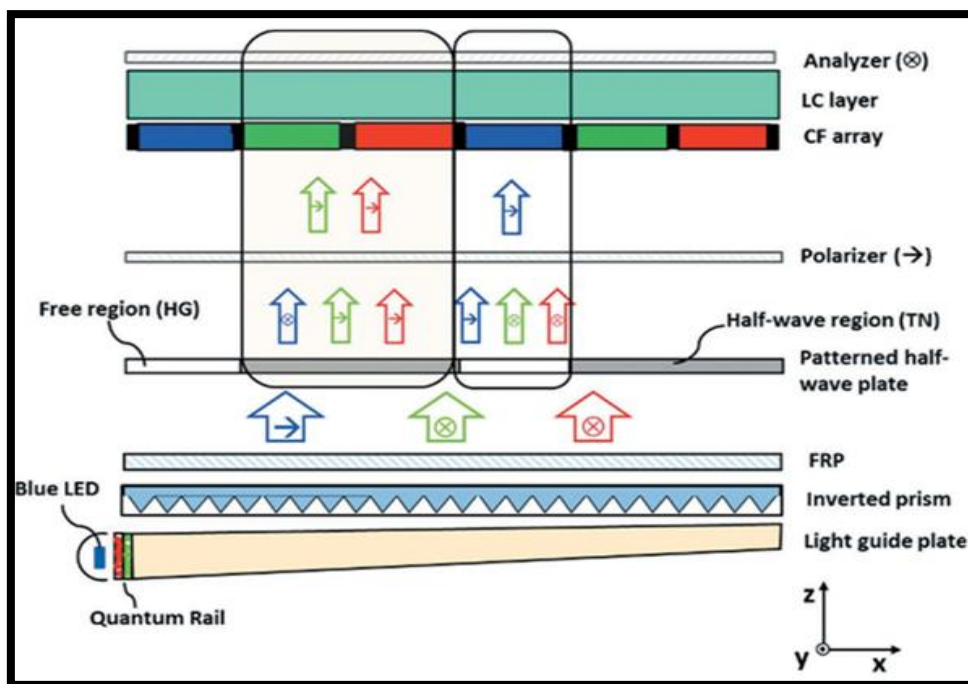


Figure 5: The functional reflecting polarizer (FRP) and pattern half-wave plate-equipped suggested backlight's schematic diagram and layout are shown. (HG: homogeneous alignment; TN: twisted nematic alignment) Reproduced from Ref. [50] with Springer Nature's permission.

- Wireless temperature and biosensors based on nematics as variable capacitors [51- 56]:** As described in the reported work of [51], the growth in the wireless communication system with novel technologies like the Internet of Things (IoT) is integrated in various smart sensors that reduce the installation and system costs. These sensors replace the weird and tedious approaches that were used in the past. It

simplifies deployment with flexibility and deal with a new set of applications. The proposal of wireless temperature sensor based on nematics as variable capacitance is regarded as a proof of concept for prospective applications. J. C Torres et al. [51] proposed a simple equivalent circuit and evaluated the performance analysis for the wireless temperature sensor. This sensor prototype was the commencement of new biomedical sensors.

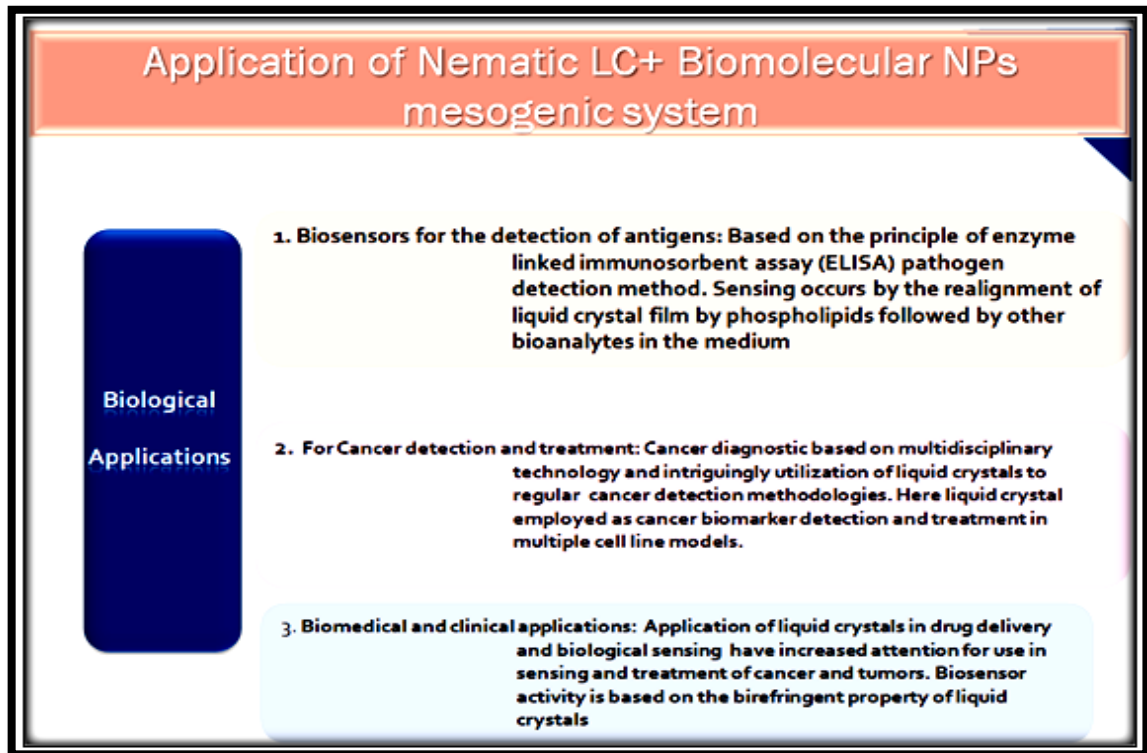


Figure 6: Biological Applications of Nematic Liquid Crystal- Biomolecular Loaded System [57].

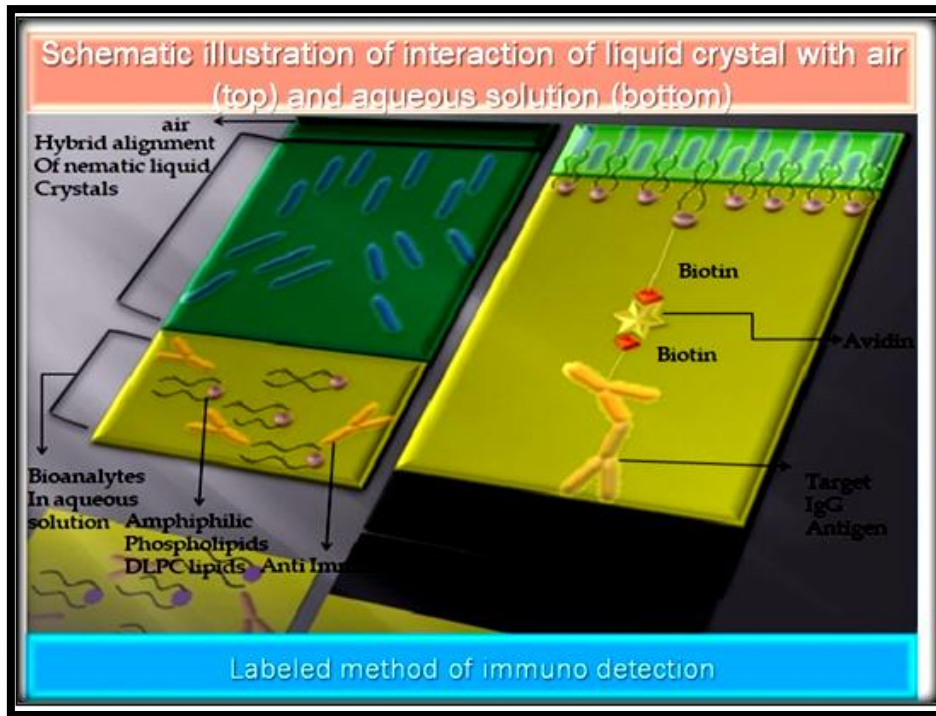


Figure 7: Schematic Illustration of Label Method of Immuno Detection using Interaction of Nematic Liquid Crystal with Air and Aqueous Solution [57].

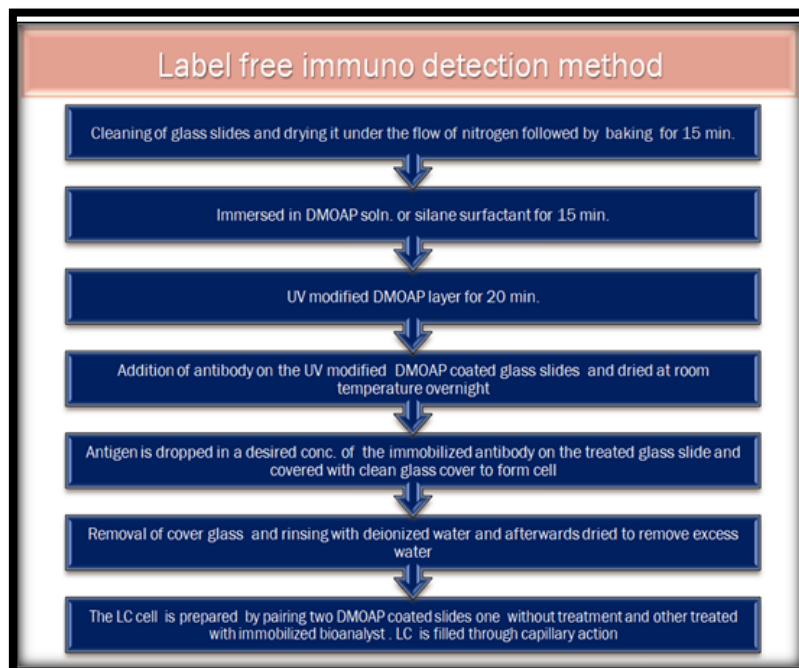


Figure 8: Flow chart representation of label free method of immuno detection [57].

The geometry and design of temperature sensors based on liquid crystals has been proposed for potential wearable applications. The high thermo - optic coefficient

[52] of liquid crystals makes them a better candidate as a base for high sensitivity temperature sensors [52]. Its sensitivity is determined from the geometry and design parameter of liquid crystal as well as the initial alignment of liquid crystal molecules and thickness of sample cell. Such materials are composed of nanoscale elongated organic molecules producing an orientational order. The important requirement for liquid crystal based temperature sensors is the anisotropic property of mesogens that provides limiting operating range up to clearing point. There are several liquid crystals that are synthesized with very broad temperature ranges from 35 oC 5 CB to higher than 180 oC in other kind of liquid crystals [54, 55]. Biological applications of nematic liquid crystals doped with porous carbon quantum dots have been described elsewhere [56]. Popov et al. [57] exemplified the label free method of immune detection using nematic liquid crystals and biomolecular nanoparticles as shown in figure 5 – 7.

- Liquid crystal lens with modified performance [58]:** As reported in the work of C. J. Hsu et al., [58] it reveals the design criterion of a floating ring electrode (FRE) embedded liquid crystal lens. The impact of FRE on the electro - optical performance of a hole - patterned liquid crystal lens were effectively revealed. Results have shown that the potential in the center of aperture hole (AH) gets strengthened by reducing the addressing voltage of the liquid crystal lens and the FRE is close to the hole-patterned electrode. The tunable focal length range was also broadened. The wave front aberration of the liquid crystal lens was instead reduced when the FRE was close to the liquid crystal layer because the embedded FRE heightens the gradients of the fringing electric field and the accompanying phase profile close to the AH perimeter. The modulation transfer function curve and root-mean-square error of the suppressed wavefront aberration were both excellent. But because the FRE close to the AH perimeter collects the fringing electric field around the AH periphery, it is inevitable that the FRE close to the liquid crystal layer increases the addressing voltage of the liquid crystal lens.

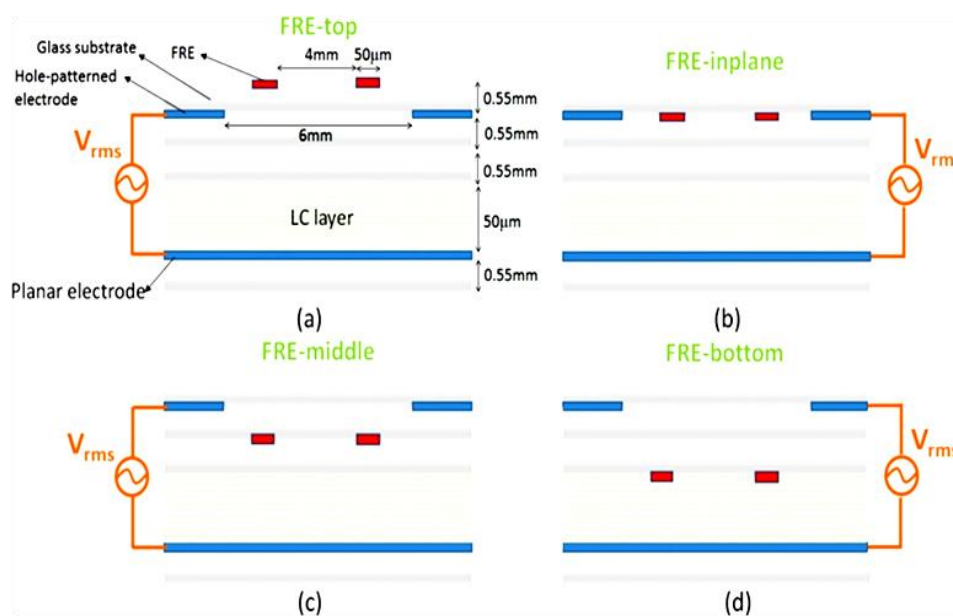
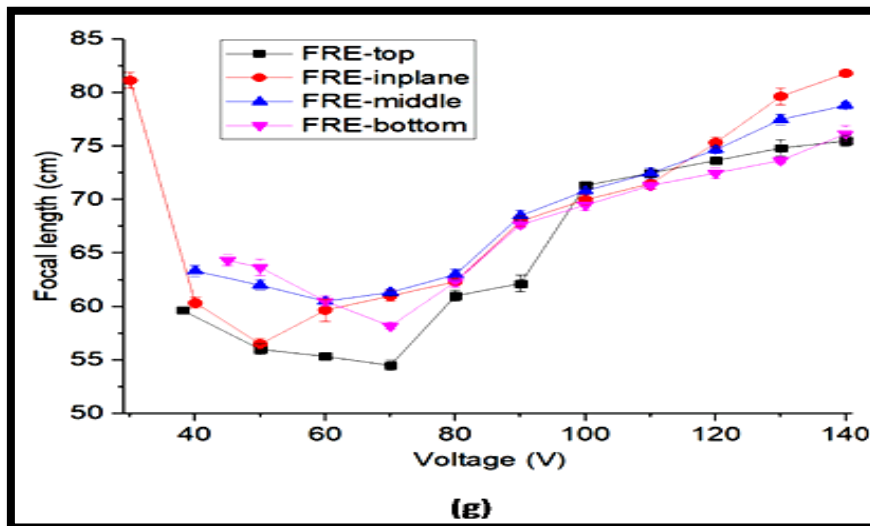
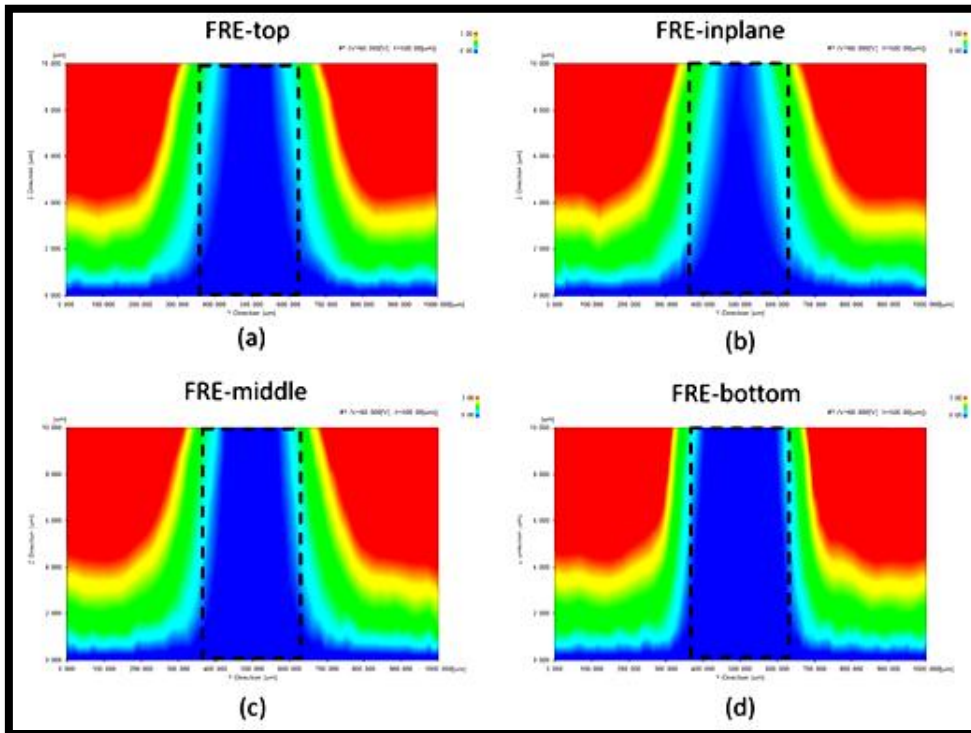


Figure 9: Schematics Oof (A) FRE-Top, (B) FRE-Inplane, (C) FRE-Middle, and (C) FRE-Bottom LC Lenses. The Red Symbols Indicate the FRE Positions [58].



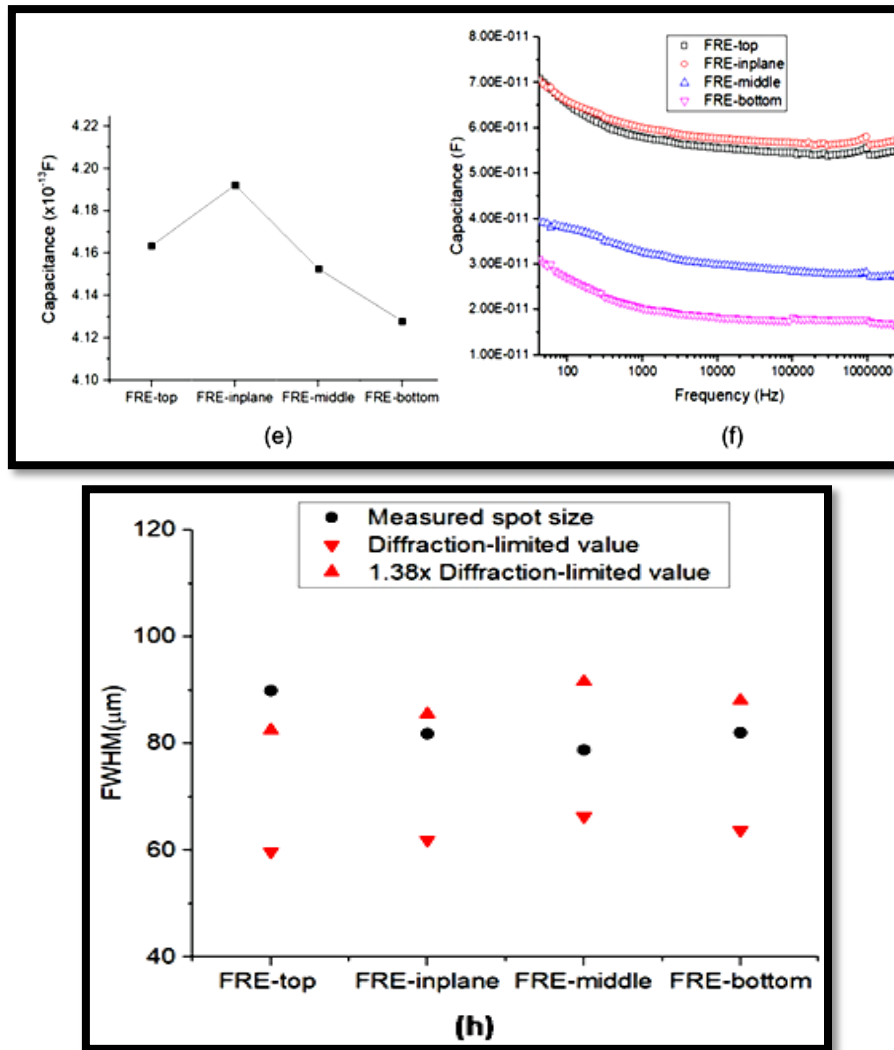


Figure 10: Calculated potential distribution of (a) FRE-top, (b) FRE-inplane, (c) FRE-middle, and (d) FRE-bottom LC lenses. (e) Capacitances variation with FRE positions, (f) Capacitances variation with frequency of the different FRE positions of LC lenses. (g) Change in focal lengths with voltage of the FRE positions of LC lenses. (h) Focusing spot sizes and calculated diffraction-limited values of the FRE-positions of LC lenses addressed at Max P [58].

- Waveguide application of liquid crystals:** Communication system is basically a collection of discrete networks, transmission systems, tributary stations, relay stations and data terminal equipments that are interconnecting and interoperating to form an integrated whole. The machineries are technically compatible, respond to controls and operate in union. Diverse wired and wireless infrastructure coexist in a seamless, all purpose network architecture platform used to migrate multiple communications. Staying ahead of the curve to ensure infrastructure is equipped to handle today's demand and tomorrow's innovation is the expertise. Researchers [59], in their constant efforts towards progress, find it essential to establish better, quicker and more numerous communication system.

The inclusion of Liquid Crystals in waveguides potentially reduces the cost of production and allocate for integration of waveguides directly into fiber optic networks which permits more direct optical switching and fewer cable lines. This technology i.e. liquid crystal waveguides has significantly reduces the infrastructure design obligatory to take fiber optic technology to both commercial and residential applications. The tremendous possibilities offered through this photonic structure are based on periodic modulation of refractive index controlled by an electric field. It has been investigated that the voltage-tunable array of liquid crystal waveguide allows the linear and non linear propagation of light which finds its application in the study of discrete optical phenomenon [60]. Such novel geometry exhibits potential for the recognition of multifunctional routers and all optical signal processors with liquid crystal. Vescent photonics [61] developed a new technology based on electro - optic waveguide platform that provides unprecedented voltage control over optical phase delays circumventing their historical limitations. The large optical phase delays in such technology enable the construction of new class of photonic devices for example 2-D analog non-mechanical beam steerers, chip scale tunable lasers, chip scale fourier transform spectrometer, tunable micro ring resonators, tunable lenses, optical time delay devices, optical switches etc. The liquid crystal waveguide photonic architecture has applications in the defense markets: remote sensing, laser illumination, phased array radar and many more. Various uses of liquid crystal waveguides require active control over light like optical computing, telecommunications, holography and industrial process analysis.

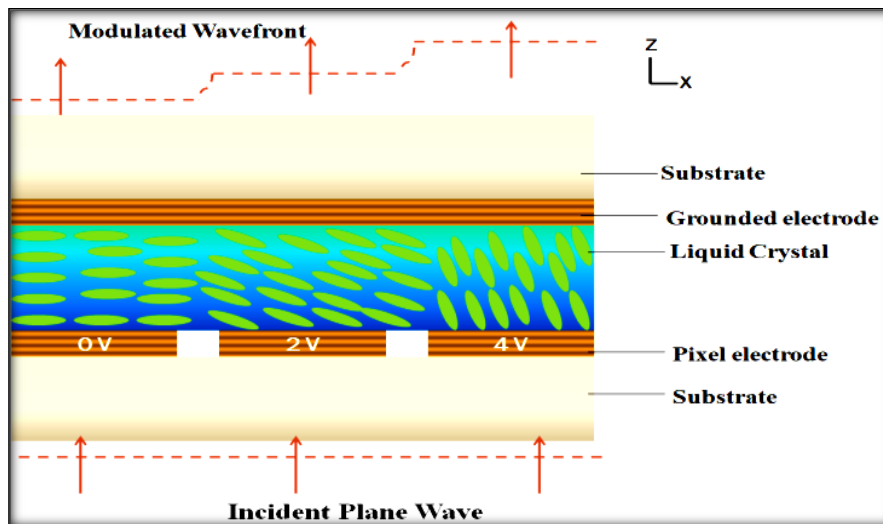


Figure 11: Photonic Application of Liquid Crystals [62].

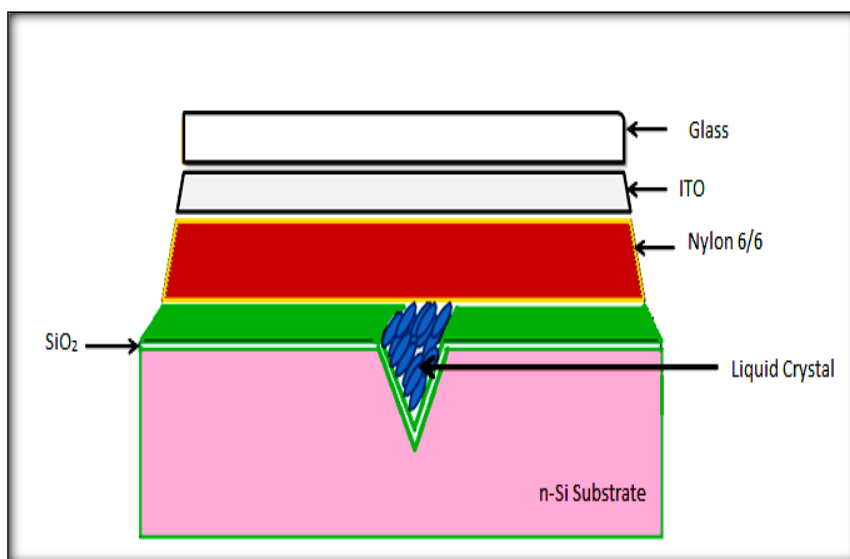


Figure 12: Waveguide Application of Liquid Crystals [62].

III. CONCLUSION

This chapter gave a general overview of liquid crystal systems doped with nanoparticles, along with information on their advantages and uses. Different characterization methods, including SEM, TEM, and XRD, have shown that nanoparticles, despite their small size, have a large surface area, making them a good candidate for a variety of applications. Additionally, the optical characteristics are also dominating at that scale, which highlights the significance of the doped materials in a variety of applications, including photocatalysis, solar energy, biological, optical electronics, and many others. The precise shape, size, and magnetic characteristics of a liquid crystal system doped with nanoparticles may be controlled using synthetic approaches.

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