Chapter 1

Introductory Chapter: Whither Liquid Crystals?

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Additional information is available at the end of the chapter

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1. Introduction

"*Whither liquid crystals?*"—a very general question that every researcher falling on the relevant research directives would ask about. A veteran researcher may also attempt to seek the answer to be abreast of the recent research developments in the area. Amazing physical and chemical properties of liquid crystals draw great attention of the research and development (R&D) community. These essentially make them indispensable for several technological applications, namely sensing [1, 2], communication systems [3], lasing actions [4, 5], flat panel displays [6], holography [7], and nanotechnology-enabled medicinal needs [8].

Though there are many different kinds of liquid crystals, nematic, smectic, and cholesteric exist as the three widely accepted phases (of these crystals) [9]. In short, the nematic version is characterized by molecules having no positional order, but aligned along the director with thread-like molecular formations. In the smectic phase, molecules have positional order only in one dimension, thereby having restricted movement within the planes. The cholesteric state is a kind of nematic phase wherein the molecular orientation undergoes helical rotation about the director. These may exist naturally or can be synthesized as well [10, 11]. Certain liquid-crystalline phases are abundant in living organisms, for example, proteins and cell membranes. Technologically developed liquid crystals are used for liquid crystal display (LCD) applications [6]. Apart from the LCD panels, there are host of other avenues where the synthesized versions of liquid crystals are used.

2. Liquid crystal properties

Liquid crystals exhibit chirality and possess very high electro-optic coefficient [12]. Chiral objects have the property to discriminate between the left-handed and right-handed electromagnetic fields [13]. These *optically active* mediums are classified into the categories of isotropic and structurally chiral ones. The isotropic chiral molecules can be formed by randomly dispersed, randomly oriented, electrically small, handed inclusions in an isotropic achiral host medium. On the other hand, the structurally chiral molecules, such as those of chiral nematic liquid crystals, are randomly positioned and exhibit helicoidal kind of orientation. One may exemplify biological structures of plants and animals, such as cholesterols, which represent chiral molecules. The director of cholesteric liquid crystal molecules exhibits periodic helical structure depending on the chirality of molecules, and may be altered due to external conditions—the feature that has great potential in technological applications [14]. For example, the changes in the helix (formed by the rotation of director) pitch due to chiral dopants would modify the phase of liquid crystals.

3. Application-oriented R&D

The unique properties of liquid crystals fueled scientists to invent new applications. Continuous research and development determine these mediums to gain increasingly important industrial and techno-scientific usages, and become vital in modern technological advancements. It is true that the research on liquid crystals tremendously bloomed after the invention of LCD panels [15]. Though the use of liquid crystals in flat panel electronic displays offers several advantages over the traditional ones, wherein cathode ray tubes (CRTs) are implemented [6], the LCDs have the drawback of having limited viewing angle, and also, higher manufacturing cost. However, these parameters have now become less significant with the advances in research, which becomes evident from the multitude of other applications of liquid crystals. This is primarily because external perturbations would introduce significant alterations in the macroscopic properties of liquid crystals [12, 13]. As an example, the chirality of liquid crystals allows these to acquire selective reflectance property, which can even be modified in the presence of external electric field. As such, these would be of great use in optical filters and imaging [16, 17] applications. Apart from these, the property of temperature dependence also makes liquid crystals to acquire the selectivity of reflection spectrum—the phenomenon that can be harnessed for devising temperature sensors [18].

Since the temperature plays a determining role to alter the refractive index values of liquid crystals, the birefringence property of these [19] allows splitting of light waves into the *slow* and *fast* components—the phenomenon which remains highly temperature dependent. A relatively higher temperature would induce a strong birefringence characteristic in certain form of liquid crystals, which would result due to higher temperature of the ambience. As such, a variation in temperature would introduce alterations in the phase difference between the incoming and outgoing light waves, thereby determining the polarization state of light.

As the properties of liquid crystals are affected by electric field, these mediums can be used to sense the field strength. Similarly, magnetic field also has effects on the properties of liquid crystals owing to the moving electric charges (magnetic dipoles are generated by the electrons moving around the nucleus in atoms). An externally applied magnetic field would make the liquid crystal molecules to align accordingly.

As stated before, the *optical activity* of liquid crystals opens up varieties of avenues. Under high external electrical fields, an optical material would exhibit nonlinear characteristics, that is, the refractive index of medium may not vary linearly with the field [20]. Liquid crystals, being optically anisotropic mediums, possess the birefringence property that remains of great potential in optics-based applications [21, 22]. The increase of birefringence happens owing to the nonlinear phenomenon that liquid crystals also exhibit. In fact, liquid crystals are characterized by extremely high optical nonlinearity. Some of the featured nonlinear phenomena would be self-phase modulation, four-wave mixing, stimulated Brillouin scattering, optical bistability, and so on. [23].

4. Liquid crystal-based fibers

Optical fibers with radially anisotropic liquid crystals have been greatly dealt with in the literature [24–26]. These have been much attractive owing to the fairly high optical anisotropic properties of liquid crystals—the feature that attracted the R&D community to introduce varieties of liquid crystal-based optical fibers in respect of geometry as well as material distributions. These include fibers of circular [25] and elliptical [26] cross-sections, and also, those with the loading of conducting helical structures, in order to achieve control over the dispersion characteristics [27–29]. It has been reported before that the radially anisotropic kind of nematic liquid crystal-loaded fibers become highly sensitive, and would be of potential for evanescent wave-based sensing applications [24, 25]. Indeed, the use of such fibers in chemical sensors would be one of the great avenues that liquid crystal mediums open up.

5. Liquid crystals for band gap features

Photonic crystals are known to exhibit band gaps, that is, the range of frequencies (or wavelengths) for which the propagation of waves remains forbidden [30–32]. Microstructured dielectric mediums can be engineered to exhibit such an excellent feature, which has been of great technological use in many optics-related applications [33]. Apart from dielectrics, liquid crystals may also be utilized due to the fact that the physical and/or chemical features of these are highly dependent on the externally applied fields. Varying thermal ambience also plays a great role in manipulating the behavior of liquid crystals, which essentially happens owing to the effects on the birefringence property. Technically speaking, thermal and electrical tuning of liquid crystals would alter the spectral characteristics. As such, photonic crystals, infiltrated with liquid crystal mediums, would exhibit tunable band gap features, which would be greatly interesting in optics-based needs.

6. Other miscellaneous applications and summary

Apart from the aforementioned applications of liquid crystals, there are many other varieties of usages that these materials offer [34]. Some of these include optical recording mediums, lasers, light modulators, and so on. Also, the area of biomedical applications is no more untouched on the exploitation of liquid crystals. For example, certain forms of liquid crystal polymers can act as nonviral vectors in gene therapy, transfecting DNA to the nucleus cell. Furthermore, functional mediums composed of specific colloid dispersion systems using liquid crystals would be greatly useful in pharmaceutical industry.

In summary, the book delineates several important advances occurring at the forefront of liquid crystal research. These are in terms of the development of fundamental theories as well as the exploitation of liquid crystals in inventing new devices. The subject matter of the book primarily focuses on the aspects of (i) varieties of liquid crystal polymer syntheses and their stability, (ii) physical and optical properties of complex liquid-crystalline states, and (iii) device applications of liquid crystals. The editor hopes that the topics included will be greatly useful for the R&D workers at universities and industries. The researchers use the book as springboard for their own thoughts in varieties of ways the different forms of liquid crystals can be exploited.

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