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Thesis title: Augmenting the dielectric, electrical and electro-optical properties of liquid crystals using nano-inclusions

Abstract

Liquid crystals (LCs) have witnessed diverse applications in display devices and gained technological importance from the viewpoint of non-display applications. They have revolutionized the display industry, spanning from tiny screens to huge flexible displays and encompassing numerous non-display applications in biosensing, tunable lasers, filters, phase shifters and adaptive lenses, to reference a few. With the advancements of modern-day industrial necessities, the present era of these applications demands enhanced functionalities in liquid crystalline materials. A significant concern is the presence of inherent ions in LCs that can adversely affect the image quality of display devices by inducing undesired effects, like image sticking and flickering. These ions can further alter the physical properties of LCs, such as their dielectric, electrical and electro-optical characteristics under the influence of an electric field, thereby affecting the performance of LC-based devices. In contrast, ions in LCs have garnered attention in recent years for their potentiality in applications, like broadband optical switches, smart windows and wavefront correctors. Therefore, the tunability of ion transport behavior and physical properties of LCs in different mesophases is required to meet the current technological needs according to the requisite applications. It can be realized by adding nanoscale entities in the LC matrix, like nanoparticles typically ranging between 1 to 100 nm. This approach is regarded as efficient in tailoring the ion transport and physical characteristics of LCs emanating from the interaction between the host molecules and guest particles. Another important aspect is that LC-based devices, specifically those utilizing the cholesteric LC, are fundamentally designed to operate in a definite state, maintained by controlling the orientation of LC molecules through an electric field. The cholesteric states in general can be electrically switched from reflective to transparent modes, offering unique optical responses, enabling their applications in various display and electro-optical devices. These devices exhibit several

limitations, including high switching voltage, slow response time, user control over switching, high power consumption and hysteresis, which entails further optimization.

Thus, the primary objective of this thesis is to examine the ion transport characteristics, distinct physical properties and phase transitional behavior of thermotropic LCs dispersed with spherical nanoparticles (NPs) in varying concentrations at different temperatures in the nematic and smectic-*A* mesophases for developing an enhanced understanding of the science behind the interaction between the LC molecules and NPs and among NPs. The impact of an external magnetic field on the phase transitional behavior of the pristine and NPs dispersed thermotropic LC systems is also studied. In the latter part of the thesis, we investigated the electrical actuation of multiple states in the cholesteric LC and exhibited a plausible application in display devices.

The first two chapters of the thesis focus on the elementary aspects of LCs, their classification, different physical properties and additive effects of NPs on them, an overview of electrically regulated different cholesteric states and utilized experimental methodologies and techniques. The third chapter elucidates the effect of dispersing CdSe/ZnS core-shell type quantum dots (QDs) in the thermotropic 5CB LC in different concentrations on the ion transport behavior employing the temperature-dependent dielectric measurements. Ionic parameters, such as mobile ion concentration and diffusion constant, are evaluated using two approaches at distinct temperatures ranging from the isotropic to nematic phase for the pure and QDs dispersed LC samples. A detailed analysis of the dielectric investigations shows that the interaction between the QD ligands and the alkyl chain of mesogenic LC molecules affects the ion transport characteristics in the nematic phase. In the fourth chapter, we present the impact of dispersing the same QDs in varying concentrations on the physical properties of the thermotropic 8OCB LC. The temperature variation of electrical properties from the experimental dielectric measurements in the isotropic, nematic and smectic-*A* mesophases is determined. We examine the thermal profiles of dielectric anisotropy, threshold voltage, splay elastic constant and rotational viscosity in the nematic phase for all the studied samples. We also present the electro-optical, transmittance-voltage and photoluminescence measurements in the nematic phase of the pure and dispersed counterparts. The fifth chapter explores the phase transitional behavior of the pure 8OCB and QDs dispersed LC samples in different concentrations by employing the temperature-dependent high-resolution optical birefringence and dielectric anisotropy measurements. We analyze the isotropic to nematic phase transitional behavior from the optical birefringence data. A dependence of QDs dispersing concentration on the nematic to smectic-*A* phase transitional nature and associated critical anomaly is established using the differential forms of optical and dielectric anisotropy data near the transition. We also investigate the coupling efficiency between the nematic and smectic-*A* order parameters for all the studied samples. In the sixth chapter, we examine the effect of multiferroic bismuth ferrite NPs dispersion in different concentrations and externally applied magnetic fields on the phase transitional characteristics of the 8OCB LC and its constituent mixtures with NPs. We utilize the temperature-dependent high-resolution optical birefringence measurements to determine the phase transitional and associated critical behavior at the isotropic to nematic and nematic to smectic-*A* phase transitions with and without applying the magnetic field. In the seventh chapter, we demonstrate an electrical field-controlled switching of the cholesteric states prepared by dispersing a left-handed chiral dopant, S811, in two different concentrations into 8OCB LC. The temperature-dependent dielectric and electro-optical investigations were performed to gain insight into the electric field-regulated switchable states. We observe an intermediate translucent state between the oblique rolls and homeotropic states by applying an electric field across the sample. We present the switching among multiple states from the transmitted power and wavelength-dependent transmission variation at different applied signal voltages, frequencies and temperatures. The switching time between various states and electro-optical stability performance is also investigated. These outcomes suggest a device proficient in regulating switching between multiple states with potential applications in displays, including smart windows and electro-optical devices. The eighth chapter summarizes the overall findings and underscores the significant contributions of the results delineated in the thesis. This chapter concludes with a brief discussion of the future endeavours of the thesis research work that can be extended from both fundamental and applied research perspectives.