Abstract

Optical devices are instruments or components that manipulate light in various ways to perform specific functions. They are fundamental in many technologies and applications, particularly those involving the transmission, modulation, or detection of light. Once fabricated, these devices are challenging to tune or reconfigure across a wide wavelength range. However, the next generation of optical devices requires dynamic reconfigurability, cost-effectiveness, and power efficiency. These capabilities can be achieved over a limited dynamic range using thermo-optic or electro-optic materials. Liquid crystals (LCs), with their high birefringence, significant electro-optic effect, and low power consumption, offer a promising solution for developing electrically tunable optical devices with a wide dynamic range. The thesis focuses on utilizing LC materials in switchable optical devices, targeting the application in the fields of optics, photonics, and solar energy harvesting.

The first two chapters of the thesis cover the fundamental concepts and properties of LCs, optical waveguides, surface plasmon resonance (SPR), and photoluminescence (PL), as well as the experimental methods and techniques used in the research. In chapters 3 and 4, we used the 5CB nematic LC in the waveguide configuration to design and fabricate the mode size converter, optical switch, and polarization selector. One of the key advantages of using LC as the core material for creating a liquid crystal core waveguide (LCW) is the capability to adjust the propagation characteristics of guided-wave devices based on LCWs. In Chapter 3, we present the numerical and experimental study of an LC core periodically segmented waveguide (PSW) based mode size converter fabricated on an ITO-coated glass substrate. Here, we have shown that the effective index and mode size of the guided modes change with the duty cycle and the applied voltage. For a fixed duty cycle, we have experimentally demonstrated that the size of the fundamental mode can be tuned by the applied voltage. The advantage of using LC-PSW for mode size transformation is that the effective index and mode size in the fabricated waveguide can be varied by an externally applied electric field. In this work, we have also experimentally demonstrated that the appropriate choice of the applied voltage can maximize the coupling efficiency between the LC-PSW and single-mode fiber. The proposed mode size converter can be used in LC photonic lightwave circuits to couple the light between optical devices with maximum efficiency. To improve the performance of LCWs in terms of threshold voltage, extinction ratio, and insertion loss, we have successfully designed, fabricated, and characterized rectangular-core channel LCWs with a cross-section of 10 μm × 5 μm (width × height) in Chapter 4. Our experimental results demonstrate that the device works as a low-voltage-controlled optical switch. The device offers several advantages, including easy integration with optical fiber pigtails, low insertion losses, low power dissipation, and electrical tunability. The fabricated device is further demonstrated as a voltage-controlled polarization selector that passes either TM or TE-polarized light with a polarization extinction ratio of 28 dB and 25 dB, respectively.

In Chapter 5, we focused on fabricating an active polarization beam splitter (PBS) by sandwiching the 6CHBT nematic LC between the two prisms. Polarization handling using an external source is highly desirable in applied optics and photonics to increase the degree of freedom of an optical system. Here, an electrically controlled LC-PBS is presented that can operate in two different modes: non-splitting mode and polarization splitting mode. The externally applied voltage can switch the mode

of the PBS, which makes the device active and flexible. The presented electrically controlled PBS exhibits features such as bistability with highly stable modes, large splitting angle, wider operating range, and ease of fabrication with lower cost. Chapter 6 investigates the method to detect the purity of an LC material using the SPR phenomena. The development of LC-based technology is happening at a quick pace in the design of various switchable optical devices due to the exceptional electro-optical properties of LCs. The purity of an LC is the primary concern for these applications. In this chapter, we present a straightforward and effective optical method to detect the purity of an LC using SPR phenomena. The Kretschmann configuration is used in the proposed technique, and an LC cavity is formed over the metal layer using a glass substrate. Various impurities are added in the pure LC, which disturbs the molecular arrangement of the LC molecules, and hence, the refractive index of LC changes. We have numerically calculated and experimentally observed the shift in the resonance angle for the impure LC as compared to the pure one. The experimentally measured sensitivity of the proposed technique is around 150^0/ RIU, which is comparable to the other Kretschmann configuration-based sensors. Compared to the existing LC purity detection method, the key advantages of the proposed method are its lightweight, compact design, label-free detection, and real-time monitoring capabilities.

In Chapter 7, we attempt to explore solar energy harvesting applications and discuss the possibilities of using LC to design and fabricate a highly efficient luminescent solar concentrator (LSC). LSC combined with photovoltaic cells is in high demand, and it is a very effective way to increase the efficiency of a commercially available silicon solar panel. This is a promising solution for building integrated photovoltaics (BIPV) and could be a highly important element of our daily life for solar energy harvesting. Despite having high potential, the optical efficiencies of the currently available LSCs are not very high. In this Chapter, we present a scattering enhanced optical efficiency of an LSC by incorporating a polymer-stabilized cholesteric liquid crystal with a high fluorescence organic dye between the two-glass substrates. In the waveguiding layer, the chiral nematic director of LC exhibits random orientation; hence, a scattering is observed in the film. These scattering elements increase the probability of light absorption of the dye in the ultraviolet region and subsequently enhance the re-emission of the light in the visible region. Moreover, the material shows a large Stokes shift and a very low overlap between the absorption and emission spectra. We have achieved a high optical efficiency of 37 %, along with a concentration factor of more than 4.5 for the fabricated LSC. A Monte Carlo simulation is also developed to calculate the efficiency of the proposed device theoretically, and it shows good agreement with the experimental results. These findings create opportunities for developing highly efficient LSC windows capable of generating power for BIPV applications. In the end, chapter 8 concludes the detailed work of all the chapters presented in the thesis. The potential applications and future scope of the proposed LC-based devices for next-generation optics, photonics, and solar energy harvesting are also described in this chapter.