Abstract

The burgeoning field of non-Hermitian formalism in photonics has recently garnered considerable attention due to its capacity to unveil unconventional phenomena. Exceptional Points (EPs) within non-Hermitian systems are particularly interesting, representing critical junctures where system behavior deviates significantly from the norm. EPs occur when coupled eigenvalues and corresponding eigenstates coalesce, leading to the collapse of the eigenspace-dimensionality of the underlying Hamiltonian. This collapse endows EPs with the characteristic of topological defects, and they have found applications in generating unique optical phenomena such as unidirectional lasing, enhanced sensing, asymmetric mode conversions, and optical isolation. This thesis explores EPs of various orders and investigates the resulting unconventional light dynamics in specialty planar optical waveguides with spatial refractive index variations and photonic bandgap waveguides. Customized planar optical waveguides and photonic bandgap waveguides featuring non-conservative elements like optical loss/gain are studied within a non-Hermitian framework to reveal topological avoided-crossing phenomena between coupled states/modes around specific singularities. The investigation delves into the intricacies of second-order, third-order, and fourth-order EPs within optical waveguides, uncovering unique mode excitation phenomena, chiral/non-chiral characteristics, and innovative methods for higher-order mode conversions. The study also extends to one-dimensional photonic bandgap waveguides, where the gain-loss processes enable precise control over TE modes through EPs. Dynamic encirclements around the EP lead to asymmetric mode conversions resilient to high fabrication tolerances. Conjugate EPs within dual-mode planar waveguides featuring $\mathcal{T}$-symmetric optical potentials and complex refractive index profiles are explored. Reverse chiral response achieved through dynamic encirclements of a second-order conjugate EPs ($EP2s$) yields varying dominant modes dependent on encirclement direction. This concept is extended to a $1D$ photonic bandgap waveguide system, emphasizing robustness in the face of high parameter tolerances. Moreover, higher order conjugate EPs in two complementary systems have also been investigated, which leads to unconventional light dynamics by exploiting the time-reversal $\mathcal{T}$ symmetry. On the other hand, the dynamical encirclement of EPs in the presence of local nonlinearity has also been studied. By incorporating Kerr nonlinearity in the presence of gain-loss, optical waveguides are able to exhibit direction-independent mode conversion. Higher-order mode-collapsing phenomenon is observed during dynamical encirclements around higher-order conjugate EPs in multimodal complementary waveguides, offering the potential for one-way light transmission and intricate optical responses. This comprehensive exploration advances the understanding of EPs in photonics and their application in unconventional optical devices, paving the way for transformative developments in integrated all photonic components and devices for next-generation communication as well as emerging quantum technological applications.