Exceptional point-based correlative nonreciprocal light propagation in nonlinear media

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The non-Hermitian Hamiltonian of an open (nonconservative) system can exhibit some spectral singularities as topological defects, called Exceptional Points (EPs), which results in a simultaneous coalescence of coupled eigenvalues and the corresponding eigenvectors. Recently, gain-loss engineering in different open systems has revealed EPs as nontrivial tools to control light-matter interactions [1]. In this context, a concept of conjugate EPs has recently been drawn [2] based on the complex parameter dependence of a non-Hermitian Hamiltonian. For a certain Hamiltonian $H(\delta)$, the presence of EPs can be realized via modulating a complex parameter $\delta = u + iv$, where two scenarios based on $v < 0$ and $v > 0$ analytically define two correlative time ($\mathcal{T}$)-symmetric variants of $H(\delta)$ [provided that $\mathcal{T} : \{x, t, i\} \rightarrow \{x, -t, -i\}$]. Such two $\mathcal{T}$-symmetric variants exhibit two conjugate EPs at two complex conjugate critical points: $\delta_c = u_c + iv_c$ and $\delta_c^* = u_c - iv_c$.

Here, we exploit such a concept of conjugate EPs in exploring a correlative nonreciprocal light guidance in two $\mathcal{T}$-symmetric nonlinear mediums. Nonreciprocity is achieved based on a controlled Kerr-type local nonlinearity in a planar gain-loss assisted waveguide with two $\mathcal{T}$-symmetric variants hosting two conjugate EPs. We establish that the dynamic gain-loss variations around two conjugate EPs (in their respective parameter spaces) allow the asymmetric transfer of two different modes through two waveguide variants, while considering the light propagation in the same direction (while no transmission in the opposite direction). Moreover, the explicit dependence of the nonlinearity-level is investigated in maximizing the nonreciprocal ratio (NR), where two $\mathcal{T}$-symmetric variants achieve their maximum NR at the same nonlinearity-level. The proposed mechanism to achieve such a correlative nonreciprocity can be implemented in microwave and optical domains. Our findings would enrich the platform to develop indispensable nonreciprocal components like isolators and circulators for a wide range of magnetic and photonic systems, including superconducting quantum circuits with microwave resonators.

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