Exceptional Line Formation and Flip-of-States in Degenerate Optical Microcavities

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1. Introduction

In the context of non-Hermitian systems flip-of-state phenomenon associated with an encircled second order exceptional point (EP) have attracted considerable attention [1, 2]. With an adiabatic variation of the chosen control parameters around an EP in parameter space, the corresponding coupled eigenvalues can be permuted in eigenvalue plane, exhibiting EP as a second order branch point. However, for an EP outside the closed loop, corresponding eigenvalues retain their initial positions. Such phenomenon exploiting continuous tuning of parameters via multiple EPS is yet to be explored. In this paper we propose a special line, coined as exceptional line that connects the successive EPS in parameter plane by virtue of the coupling parameters. Exploiting the interplay between the EPS on cascaded state-flipping mechanism along exceptional line we report the robustness of such phenomenon in presence of multiple EPS inside/outside the contour described by smooth /fluctuating variation of coupling parameters.

2. Design of microcavity and numerical results

Towards our goal, we design a 10μm 1D non-Hermitian Fabry-Parot type optical cavity with spatially imbalanced gain-loss as shown in Fig. 1(a) [3]. Using S-matrix formalism, we have identified five arbitrary pairs of poles, as an analogy to the complex eigenvalues of the associated Hamiltonian, for a chosen frequency range. With introduction of non-uniform gain-loss, a chosen pair of poles is mutually coupled. Adjusting the factor τ over the gain co-efficient (γ) up to 0.1, five different EPS are embedded and plotted in the (γ, τ)-plane as shown in Fig. 1(b). The best fitted curve indicates the formation a special single line, supporting all those EPSs, proposed as exceptional line. Now, exploiting the benefit of exceptional line, via switching between them with proper tuning on the coupling parameters we have exemplified the flip-of-state phenomenon following the encirclement [1] of single or multiple EPSs. In complex κ-plane, trajectories represents evolution of two eigenvalues associated with an EP, followed by the anticlockwise evolution of on the described contours in (γ, τ)-plane.

Accordingly, for study of mutual dependence on eigenvalue dynamics between two nearby EPSs, we display the eigenvalue behavior corresponding to EP3, for two different system configurations with respect to EP1. EP2 is located outside or inside the chosen contours around the EP1, as shown in Fig. 1(c)-[i] & [ii] for two different radii respectively. While considering the first case for two successive cycles around EP1 in (γ, τ)-plane both eigenvalues corresponding to EP3 return back to their initial position forming individual loops in κ-plane. Whereas for the second case they form a complete loop after second permutation.

3. Conclusions

Designing the unconventional microcavity, we have reported for the first time the formation of exceptional line supported by multiple EPSs. Via suitable tuning of coupling parameters along the exceptional line we have exemplified the robustness of state-flipping mechanism associated with EPSs. We have established that as long as we encounter an EP inside the enclosed loop, the flip-of-state mechanism is omnipresent irrespective of any moderate fluctuations. Novel cavity performance based on such robust scheme may open up a new class of integrated photonic devices.

To analyze the stability of such state-flipping mechanism against any unwanted deformation in the encircling parameters, we study the eigenvalue behavior of three consecutive EPSs in Fig. 1(d). The results are shown for a particular set of encircling parameters with deliberate fluctuations relative to an arbitrary center following the exceptional line such that EP2 and EP3 are present inside the loop and EP1 stays outside the loop. After two successive encirclements in parameter plane, the eigenvalues corresponding to EP2 and EP3 form a closed loop in κ-plane after second permutation in a very generic fashion, whereas the eigenvalues corresponding to EP1 form individual loops avoiding any permutation.

References