Non-Hermitian resonant energy transfer

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Abstract: Non-Hermiticity exhibits an excellent platform to achieve new insights in physics and technology. Here we discuss the influence of non-Hermitian environments on emission properties of a dipole. Using the perturbation theory, we reveal that resonant energy transfer between donor and acceptor molecules strongly enhances at the exceptional point. Our results are essential for nanooptical applications including light energy transport and signal processing on a chip.

Introduction

Parity-time (PT) symmetry and non-Hermiticity is a remarkable tool for tailoring light-matter interaction. It has been already achieved advantageous behaviors in scattering, lasing, coherent perfect absorption, wireless power transfer, etc. Therefore, this topic is under a close attention from the photonic community.

Non-Hermitian physics initiated by Bender and Boettcher [1] in relation to quantum mechanics was extended to optics due to possibility to associate a Hamiltonian with an optical system [2,3]. The optical non-Hermitian Hamiltonians including PT-symmetric ones then can have real eigenvalues. By changing system's parameters one is able to reach an exceptional point, in which sets of both eigenvalues and eigenvectors coalesce. The physics in vicinity of exceptional points is rich and can be analyzed from mode, topology and symmetry points of view. Many prospective applications of non-Hermitian systems as CPA-lasing and sensing are related to the behaviors near exceptional points [4]. In the particular case of a PT-symmetric system exceptional points separate PT-symmetric and broken-PT-symmetric states. Here we deal with some nanophotonic issues, namely, resonance energy transfer and spontaneous emission of dipoles interacting with non-Hermitian systems. In order to describe the system in vicinity of higher-order exceptional points we develop the appropriate perturbation theory.

Results

We consider a generic system described by the non-Hermitian Hamiltonian as a sum of unperturbed and perturbed parts [an example of such a system is shown in Fig. 1(a)]. The unperturbed Hamiltonian corresponds to that at the exceptional point, while the perturbed Hamiltonian is proportional to the small perturbation parameter ε. In the perturbation series for eigenvalues and eigenvectors the leading terms are proportional to $\varepsilon^{1/n}$, where n is the order of the exceptional point. Owing to the perturbation the degeneracy available at the exceptional point is lifted and we can generally determine the eigenvalues in two non-Hermitian phases corresponding to $\varepsilon<0$ and $\varepsilon>0$ [5]. We demonstrate such a behavior in Fig. 1(b) for PT-symmetric system possessing a second-order exceptional point at $\varepsilon=0$. Green's function as a Mittag-Leffler expansion can be also presented through the perturbation parameter ε. The Green function is indispensable for finding the local density of states and resonance energy transfer.

Using the perturbation theory, we can find the eigenfrequencies of the modes and compare the results with a numerical simulation. The degenerate eigenfrequency of unperturbed modes is generally a complex number $\omega_0 = \omega_0' + i\omega_0''$, the imaginary part of which determines decaying properties (both radiation and non-radiation) of the modes. When the decay is small, the local density of states and, therefore, the Purcell factor can increase at the

exceptional point [6]. Otherwise, the exceptional point does not affect the local density of states. It was confirmed in numerical and analytical calculations of the Purcell factor for the system of two coupled PT-symmetric rectangular waveguides [7]. The resonant energy transfer in a non-Hermitian system can be characterized by a spectral function $T(\omega)$ maximizing at the exceptional point. As it is seen in Fig. 1(c), the spectral function rapidly grows with the order of exceptional point. The increase of $T(\omega)$ with the order n is shown in [5] as a result of numerical simulation for mirror-assisted system of coupled resonators.

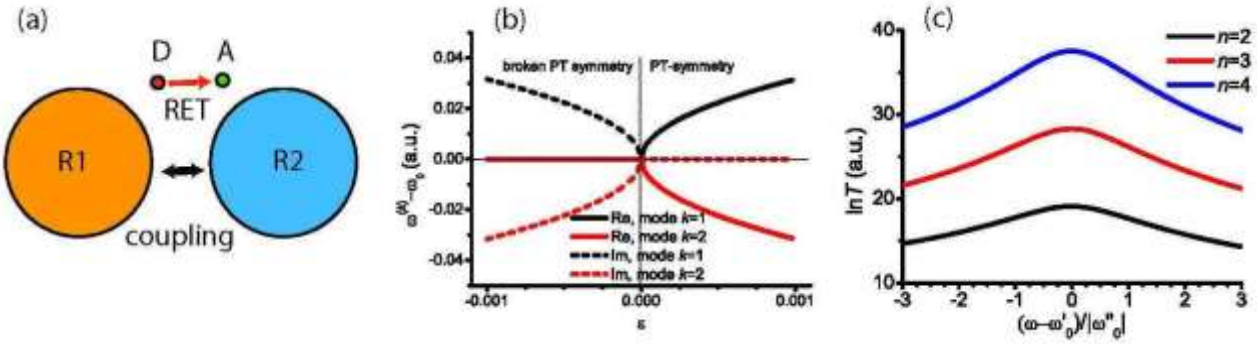

Figure 1. (a) Non-Hermitian system of coupled resonators to enhance resonance energy transfer (RET) between donor (D) and acceptor (A) molecules. (b) Departure of the eigenfrequencies $\omega^{(k)}$ of modes k from the degenerate frequency ω_0 as function of the perturbation parameter ε (order of exceptional point n=2). (c) Frequency dependence of spectral function $T(\omega)$ of the RET for different orders n of exceptional points.

To sum up, exploiting the developed perturbation theory near a higher-order exceptional point we have determined the closed-form frequency dependences of the local density of states and resonance energy transfer. Our results may find application for tailoring response of non-Hermitian systems at the nanoscale.

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