Coherent Excitation of Embedded Eigenstates in non-Hermitian $\mathcal{PT}$-Symmetrical Systems

Alex Krasnok[1*], Zarko Sakotic[1,2], Norbert Cselyuszka[2], Nikolina Jankovic[2], and Andrea Alú[1*]

[1]Advanced Science Research Center, City University of New York, New York, NY 10031, USA
[2]BioSense Institute-Research Institute for Information Technologies in Biosystems, University of Novi Sad, Dr Zorana Djindjica 1a, 21101, Novi Sad, Serbia
Author e-mail address: akrasnok@gc.cuny.edu, aalu@gc.cuny.edu

Abstract: The recently emerged concepts of coherent perfect absorption (CPA), i.e., the time-reversed counterpart of a laser and its generalization to Hermitian systems, coherent virtual absorption (CVA), are shown to be ideally suited for all-optical light manipulation. In this work, we demonstrate how the concept of coherent excitation can pave the way to light scattering control in an extreme fashion in non-Hermitian $\mathcal{PT}$-symmetrical systems supporting an embedded eigenstate.

The concept of embedded eigenstates (EEs), also known as bound states in the continuum (BIC) was originally proposed in 1929 by von Neumann and Wigner as a mathematical anomaly in quantum mechanics. In this regime, the electron wavefunction is predicted to be localized with no radiation within an open system, atom or potential well, inside the continuum of unbounded states. In recent years, the existence of EEs has been demonstrated in different areas of wave physics, including acoustics, hydrodynamics, and photonics reviling its general nature for wave physics. In this context, photonic structures have emerged as a particularly attractive platform for EE engineering owing to the ability to tailor their material and structural properties with unprecedented accuracy. It is commonly believed that true EEs can exist only in Hermitian systems, i.e., possessing no loss and gain, which stems from the fact that the EE requires a pole of the system scattering ($\hat{S}$) matrix to be coalesced with its zero on the real frequency axis. Nevertheless, EEs in $\mathcal{PT}$-symmetrical systems of coupled oscillators or waveguides have been theoretically predicted in recent studies.

Here, we present our recent observation of reviving quasi-EEs with large Q-factors in a non-Hermitian $\mathcal{PT}$-symmetrical regime. We show that $\mathcal{PT}$-symmetry is a necessary but insufficient condition to induce an EE in a non-Hermitian system. Our system consists of a dielectric resonant layer (permittivity of 2.25) sandwiched between two layers of epsilon-near-zero (ENZ) materials with Drude dispersion. This structure supports a BIC state at the intersection of the resonance of the dielectric slab and the plasma resonance of a zero-permittivity material, and it can be observed under *p*-polarized excitation. Adding a small amount of loss to ENZ layers (permittivity of 0+i0.01 at plasma frequency) turns the structure to non-Hermitian, implying the prompt disappearance of the BIC state. Although, adding gain to one of the ENZ slabs, making it $\mathcal{PT}$-symmetrical, restores a quasi-BIC spectrum, the non-Hermitian system does not support a true EE, but it does support a very sharp resonance.

Interestingly, we show that this quasi-BIC can be manipulated to induce a new type of BIC singularity in the complex frequency plane when considering coherent excitation of the $\mathcal{PT}$-symmetrical system by adding a monochromatic wave impinging on the opposite side of the slab, which allows achieving all-optical light transmission and reflection control. This coherent excitation in $\mathcal{PT}$-symmetrical system is a generalization of coherent absorption mechanisms in the special case of $\mathcal{PT}$-symmetry, and it allows light scattering control in extreme fashion.