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Parity-time symmetric waveguides with tailored dipoles and chiral features

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Abstract: We extend the standard coupled waveguide system with balanced gain and loss for PT-symmetry, in order to exploit and tailor the exceptional points. First, we place an electric dipole source between the waveguides, to create a contrast between wave propagation on both sides of the dipole by controlling its polarization. Secondly, we study the influence of chirality on the guided modes, by inserting a chiral material in the waveguide gap. We observe a strong chiral impact at degeneracies, and interesting avoided crossings at exceptional points arise.

Parity-time (PT) symmetry is the focus of various research projects due to its unique properties. [1] A standard photonic structure for PT-symmetry concerns coupled waveguides, one made of a gain material and the other with an equal amount of loss. The imaginary part of the refractive index in the waveguides defines the gain/loss parameter γ, that determines the operating regime: PT-symmetric when the two modes propagate without gain or loss, and PT-broken when one mode is amplified and the other decays. The transition between these two regimes occurs at the exceptional point (EP). On the one hand, we tailor an electric dipole source to the features of PT guided modes to create a contrast between wave propagation on both sides of the dipole. [2] On the other hand, we study the influence of chirality on these modes by inserting a chiral material in the gap between the waveguides.

Coupling a circularly or elliptically polarized electric dipole to a single waveguide can lead to directional excitation of waveguide modes. [3] This directionality is lost if the dipole is at the center of coupled waveguides but can be restored by taking advantage of the unique characteristics of PT modes. We place an electric dipole in the center of the air layer separating two PT-symmetric slab waveguides (fig. 1(a)). This setup is numerically simulated using an eigenmode expansion Maxwell equations' solver (CAMFR).

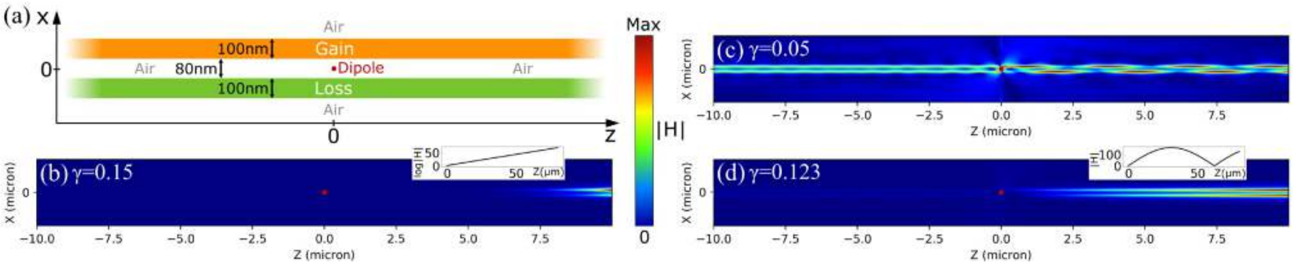

Figure 1 - (a) PT-symmetric coupled waveguides, infinite in the z direction. The dipole is at the red dot. (b-d) Magnetic field absolute value in the structure for various γ. The insets show the value at x=0. The value of the gain/loss parameter at the EP for our structure is γ_{EP} = 0.123.

For each γ, we search for the electric dipole that excites only one mode on one of the sides of the dipole. In the PT-broken regime ($\gamma > \gamma_{EP}$=0.1231 – fig. 1(b)), we choose to cancel the gain mode on the left, making the field considerably smaller than on the right side, as the gain mode on the right increases the field exponentially. In the PT-symmetric regime ($\gamma \le 0.1231$ – fig. 1(c,d)), one of the two propagating supermodes of the structure is removed on the left which produces a uniform field profile, while exciting both modes on the right causes a beating (fig. 1(c)). As γ increases, the beating pattern on the right side elongates until γ reaches the EP, where it is infinitely long (fig. 1(d) shows a close situation). Moreover, each of these contrasts can be switched between left and right by adapting the dipole polarization, which can be useful in integrated photonics applications.

Instead of a dipole, we then introduce a chiral material in the gap between PT-symmetric rectangular waveguides (fig. 2(a)). We simulate this setup with the finite element method using the SimPhotonics software, a Matlab Toolbox developed at the Laboratoire Charles Fabry. The gain/loss parameter is varied to explore the different regimes. The width of the gap is tuned to obtain desired features in the mode dispersion. We observe that chirality has the most effect on the modes when their dispersions cross, i.e., when they are degenerate. When the gap is narrow and achiral, the fundamental modes cross: a quasi-TM mode and the quasi-TE symmetric mode. An anticrossing appears between these modes when chirality is introduced in the gap (fig. 2(b)). An intermediate situation can be obtained for medium gaps: the TM-mode crosses the EP for an achiral gap, so chirality prompts a trimodal interaction that generates a complex, hybrid dispersion (fig.2(c)). For a larger gap, the quasi-TM mode crosses the antisymmetric TE-mode of a PT fork, leading to a `symmetry recovery' zone (an `inverted' EP, fig.2(d)).

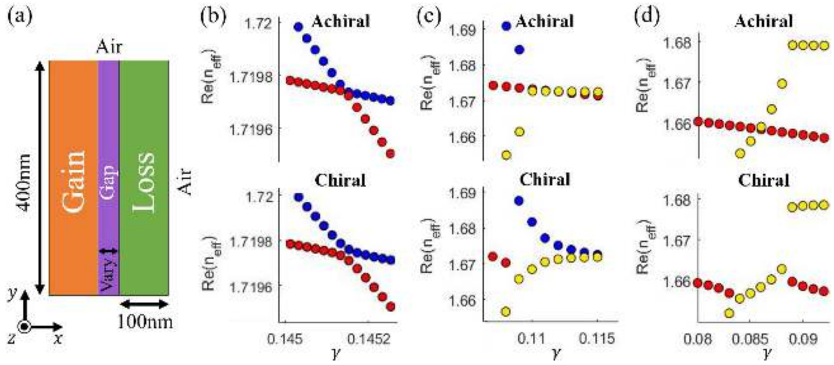

Figure 2 - (a) PT-symmetric rectangular waveguides and chiral gap, infinite along *z*. (b-d) Dispersion with an achiral (top) or chiral (bottom) gap, with width (b) 12nm, (c) 32nm, or (d) 44nm.

In the end, by using an adequate dipole coupled to PT-waveguides, a contrast in the mode excitation can be obtained between both sides, which can be exploited in integrated photonic structures. Furthermore, introducing a chiral material in the gap results in noticeable and rich avoided crossing patterns, which could be exploited in integrated chiral sensing applications.

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References

1. Feng, L., R. El-Ganainy and L. Ge, "Non-Hermitian photonics based on parity-time symmetry," Nat. Photonics, Vol. 11, 752-762, 2017.
2. De Corte, A. and B. Maes, "Tailoring of electric dipoles for highly directional propagation in parity-time-symmetric waveguides", Phys. Rev. A, Vol. 10, No. 023509, 2022.
3. Picardi, M. F., A. V. Zayats and F. J. Rodríguez-Fortuño, "Janus and Huygens Dipoles: Near-Field Directionality Beyond Spin-Momentum Locking," Phys. Rev. Lett., Vol. 120, No. 117402, 2018.