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Non-hermitian coupled modes controlled by the slot chirality in a parity-time symmetric waveguide pair.

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Abstract: Chiral materials inserted in the gap of PT-symmetric coupled dielectric waveguides induce a coupling of their non-Hermitian modes. The interplay of chirality-induced polarization-related anticrossing and exceptional points unveils a rich physics, featuring enhancement mechanisms such as slot geometries and providing unusual dispersion around exceptional points.

Coupling of two polarizations is at the core of chirality. Another coupling, the coupling of two waveguides, has been widely revisited in the presence of parity-time symmetric setting, i.e. a gain waveguide and a lossy waveguide, leading to the occurrence of an exceptional point (EP) where eigenvalues and eigenmodes coalesce. The aim of this exploration is to investigate the interplay of polarization coupling and mode coupling in terms of dispersion and fate of exceptional point, but in the waveguide geometry[1], unlike studies of layered systems such as [2]. To this aim we chose to study the case of two waveguides of identical elongated shape with a thin spacer between them, filled of chiral or achiral material (see black contours on Fig.1, the single guide cross section is 100x400 nm and the real part of its refractive index has a real part Re(n)= 2, the gap has index n=1.479 (achiral basis), the rest around is vacuum n=1). Among the scopes of keeping the chiral material thin is the issue of performing sensing of very small, comparable to those of the most sensitive biomolecular label-free techniques.

We thus study the dispersion and eigenmodes of coupled waveguides with a "chiral gap" as compared to an achiral gap, and attempt to get interactions that involve on a similar footing the PT symmetry features and the chiral features. Specifically, the chosen geometry, basically establishing non-interacting TE and TM polarization in the achiral case, is such that the achiral EP due to gain+loss in one polarization is also met by one of the branches of the other dispersion, so that the study can be seen as the quest of the nontrivial features arising from the anticrossing induced by chirality combined with a standard EP. Prior studies of 4-mode coupling [3] unveiled "symmetry recovery" effects, for instance, that we find as well here.

We model waveguide structures with using the SimPhotonics software implementing the finite element method. SimPhotonics is a Matlab toolbox developed at the Laboratoire Charles Fabry, it was modified to include the core coupling of chirality, the direct local coupling of E-field to H-field with a linear coefficient.

Besides the results of exact modal calculations, we have also exploited various basis to provide a quasi-analytical form to the dispersion. Specifically, we use either the individual mode basis (TE,TM in each waveguide) or the supermode basis (coupled waveguide) to interpret the various phenomena and check the underlying physical mechanisms.

Beside the specific interplay of the two effects (the EP behavior and the chirality), we explore the amount of "effective chirality" as observed from the coupling of modes and compare it to the bulk coupling. With a specific gap of 32 nm, we find the E-field patterns of Fig.1 (x is horizontal, y is vertical, z is along the waveguide), whereby a large field enhancement exists for the E_x component in the slot in the achiral case (top). We hypothesize that this slot effect is of foremost importance to get to the same degree of "effective chirality" as a bulk medium with the same chiral constant (κ=0.012 here, a value to make coupling appear neatly enough) as the one present only in the 32 nm gap.

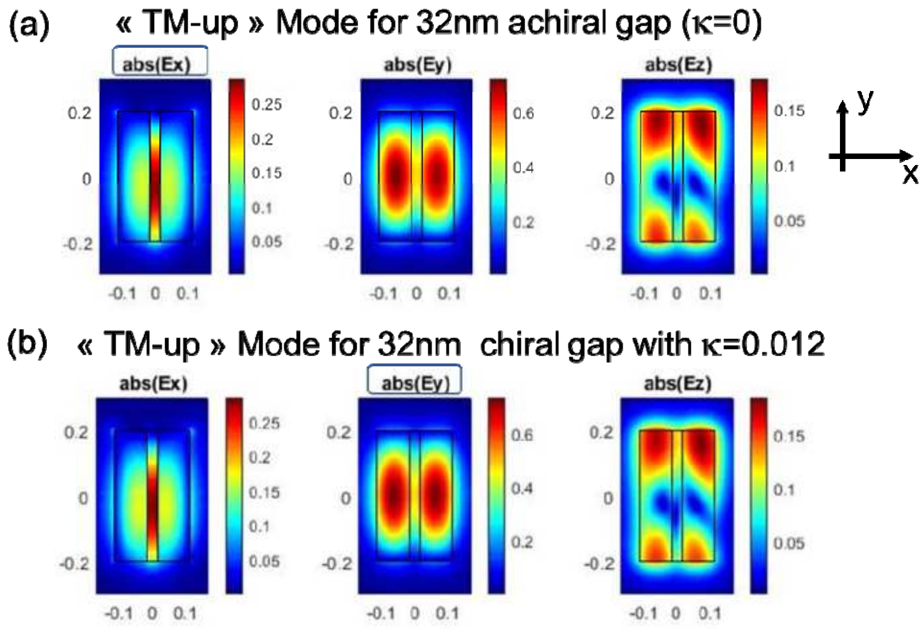

Figure 1 : Modes and coupled PT-symmetric waveguide geometry (black lines), operated at λ=350 nm, with a 32 nm gap. The right-side guide has gain and the left-side guide has loss. The gap is either achiral for the mode pictured in (a) or chiral for the mode pictured in (b). The mode is the « TM up » mode [1].

To conclude, we have unveiled a novel potential of PT-symmetric waveguides to get sensitive responses to chiral materials in small volume, thanks to the interplay of the various coupling operating in this situation.

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References

1. A. De Corte, M. Besbes, H. Benisty, B. Maes, "Chiral materials to control exceptional points in parity-time-symmetric waveguides," Phys. Rev. A Vol.109, 023521, 2024.
2. I. Katsantonis, S. Droulias, C. M. Soukoulis, E. N. Economou,T. P. Rakitzis, and M. Kafesaki, "Chirality sensing employing parity-time-symmetric and other resonant gain-loss optical systems," Phys. Rev. B, Vol.105, 174112, 2022.
3. N. X. A. Rivolta and B. Maes, "Symmetry recovery for coupled photonic modes with transversal PT symmetry," Opt. Lett., Vol.40, 3922 (2015).