Parity-Time coupled microresonators: Kramers-Kronig limitation

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New complex photonics structures, namely parity-time (PT)-symmetric structures, have inspired the innovative exploration of photonic structures with combined gain and loss. PT-symmetric structures are identified by their signature exceptional point (EP); operation below this point yields a completely real eigenmode/frequency, but above this point the eigen-frequencies are complex conjugates [1], [2]. Several PT-symmetric structures, such as coupled waveguides and Bragg gratings, have been studied theoretically and experimentally, and exhibit exciting behaviour and components such as unidirectional loss-induced transparency, a coherent perfect absorber laser, and a photonic analogue of a topological insulator.

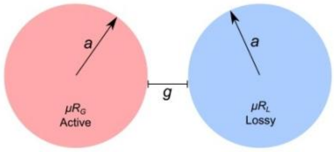

Fig. 1 Illustration of coupled micro-resonators, each with radius a, separated with a gap g and surrounded by air. μR_G acts as an active resonator and μR_L as a lossy resonator,.

In passive structures, the relation between dispersion and losses is described by the Kramers-Kronig equations (KKE). Recently, the validity of those equations has been confirmed for PT-symmetric structures under a broadband excitation[3]. In this talk, we use a KKE argument to show that the presence of dispersion alters the eigen-frequencies of coupled PT coupled microresonators (Fig. 1), so that their eigen-frequencies are no longer complex conjugates after the EP. In a dispersive material the gain/loss spectra align to the resonant frequency only at a single frequency. Fig. 2(a) shows the real part of the eigen-frequencies of mismatched PT-coupled micro-resonators for material with gain/loss spectra centred at $\omega_\sigma = 2\pi(f_0 + \delta)$, for $\delta = 0.05$ THz. It is noted that the coupled system no longer has an EP; the imaginary part of the eigen-frequencies splits early compared to the matched case, $\delta = 0$. The difference in the real part of eigen-frequency for a fixed gain/loss parameter $\gamma_\sigma = 7.5$ rad/ps, is denoted by Δ (see Fig. 2(a)) and is shown in Fig. 2(c). The figure shows that the operation of PT-coupled micro-resonators with practical parameters requires that the gain/loss spectra align with the resonant frequency of the resonator.

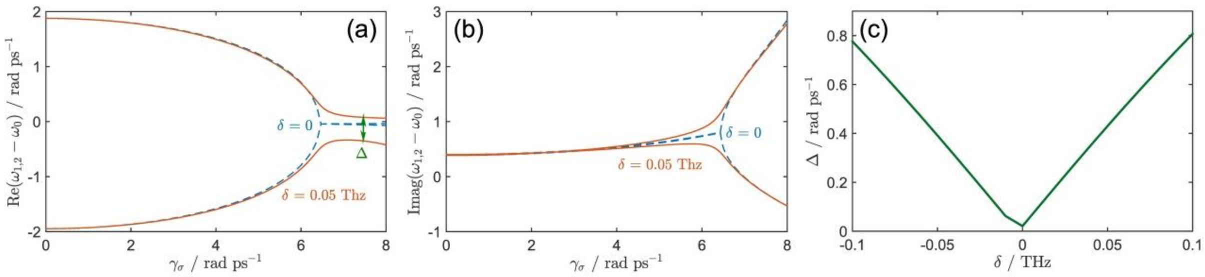

Fig. 2(a,b) Real and imaginary part of the eigen-frequencies of PT-coupled microresonators with mismatch between the material atomic transitional frequency and the resonant frequency where $\omega_\sigma = 2\pi(f_0 + \delta)$; (c) the difference of real part of eigen-frequency Δ (see Fig. 2(a)) for a fixed value of gain/loss parameter $\gamma_\sigma = 7.5$ rad/ps and different mismatch parameter δ. Operation in the (7,2) mode with resonant frequency $f_0^{(7,2)} = 341.59$ THz. $a = 0.24$ μm and $g = 0.24$ μm. For material model refer to [4].

References

[1] C. E. Rüter, K. G. Makris, R. El-Ganainy, D. N. Christodoulides, M. Segev, and D. Kip, “Observation of parity–time symmetry in optics,” *Nat. Phys.*, vol. 6, no. 3, pp. 192–195, Jan. 2010.

[2] K. G. Makris, R. El-Ganainy, and D. N. Christodoulides, “Beam Dynamics in PT Symmetric Optical Lattices,” *Phys. Rev. Lett.*, vol. 100, no. 10, p. 103904, Mar. 2008.

[3] A. A. Zyablovsky, A. P. Vinogradov, A. V. Dorofeenko, A. A. Pukhov, and A. A. Lisyansky, “Causality and phase transitions in PT-symmetric optical systems,” Phys. Rev. A, vol. 89, no. 3, p. 033808, Mar. 2014.

[4] S. Phang, A. Vukovic, H. Susanto, T. M. Benson, and P. Sewell, “Impact of dispersive and saturable gain/loss on bistability of nonlinear parity-time Bragg gratings.,” *Opt. Lett.*, vol. 39, no. 9, pp. 2603–6, May 2014.