オプトメカニクス系における PT 対称性の光学的制御：理論的検討

Optical control of parity-time symmetry in optomechanical systems: theoretical analysis

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Introduction: Studies of parity-time (PT) symmetry in photonics endow researchers with new methods to manipulate light by controlling gain, loss and the coupling between optical componenents [1]. Optomechanics tells us that optical cavities can be used to either amplify (gain) or cool (loss) mechanical resonators, which are the inherent advantages of optomechanical (OM) systems for the studies of PT symmetry. In a previous proposal [2], authors controlled the gain/loss but fixed the coupling with mechanical connections. In this work, we theoretically investigate an OM system with a tunable parametric coupling between two mechanically separate resonators via optical spring effect, which thus can realize the all-optically-controlled gain, loss and coupling rate for PT-symmetric operations.

Results: The system consists of two mechanical resonators and three optical cavities (see their respective functions in Fig. 1). Its mechanical equilibrium can be described by ***F***X=0 (***F***: force operator, X: displacement function. See the matrix and vector in Fig. 1). Γ_{eff} is effective damping rate, consisting of intrinsic (Γ_{intr}) and the optically-induced (Γ_{opt}) damping rates, and the gain (loss) is realized by $\Gamma_{\mathrm{eff,L}}<0$ ($\Gamma_{\mathrm{eff,R}}>0$). g represents the cavity-mediated coupling rate. Eigenfrequencies of the resonators can be solved by $|\boldsymbol{F}|=0$. The values of all the parameters are taken from a practical device [3]. The calculated g and Γ_{eff} (experimentally accessible values) versus laser detuning ($\Delta=\omega_{\mathrm{laser}}-\omega_{\mathrm{cavity}}$) and OM coupling strength are shown in Fig. 2(a,b). We set $\Gamma_{\mathrm{eff}}=\Gamma_{\mathrm{eff,R}}=-\Gamma_{\mathrm{eff,L}}$ (dashed lines in Fig. 2(b) for example) for PT-symmetric operations. The calculated eigenfrequency deviation of the left resonator as functions of Γ_{eff} and g are shown in Fig. 2(e,f). The exceptional points (EPs), which emerge at by $\Gamma_{\mathrm{eff}}=2g$, are observed.

Conclusion: We theoretically demonstrated that PT-symmetric and PT-symmetry-broken phases in a practical OM system can be switched solely by optical means. This scheme could be applied for RF signal processing and inertial sensing.

References: [1] R. El-Ganainy *et al., Nat. Phys.* **14**, 11-19 (2018). [2] Z. Feng *et al., Opt. Lett.* **43**, 4088 (2018). [3] F. Tian *et al., JSAP spring* **66th**, 12a-W631-2 (2019).

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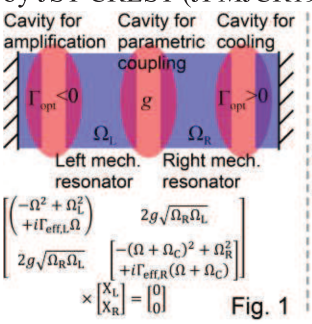

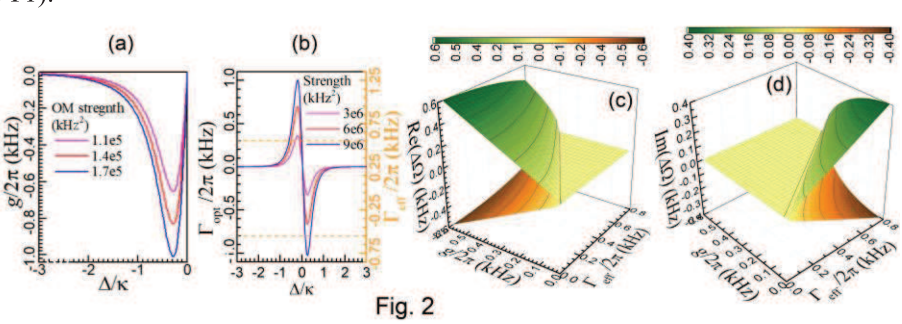

Fig. 1 Upper: schematic of the system. $\Omega_{\mathrm{L(R)}}$, Γ_{opt} and g denote angular frequency of the left (right) mechanical resonator, optically induced damping rate, and cavity-mediated coupling rate between the resonators, respectively. **Lower:** detailed equation of motion describing the system. $X_{\mathrm{L(R)}}$, $\Gamma_{\mathrm{eff,L(R)}}$ and Ω_C denote displacement, effective damping rate, and frequency for parametric coupling, respectively. $\Gamma_{\mathrm{eff}}=\Gamma_{\mathrm{intr}}+\Gamma_{\mathrm{opt}}$ and we select $\Gamma_{\mathrm{intr}}=0.25$ kHz×2π here.

Fig. 2(a) g as a function of laser detuning (Δ), where $\Delta=\omega_{\mathrm{laser}}-\omega_{\mathrm{cavity}}$ and is normalized by the cavity decay rate (κ). Note: OM strength is calculated by $n_c(g_{OM}/2\pi)^2$, where n_c is the photon number circulating in the cavity and g_{OM} is the OM coupling rate. **(b)** Γ_{eff} and Γ_{opt} as functions of laser detuning. **(c,d)** Eigenfrequency (incl. real and imaginary parts) of the left resonator deviated from its intrinsic frequency ($\Delta\Omega=\Omega_{\mathrm{eigen}}-\Omega_{\mathrm{L}}$) as functions of g and Γ_{eff} ($\Gamma_{\mathrm{eff}}=\Gamma_{\mathrm{eff,R}}=-\Gamma_{\mathrm{eff,L}}$).