Time-symmetry breaking phase transition at a meeting point of exceptional point and Fano resonance in a microcavity exiton-polariton system

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We have found out that time-symmtery breaking occurs as a third-order phase transition in a microcavity exciton-polariton system which is coupled with a one-dimensional photonic band, when an exceptional point and Fano resonance point meet together at a band edge with the Van-Hove singularity of a photonic band. At this critical point, a decay rate as a function of an exciton-polariton energy ε changes from $\varepsilon^{1/2}$ to $\varepsilon^{5/2}$, as shown in Fig.1, where third order derivative with respect to ε diverges. Around this critical point, an analytical expression of a decay rate is represented by

$$\mathrm{Im[z]} = \pm \frac{\varepsilon^{5/2}}{4\sqrt{2}\alpha^2} \qquad (\varepsilon > 0) \ , \tag{1}$$

as shown in dashed lines in Fig.1(b). This higher order phase transition indicates that a large fluctuation in time scale emerges around this critical point. The result Eq.(1) also shows the non-analyticity with respect to the coupling constant at $\alpha = 0$. Hence one cannot obtain this result through the ordinary perturbation analysis.

This is quite contrast to a time-symmetry breaking phase transition described by a phenomenological effective Hamiltonian with a two-by-two Jordan block structure where its complex eigenvalues and eigenstates coalesce, as known as an exceptional point.[1, 2] Since a phenomenological effective Hamiltonian does not take into account its own eigenvalue dependence, it gives rise to a first order phase transition. It is found that a persistent bound state (PBS) plays an important role in this non-analytic behavior.

In this work, based upon the microscopic dynamics, we have solved a nonlinear complex eigenvalue problem of the energy-dependent effective Hamiltonian that leads to time asymmetric resonance states. [3] Through this argument we see an interesting relation to complex eigenvalues of the resonance state, exceptional points with the Jordan block structure, the Fano resonance, PBS, and time-symmetry breaking phase transition.

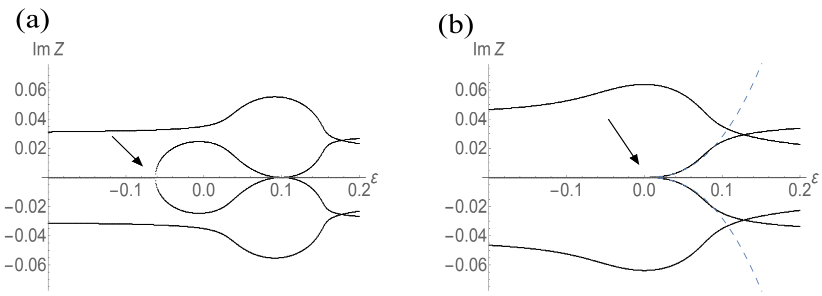

Figure 1: Decay rate as a function of one of the exciton-polariton energy. In (a), the other exciton-polariton energy is fixed at $\varepsilon_d = 0.1$, where Fano point and EP are separated, while in (b) the both coincide at $\varepsilon = \varepsilon_d = 0$. The arrow indicates a time-symmetry breaking point. Dashed lines reoresent Eq.(1).

References

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[2] N. Hatano and G. Ordonez, *J. Math. Phys.* **55**(2014)122106, and *references therein*, S. Garmon, I. Rotter, N. Hatano, and D. Segal, *Int. J. Theor. Phys.* **51,** (2012) 3536.

[3] E. C. G. Sudarshan, C. B. Chiu, and V. Gorini, *Phys. Rev. D* **18** (1978) 2914, T. Petrosky, I. Prigogine, and S. Tasaki, *Physica A* **173** (1991) 175.