Parity-time-symmetric whispering-gallery microcavities

2016.04.05

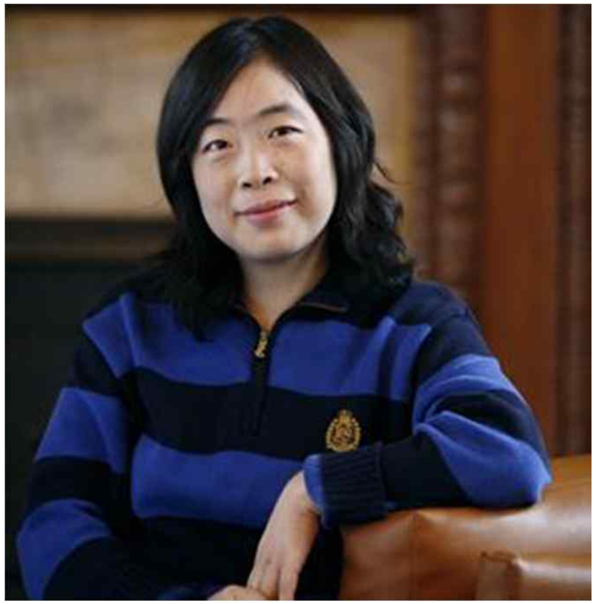
QFLL Journal Club
Jaewon Shim

Tables of Contents

- Research Group
- Introduction
- Experimental Setup
- Results
- Summary

Research Group

Principal Investigator



Lan Yang(Edwin H. & Florece G.S. Prof.)
Washington Univ. in Saint Louis.
Dept. of Engineering & Applied science

BS, Univ. of Science & Technology of China, 1997
MS, Univ. of Science & Technology of China, 1999
MS, Caltech, 2000
PhD, Caltech, 2005

PhD Candidate

Bo Peng

Fellow Researcher

Sahin Ozdemir

Research Group

Recent publishes of Lan Yang Group

"Loss induced suppression and revival of lasing"
B. Peng, S. K. Ozdemir, S. Rotter, H. Yilmaz, M. Liertzer, F. Monifi, C. M. Bender, F. Nori, and L. Yang
Science. Vol. 346, Issue 6207, 328-332 (2014)

"Highly sensitive detection of nanoparticles with a self-referenced and self-heterodyned whispering-gallery Raman microlaser"
SK Ozdemir, J Zhu, X Yang, B Peng, H Yilmaz, L He, F Monifi, GL Long, L Yang
Proceedings of the National Academy of Sciences (PNAS), Vol. 111, No. 37, E3836-3844 (2014)doi: 10.1073/pnas.1408283111

"What is- and what is not- Electromagnetically-Induced-Transparency in Whispering-Gallery-Microcavities"
B. Peng, SK Ozdemir, W. Chen, F. Nori and L. Yang
Nature Communication, Vol. 5, Article number: 5082 (2014)

"Interfacing whispering-gallery microresonators and free space light with cavity enhanced Rayleight scattering"
J. Zhu, SK. Ozdemir, H. Yilmaz, B. Peng, M. Dong, M. Tomes, T. Carmon, and L. Yang
Scientific Report, Vol. 4, Article number: 6396 (2014)

"Label-free particle sensing by fiber taper based Raman spectroscopy"
P. S. Edwards, C. T. Janisch, B. Peng, J. Zhu, S. K. Ozdemir, L. Yang, and Z. Liu
IEEE Photonics Technology Letters, Vol. 26, Issue 20, 2093-2096 (2014)

"On-Chip Titanium Dioxide Whispering Gallery Microcavities"
J. Park, SK. Ozdemir, F. Monifi, T. Chadha, S. H. Huang, P. Biswas, and L. Yang
Advanced Optical Materials, Vol. 2, Issue 8, 711-717, August 2014

"Parity-time(PT)-symmetric phonon laser"
H. Jing, SK.Ozdemir, X.Y. Liu, J. Zhang, L. Yang and F. Nori
Physical Review Letters, 113, 053604, July 30, 2014

Introduction

Parity-Time Symmetry

$P: p \to -p$
$T: t \to -t$

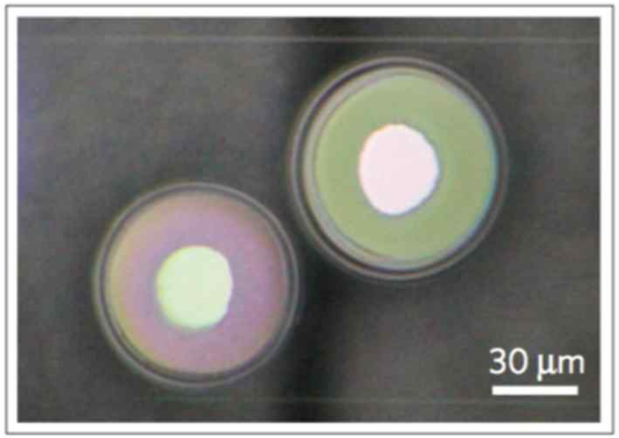
Even for non-Hermitian Hamiltonian, under the PT symmetry, it can have real eigenvalue spectra

PT symmetric Hamiltonian

$$PTH = HPT$$

To make PT-symmetric system, turn the pump on to the active resonator.
It is easy to exchange the energy each other. These identical resonators consistent with PT symmetry.

b



Introduction

Rate equation for the two coupled-resonator system

$$\frac{da_1}{dt} = -iw_1 a_1 - \frac{\gamma_1 + \gamma_c}{2} a_1 - i\kappa a_2 - \sqrt{\gamma_c} a_{in}$$

$$\frac{da_2}{dt} = -iw_2 a_2 - \frac{\gamma_1}{2} a_2 - i\kappa a_1$$

Corresponding eigenfrequencies.(tune the resonances to degenerate)

$$\omega_{\pm} = \left[\omega_0 - \frac{i}{4}(\gamma_1 + \gamma_c + \gamma_2)\right] \pm \frac{1}{4}\sqrt{16\kappa^2 - (\gamma_1 + \gamma_c - \gamma_2)^2}$$

If strong coupling, then it is called two super modes.

Input-output relation

$a_{out} = a_{in} + \sqrt{\gamma_c}$

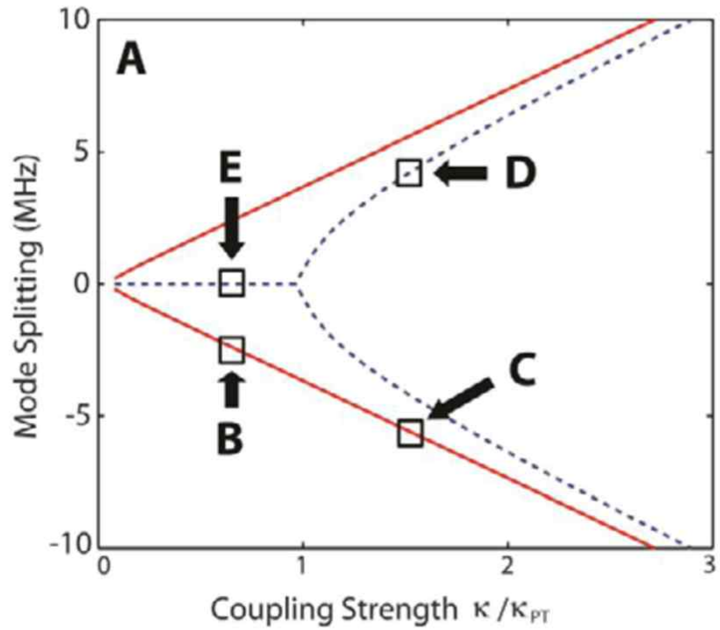
a_i: input fields in resonators

κ: coupling strength

γ_c>0: coupling loss between resonator and fiber waveguide

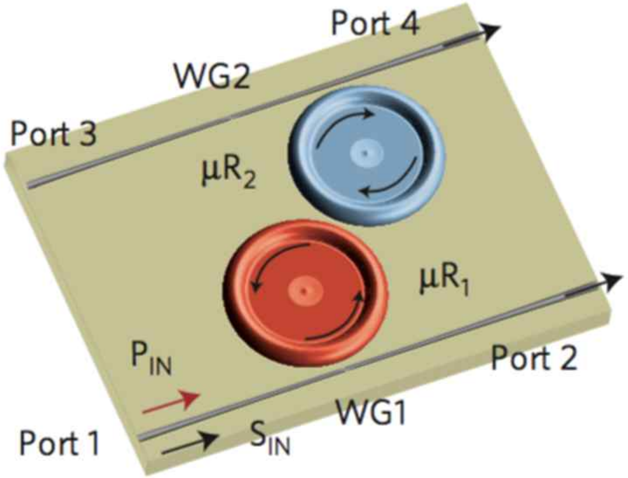
γ_k: loss or gain of resonator

(γ_k>0: loss, γ_k<0: gain)

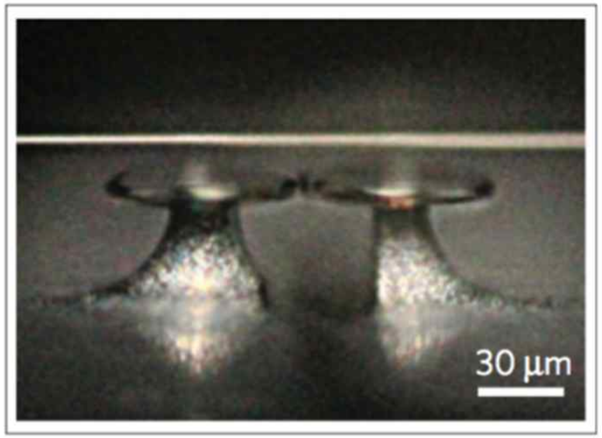


Experimental Setup

a



c



$Er3^+$ doped active resonator(red) & passive resonator(blue).

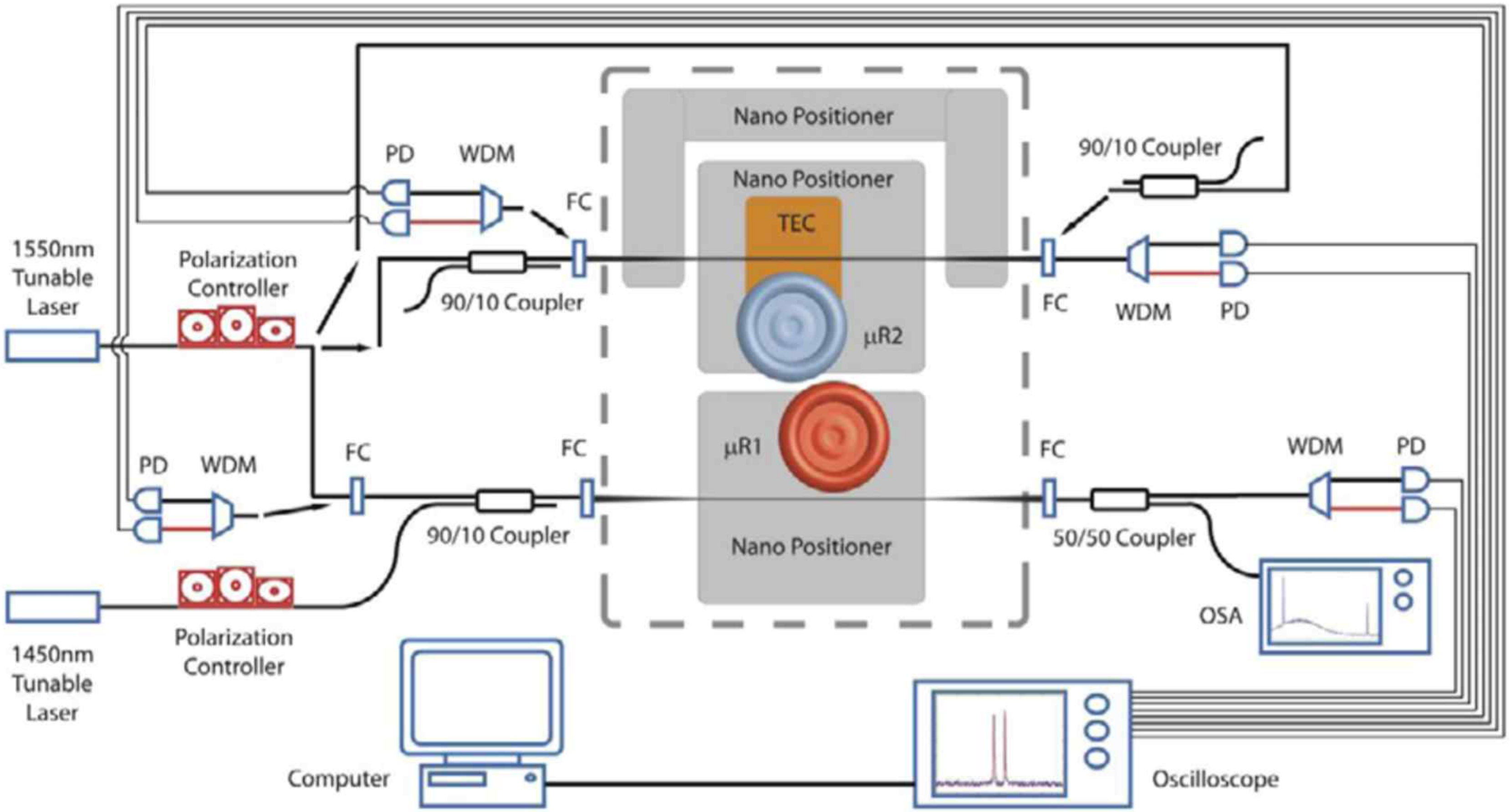
They are coupled to each other by evanescent waves.

Fiber tapers placed parallel to each other with similar wait size.

1550nm band pump to active resonator & 1460nm band pump to passive.

They are fabricated by lithographic procedure.

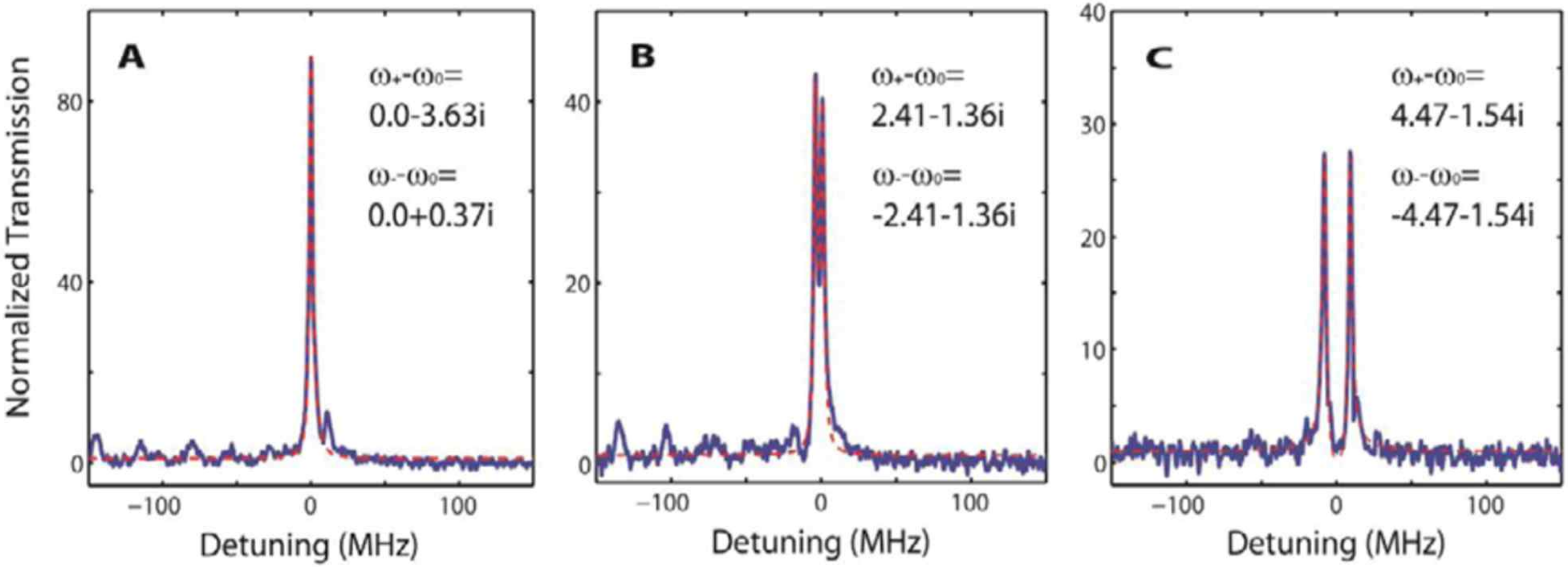
Experimental Setup



Results

As optically pumped to active resonator, it achieves gain and passive have loss.

At fixed gain-loss ratio, varying the coupling constant κ, observed PT phase transition. In this experiment κ_{PT}=4.16MHz



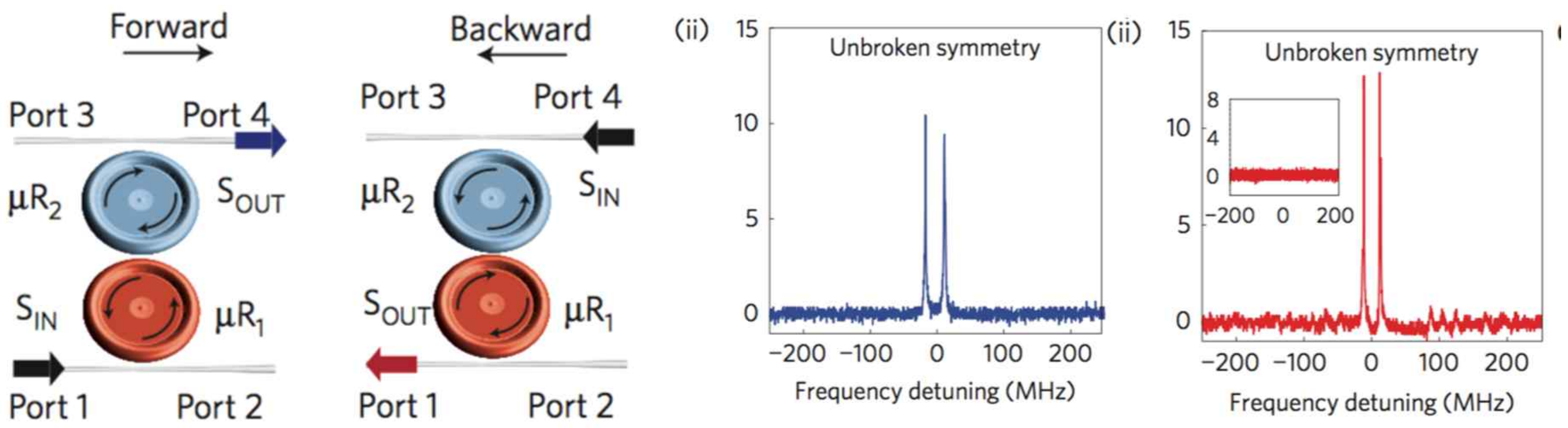
$\kappa = 2.95MHz$ $\kappa = 4.16MHz$ $\kappa = 9.75MHz$

Results

PT phase transition is said to be the optical system behaves as reciprocal to non-reciprocal in this experiment.

At low power(1μP) both broken & unbroken symmetry is reciprocal. But turn pump on, balanced gain-loss achieved. It results unbroken symmetry.

Mode splitting due to coupling is showing the gain compensates the loss.

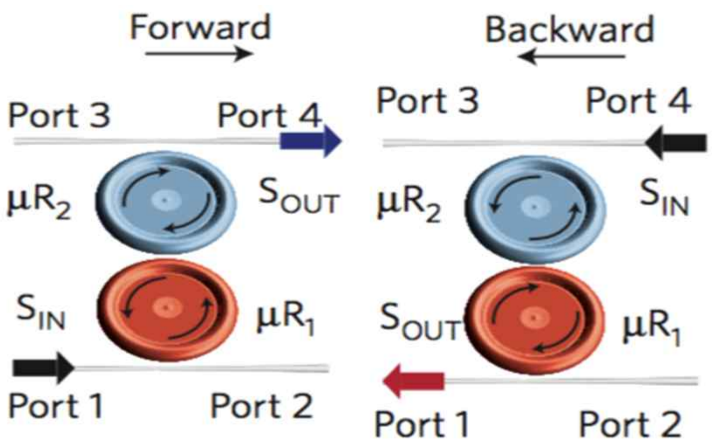


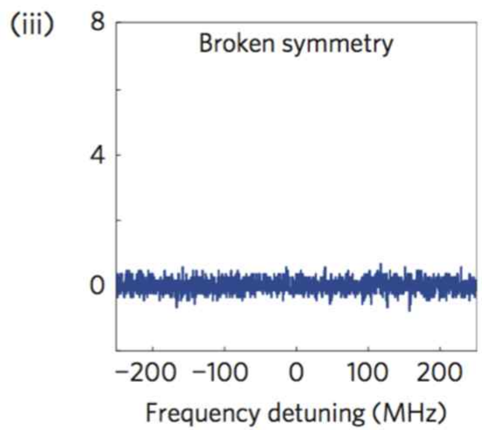
Forward Backward

Results

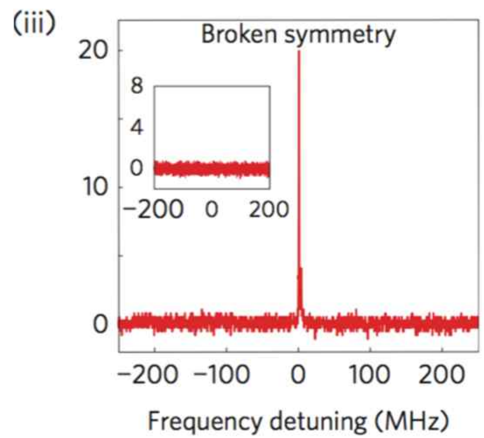
However as coupling strength κ decreases system transit to the broken symmetry. It appears non-reciprocal behavior.

The lower input power is 80nW in this case. No signal detected Forward direction.



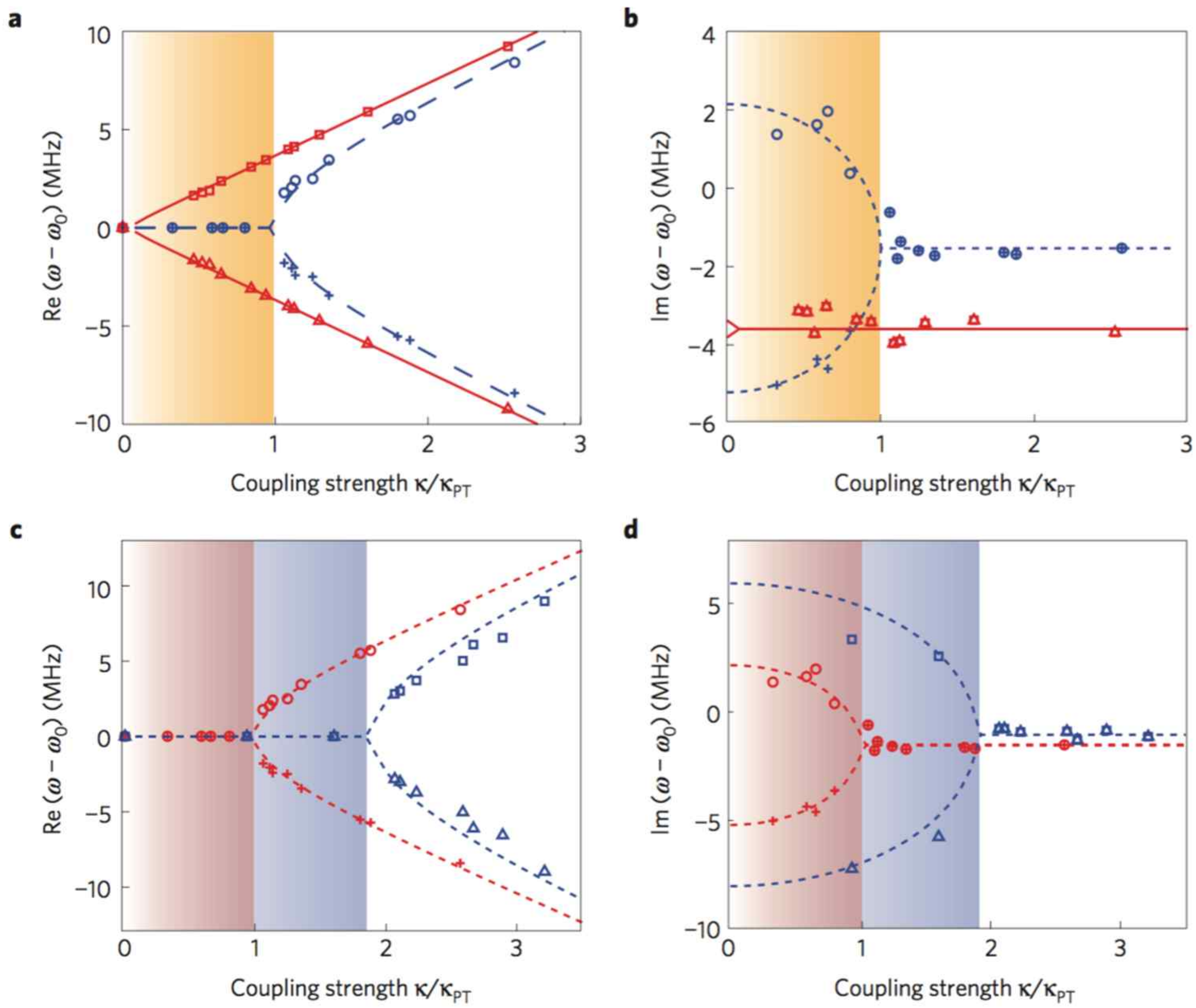


Forward



Backward

Results



a
b
c
d
Re (ω − ω0) (MHz)
Im (ω − ω0) (MHz)
Coupling strength κ/κPT
Coupling strength κ/κPT
Coupling strength κ/κPT
Coupling strength κ/κPT

Results

Their experiment extend PT-symmetric optics from cm/m scale structres to on-chip micro-scale structures.

They made PT-symmetric systems by microresonators instead of waveguides.

Authors observed strong non-reciprocity in the nonlinear regime with a very low power threshold in this PT symmetric system.

This system could be applied to the electromagnetically induced transparency in coupled resonators may benefit from PT symmetric microresonators.

Could lead to a new style of synthetic optical systems of on-chip manipulation and control the light propagation.

Q&A