Observation of Anti-parity-time Symmetry on Chip

Heng Fan[1,2], **Jiayang Chen**[1,2], **Zitong Zhao** [1,2], **Jianming Wen** [3], **Yuping Huang** [1,2,*].

1 Physics Department, Stevens Institute of Technology, Castle Point at Hudson, Hoboken, NJ, 07030, USA
2 Center for Quantum Science and Engineering, Stevens Institute of Technology, Castle Point at Hudson, Hoboken, NJ, 07030, USA
3 Department of Physics, Kennesaw state University, Marietta, Georgia 30060, USA
**yhuang5@stevens.edu*

Abstract: We report an on-chip realization of non-Hermitian optics with anti-Parity-Time(Anti-PT) symmetry by constructing a fully-passive, nanophotonic platform consist-ing of three evanescently-coupled nanowaveguides.

1. Introduction

Non-Hermitian optics attracts much of attention due to its peculiar property and potential applications such as enhanced sensing at exceptional points [1], and PT-symmetric laser [2]. Physical realizations of PT symmetry are usually proposed with arrangement of gain and dissipation elements in optics to construct complex potential energies, owing to the mathematical equivalence between the quantum Schrodinger equation and paraxial electromagnetic propagation equation [3]. As a counterpart, anti-PT symmetry is far beyond a trivial unitary transfer from PT symmetry. First, it releases the balanced gain and loss strain imposed on PT symmetry experiment. Especially for optical gain, sources are limited and not flexible on spectrum and gain power. It offers a more convenient method to realize functional components to explore non-Hermitian physics on a broader view, compared to PT symmetry experiments. Second, there are vastly different dynamics between PT and anti-PT symmetry systems. The eigenvalues of anti-PT symmetry evolve from pure imaginary in symmetry phase to complex in symmetry broken phase, as opposite to PT symmetry systems whose eigenvalues are transited from pure real number to complex,versatile, around the striking phase point. The novel dynamics could lead to intriguing phenomena, such as equal power splitting we present later.

2. Experimental design and results

A schematic of the anti-PT nanophotonic circuit is depicted in Fig. 1(a) and (b), which implements the proposal in Ref. [4, 5]. It consists of three evanescently coupled waveguides, labeled as 1, 2, and 3. They are fully etched by ion milling on a Z-cut lithium niobate thin film bonded on silicon oxide above a silicon substrate. To construct a anti-PT system, a Chromium strip, deposited upon Waveguide 2, introduces a huge loss γ to mode in Waveguide 2. The effective imaginary coupling strength $\Gamma = \kappa^2/\gamma$ between Waveguides 1 and 3 formulates through adiabatic elimination of mode in Waveguide 2, where κ is the coupling strength between adjacent waveguides. The phase transition happens when Γ is equal to half of the modal propagation constant difference between Waveguide 1 and 3 [$\Delta = (K_1 - K_3)/2$]. When $\Gamma > \Delta$, this system resides in anti-PT symmetry region. Two eigenvalues are pure negative imaginary which means two eigenstates propagate though this structure with different dissipation rate. Especially, the extinction ratio between two eigenstates is maximized when Δ is zero. Only one eigenstate could survive when the length of structure is long enough, under this circumstance. The peculiarity, equal power distribution in Waveguide 1 and 3 of eigenstate in symmetry region, could be used to realize a broadband equal power splitting function. When $\Gamma < \Delta$, this system evolves into anti-PT symmetry broken region. This system exhibits non-reciprocal behavior. The optical power remains in one waveguide when Δ is large. To continuously observe system's dynamical evolution from symmetry to symmetry broken phase and vice versa, we fabricate two micro-heaters on Waveguide 1 and 3. Δ is swept through thermo-optic effect. To increase tunability of the micro-heaters, only fundamental transverse-magnetic mode (TM) is excited in waveguides, and a trench to partially block thermal flow is etched.

In our experiment [6], a polarized beam is injected into Waveguide 3 through an objective lens. The output of Waveguide 1 and 3 are collected by a lensed fiber, then measured by a power meter, respectively. Electrical power is firstly applied to the micro-heater on Waveguide 1. Both output power of Waveguide 1 and 3 increase along the increasing of heating power. The output power reaches maximum simultaneously when the heating power is 144 mW, a sign that Δ is close to zero. The output power from two waveguides are almost equal at this time. We demonstrate a broadband equal power splitter when the heating power is fixed at 144 mW. The output power is measured as the input wavelength is swept. Result is presented in Fig. 1 (d). Then, the electrical power is switched to the micro-heater on Waveguide 3. Both output power plummet as expected along the increasing heating power. The power measurement result is presented in Fig. 1 (c) where negative and positive heating power represent the electrical power applied to the micro-heaters on Waveguide 1 and 3, respectively. Black region means symmetry broken phase.

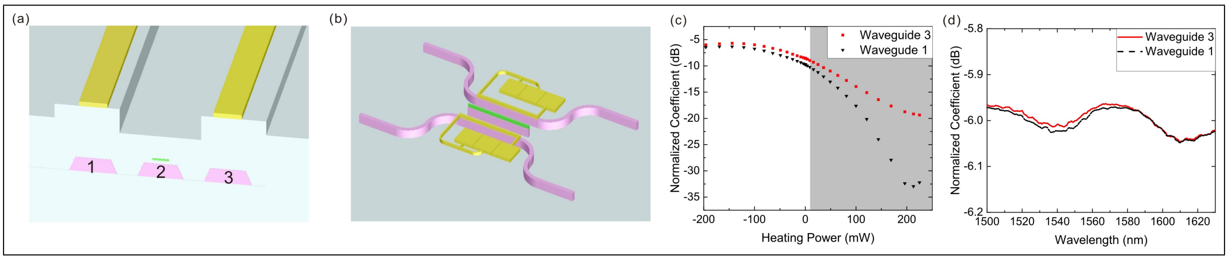

Fig. 1. Anti-PT structure with three laterally coupled waveguides. (a) and (b) show the side and top views. The top gap between the Waveguides is around 820 nm. The width and thickness of the middle trench are 1.9 μm and 690 nm, respectively. Its side wall, etched through ICP-FL, is at an angle close to 90 degree. (c) Summary of power measurement result. (d) Broadband equal power splitting result.

In conclusion, we have demonstrated anti-PT symmetry and its transition into a broken phase using an all-passive, nanophotonic platform. By thermal tuning, we observed striking phenomena like power equal splitting which would be useful in large scale photonic circuits, with its exceptional resistance to fabrication errors.

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