# Electro-optic tuning of non-Hermiticity in a silicon microring resonator

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**Abstract:** We demonstrate a silicon photonic passive PT-symmetric structure operating at an exceptional point, with dynamic mode-splitting tunability enabled by a local heater. 

## 1. Introduction

Exceptional points (EPs) are non-Hermitian spectral degeneracies where both the eigenvalues and the corresponding eigenstates of a system coalesce. Optics has been a fertile field to study the EP physics and the effects of EPs on wave transport and control, including loss-induced lasing, unidirectional reflectionless light transport and enhanced response to external perturbations [1-4]. The majority of these systems are either fabricated to operate in the vicinity of an EP without tunability or tuned towards an EP by 3D nanopositioners. Here we demonstrate deterministic control of chiral EPs in a silicon microring resonator by electro-optical tuning of the relative phase between two notches of asymmetric geometries using an integrated local heater. By varying the electrical input of the heater, we effectively tune the system towards and away from an EP [5].

## 2. Device principle

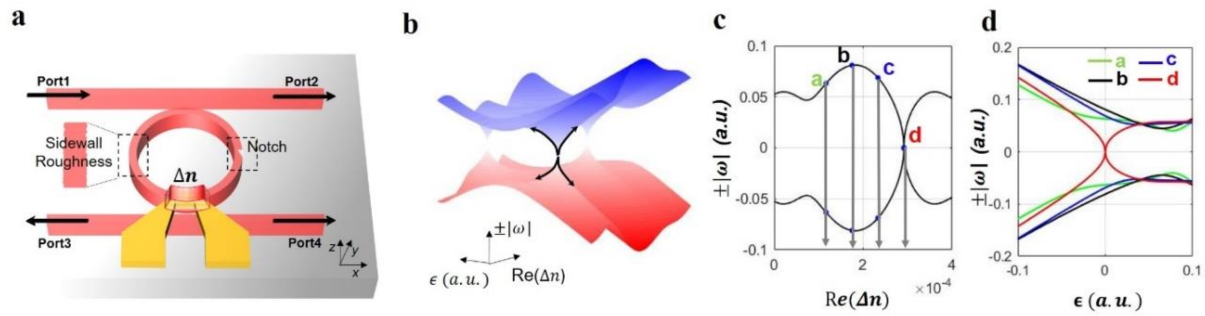


**Figure 1| Device schematics and principle.** (a) Our device is a silicon-on-insulator (SOI)based add-drop filter ring fabricated with a notch of asymmetric geometry and an integrated local heater. The sidewall roughness of the ring induced intrinsic backscattering leading to mode splitting. The notch is fabricated to compensate the intrinsic backscattering and induce an asymmetric coupling between CW and CCW modes of the ring. The asymmetric coupling strength is tuned using the thermal heater. (b) 3D energy splitting diagram when varying the index of the microring using the local thermal heater at different strengths $\epsilon$ of an external perturbation. (c) 2D energy splitting diagram without the external perturbation i.e. the cross-section of the 3D splitting diagram shown in (b) when $\epsilon = 0$, at each point of index tuning. (d) Effect of $\epsilon$ on different index tuning points namely a, b, c and d. At the exceptional point 'd', the splitting scales $\epsilon^{\frac{1}{2}}$.

Fig. 1a shows the device schematics. The scattering between the clockwise (CW) and the counterclockwise (CCW) modes in the resonator is controlled by two types of asymmetric nanoscatters - random sidewall roughness [6-7] and the designed asymmetric scatterer [5]. This system can be described by a non-Hermitian 2 × 2 matrix, where the off-diagonal elements represent the asymmetric coupling strength (complex numbers) between CW and CCW modes. These coupling strengths can be tuned precisely by varying the spatial distance (optical path differences) between the two scatterers. We implement this by thermally tuning the optical path lengths using the integrated local heater [3,5]. We calculated the complex coupling strengths through numerical simulation. Tuning the optical path difference between the asymmetric scatterers lead to the emergence of the EP spectral degeneracy (Fig. 1b-c). Adding an external perturbation $|\epsilon|$ to this systems, pushes the system away from the degeneracy by an amount proportional to $\sqrt{\epsilon}$, as expected for a system operating at an EP [3,5] (Fig. 1d).

## 3. Experimental implementation

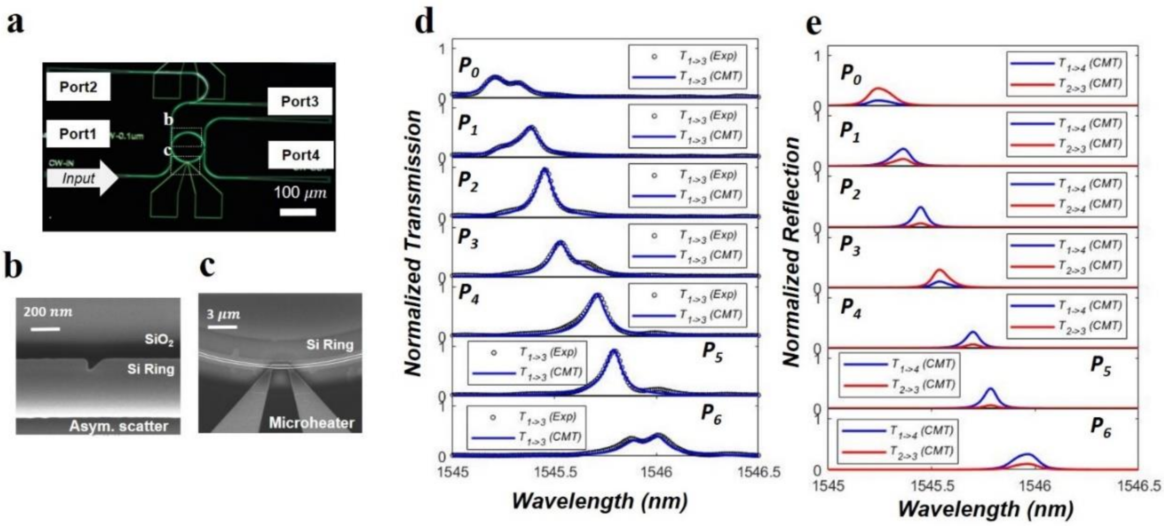


**Figure 2| Experimental demonstrations of the tunable system.** (a) Top view SEM image of Si microring resonator. (b) SEM image (top view) of the asymmetric scatterer (75 nm high 120 nm wide). (c) SEM image (top view) of the local thermal heater, where Si Microring underneath the cladding layer ($SiO_2$) is drawn to show the good alignment between the center of the thermal heater to the center of the Si Microring.(the white line represents the good alignment) (d) Measured optical transmission spectra at different amounts of electrical power applied on the thermal local heater ($P_o \rightarrow P_6$). Fitting curves (blue solid) using coupled-mode theory (CMT) allows to extract the characteristic parameters of the microring from the measured transmission spectra. (e) Calculated reflection spectra using the device parameters extracted in Fig. 2d in CMT.

The designed system is fabricated on a SOI substrate with 250 nm thick silicon on the top of 3μm-thick silicon dioxide (Fig. 2a) [5]. The structures are patterned using E-beam lithography with a positive resist (AR-P-CSAR 6200.09) followed by a Fluorine based inductively coupled plasma etching ($C_4F_8$:$SF_6$ =1:1). Asymmetric nanoscatter (75 nm by 120 nm) is defined in the waveguide layer (Fig. 2b). PECVD silicon oxide is then deposited on silicon for protection and optical isolation to the metal layer. The micro heater is aligned to the perimeter of the ring (Fig. 2c). The heater layout is firstly defined on a double-layer resist, followed by metal deposition in a dual electro-beam evaporator (Pt: 100 nm, Ti: 5nm). We measured the transmission spectra of this device at different power levels applied to the heater (Fig. 2d). Our experiments clearly show that the local heater effectively tunes the asymmetric coupling strength by tuning the relative phase between the scatterers. The mode-splitting in the transmission spectra disappeared as the electrical power on the thermal local heater was increased from 0 mW ($P_0$) to 5.6 mW ($P_2$) as seen in Fig. 2d. With further increase of the power, the splitting revives back which reveals the frequency crossing. Reflection spectra calculated using the device parameters extracted from curve fitting to the experimentally obtained transmission spectra in Fig. 2d reveals significant asymmetry in reflection when the system is in the vicinity of an EP degeneracy (Fig. 2e).

## 4. Conclusion

In this work, we have designed and fabricated an electrically tunable non-Hermitian system on a CMOS compatible photonic platform. Such a tunability may pave the way for building EP-based low power optical switches, modulators, and sensors.

## 5. References

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