

Demonstration of Electrically Injected Parity-Time-Symmetric Microring Lasers

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Abstract: Single-mode lasing is demonstrated in an electrically injected coupled microring arrangement at telecommunication wavelengths by exploiting the unique physics associated with parity-time-symmetry. © 2018 The Author(s)

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The pursuit of superior electrically pumped on-chip light sources has motivated a number of research endeavors in the past few decades. These lasers are expected to occupy a small foot print and display a low lasing threshold while only emitting light into a single mode. Seeking devices with these features has led to the development and advancement of many semiconductor lasers, such as the vertical cavity surface emitting laser (VCSEL), the distributed feedback (DFB) laser, and the distributed Bragg reflector (DBR) laser, to name a few [1]. One oft-overlooked cavity is the microring, a promising resonator with miniature size, a high quality factor, and large mode confinement [2]. However, such cavities inherently support several resonances exhibiting near equal Q-factors within the characteristically broad lineshape of semiconductor active gain media; subsequently multiple modes tend to oscillate in such lasers. A few years ago, our group demonstrated a method to enforce single-mode lasing in a pair of optically pumped microrings by capitalizing on the unique peculiarities that arise in PT-symmetric systems [3]. Here we report the first realization of an electrically injected parity-time-symmetric microring laser based on an InGaAs gain system at telecommunication wavelengths.

The concept of PT-symmetry was first introduced in the context of quantum field theory [4] and more recently has gained considerable attention in the field of optics. A photonic system is considered PT-symmetric provided its corresponding Hamiltonian commutes with the *PT* operator. The non-Hermiticity of these arrangements results in the manifestation of exceptional points (PT-symmetry breaking points) in the parameter space. Such an arrangement can readily be realized by a pair of coupled microrings, where one cavity provides gain and the other loss. The eigenfrequencies of such systems can be entirely real, provided that the gain-loss contrast is lower than the coupling coefficient. However, if this gain-loss contrast exceeds the coupling, the associated frequencies transition to the complex domain (marking the presence of the exceptional point) and bifurcate along the imaginary axis. In our previous works, we reported on how selective breaking of PT-symmetry mediated by the intrinsic curvature of the lineshape can promote single-mode lasing in coupled microring cavities [3,5].

Here we report the first and smallest electrically pumped PT-symmetric microring laser. Figure 1(A) depicts a schematic of the laser. It is comprised of two identical rings (radii of 10 μm , thickness of 1 μm) separated by 100 nm.

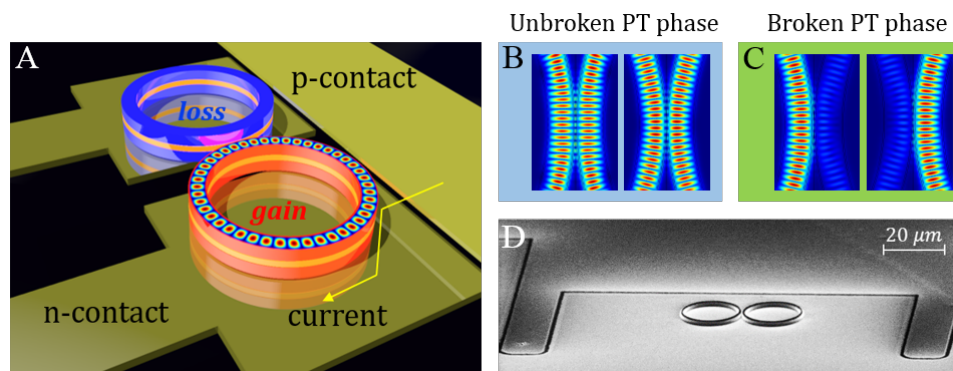


Figure 1. (A) Schematic of the electrically injected PT-symmetric microring laser. (B) & (C) zoomed in top view image of a 3-D FEM (COMSOL) simulation when the gain-loss contrast is below the coupling coefficient (B) and when it exceeds the coupling (C). In (C) the modes split, one residing in the lossy cavity and the other occupying the cavity with gain. (D) Scanning Electron Microscope image of the electrically injected rings after p-contact formation.

They contain a 300 nm InGaAs active layer that is cladded on the top and bottom by p- and n-type InP. The 3-D finite element method (FEM) simulation (COMSOL) provided in Fig. 1(B) shows the supermodes reside in each cavity equally when the device is operating in the unbroken PT regime. However, once the exceptional point is surpassed, the rings effectively decouple from one another (Fig. 1(C)). A scanning electron microscope (SEM) image of the rings after an intermediate fabrication step is offered in Fig. 1(D).

The lasers are next characterized in a micro-electroluminescence setup. When both rings are evenly pumped (Fig. 2(A)), the fundamental mode at 1533 nm is first to rise (notice the splitting due to level repulsion). At even higher currents, another mode develops and ultimately dominates the spectrum. In this scheme, the mode resides equally in both cavities (Fig. 2(A) inset). However, when pumping only a single ring (Fig. 2(B)), only the fundamental mode emerges and, due to selective PT-symmetry breaking, remains the sole mode – even at currents exceeding 10 times the threshold. As observed in the inset of Fig. 2B, this mode resides almost entirely in the active ring. Furthermore, the efficiency of the device is not compromised, despite the proximity of the lossy resonator, because above the PT-symmetry breaking point, for the mode of interest, the two cavities effectively decouple. Figure 2(C) displays the light-current (L-I) curve that encompasses the power over all modes, resulting in near equal efficiencies in both instances. However, the PT-symmetric laser offers vastly superior performance when considering only the fundamental mode (Fig. 2(D)).

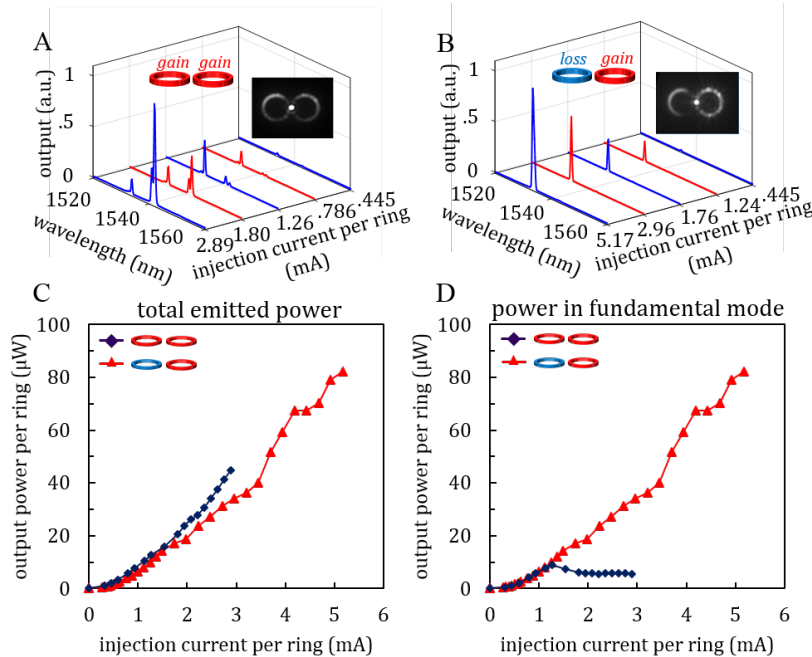


Figure 2. (A) Spectral evolution when both rings are pumped. Multiple split resonance modes emerge. The inset shows the modes occupy each ring equally. (B) Only a single ring is pumped, selectively breaking the PT-symmetry. The spectrum remains single-moded at all pump currents. The mode mostly resides in the active cavity. (C) & (D) The total emitted power and the power emitted in the fundamental mode, respectively, for both pumping scenarios.

In conclusion, we have reported on an electrically injected parity-time-symmetric microring laser operating in a single mode at telecommunication wavelengths. This laser has a small footprint, low threshold, generates light in plane, and could potentially have a high direct modulation bandwidth. In addition, the fabrication process is completely regrowth free. This work may pave the way towards a new class of fully integrable on-chip coherent light sources to be used in photonic circuits.

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