Tunable Parity-Time-Symmetric Microring Lasers

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Abstract: Wavelength tuning in a single mode parity-time (PT) symmetric semiconductor microring laser is demonstrated. Stable continuous tuning over a spectral range of 4 nm has been obtained at telecom wavelengths by adjusting the ambient temperature.
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Single mode tunable semiconductor lasers are key components for numerous applications ranging from spectroscopy and optical communications, to metrology and beam-steering. Due to the inherent large gain bandwidth of semiconductors, efficiently controlling the total number of oscillating longitudinal modes in this class of laser is generally challenging. Nevertheless, single frequency lasing has been demonstrated using distributed feedback (DFB) arrangements [1], distributed Bragg reflectors (DBR) or via the integration of passive resonator segments and active gain in a large common laser cavity [2]. However, despite the remarkable success of these techniques in providing wavelength selectivity in a number of configurations, they cannot be readily applied to microring configurations- a prominent class of semiconductor lasers with high prospects for integrated photonics. In the absence of wavelength selectivity, spectral tuning techniques like temperature adjustment are also ineffective as they may cause mode hopping and instabilities. This has motivated some of the recent works exploring alternative designs to enforce single mode lasing in such microring resonators [3,4,5].

Recently, it has been shown that by pairing a microring laser with an identical yet unpumped cavity, all the undesired longitudinal modes can be successfully suppressed. The observed mode discrimination is achieved by exploiting the parity-time symmetry of this structure. In such an arrangement, depending on the ratio between the gain-loss-contrast (2γ) and temporal coupling between the rings (κ), the respective longitudinal modes can experience a net gain (lase) or remains neutral (not lase). Under such premises, the intrinsic mode discrimination associated with the curvature of the gain bandwidth of the active material will be enhanced [5]. By judiciously setting the gain-loss-contrast between the rings, such wavelength selectivity can be attained without a measurable penalty on the output power. The schematics in Figs. 1(a) and (b) compare the modal contents of a single microring laser to that of a parity-time-symmetric configuration. Figure 1(c) shows an SEM image of a double InGaAsP microring arrangement on InP substrate.

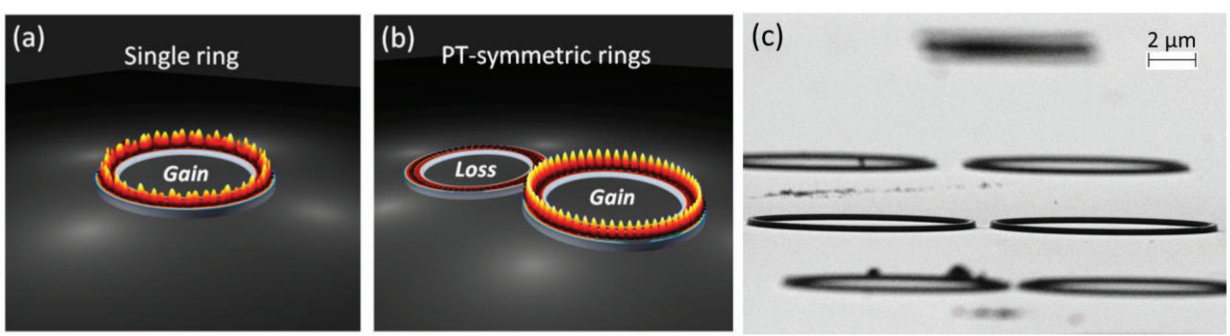

Fig. 1. (a) In a single microring resonator, multiple longitudinal modes can lase simultaneously, (b) in a PT-symmetric arrangement, on the other hand, only one longitudinal mode enjoys lasing, and (c) an SEM image of a PT-symmetric double ring laser arrangement.

Here we experimentally demonstrate the spectral tuning capability of this class of parity-time-symmetric microring lasers. The laser system is composed of two coupled microrings (radii 10 µm, widths 500 nm, spacing 300 nm). Optical pumping (wavelength 1064 nm) is selectively applied to one of the rings to establish a parity-time-

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symmetric refractive index profile. The ratio of gain-loss contrast and the coupling between the two ring resonators is designed such that all of the longitudinal modes but one remain below PT threshold. The tuning is achieved by adjusting ambient temperature of the rings by placing the samples in a cryostat (LN2 cooled) that is equipped by a closed loop feedback temperature controller. Due to the large thermo-optic coefficient of InGaAsP quantum wells, we expect more than 0.1 nm wavelength shift per Kelvin. Using this technique, ~ 4 nm continuous wavelength tuning is obtained by adjusting the ambient temperature from 270K to 300K. Figure 2 (a) shows the spectrum of a PT laser as the temperature is changed. On the other hand, for a single ring laser the temperature shift leads to mode hopping between the longitudinal resonances as shown in Fig. 2 (b). These results clearly indicate that parity-time-symmetric microring lasers can be used in a stable fashion in applications where spectrally tunable single mode lasing at telecom wavelengths is required.

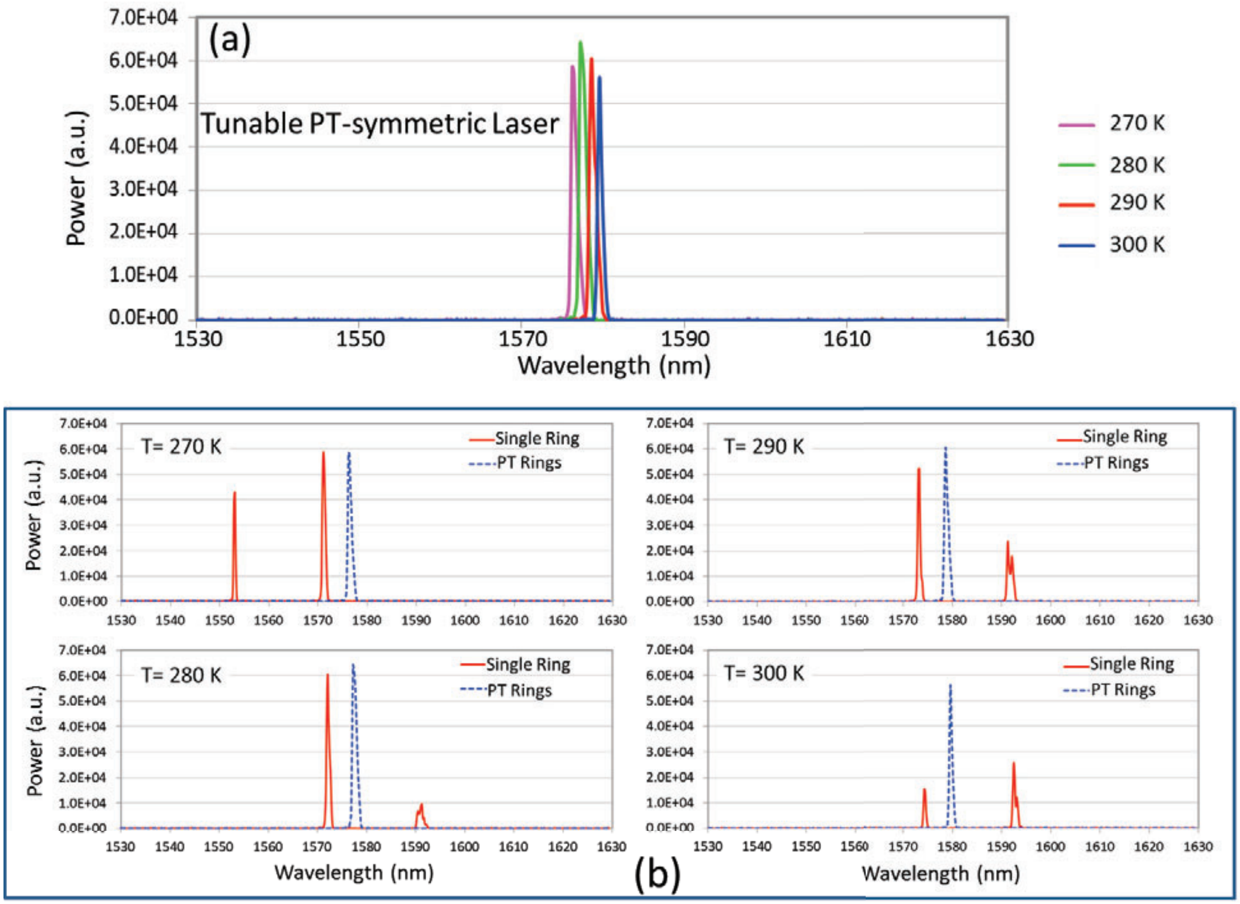

Fig. 2. (a) Emission spectrum of a PT-symmetric microring laser at 270-300 K, exhibiting wavelength tunablity over ~ 4 nm. (b) Detailed spectra of parity-time symmetric lasers as compared to its corresponding single ring laser.

In conclusion, we have demonstrated stable wavelength tuning of a single mode parity-time (PT) symmetric semiconductor microring laser.

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