PT-symmetric microring lasers

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Abstract: We show that a multimode laser cavity when accompanied by an identical but lossy partner can lase at a single longitudinal mode. Our experimental results demonstrate this mode-selective effect in parity-time (PT) symmetric micro-rings lasers.

OCIS codes: *(140.3570) Lasers, single-mode; (140.3560) Lasers, ring; (140.3410) Laser resonators*

Microring resonators are desirable for a number of on-chip photonic applications including lasers [1]. Such high index contrast cavities have a small footprint and can afford relatively large radii of curvature with minimal radiation losses. However this comes at the price of lasing at multiple longitudinal modes. Of interest would be to devise methods to suppress undesirable modes, thus forcing the device to lase at a single frequency.

Quite recently, notions from parity-time (PT) symmetry have been theoretically proposed as a means to achieve single-transverse-mode lasing in dielectric cavity lasers [2]. PT symmetric structures, i.e. systems utilizing a balanced gain and loss profiles, have recently attracted considerable attention in optics because of their unusual characteristics that are otherwise unattainable in passive environments [3-6].

Here, we report the first experimental demonstration of a PT-symmetric laser. As we will show, stable single-mode operation can be enforced in a symmetric coupled arrangement of gain and loss microring resonators.

The interaction between the n'th longitudinal modes residing in the gain and loss microrings can be described via temporal coupled mode theory [7]. By assuming a mutual coupling of κ_n and a gain/loss coefficient of $\pm\gamma_n$ in the two cavities, one can simply show that the n'th longitudinal modes of the isolated cavities pair together in two supermodes. The eigenfrequencies of these two supermodes are obtained via $\omega_n^{(1,2)} = \omega_n \pm \sqrt{\kappa_n^2 - \gamma_n^2}$. This simple relation shows the presence of two different regimes; (a) below PT threshold when $\gamma_n < \kappa_n$, and (b) above PT threshold when $\gamma_n > \kappa_n$ (broken PT symmetry regime). Obviously the act of lasing (associated with complex eigenfrequencies) can occur only in the second regime when the gain/loss coefficient γ_n exceeds that of the mutual coupling κ_n. As a result by adjusting the coupling constant one can design the system in such a way that only one of the longitudinal modes falls into the broken PT symmetry regime thus achieving single mode operation. This process is illustrated in Fig. 1.

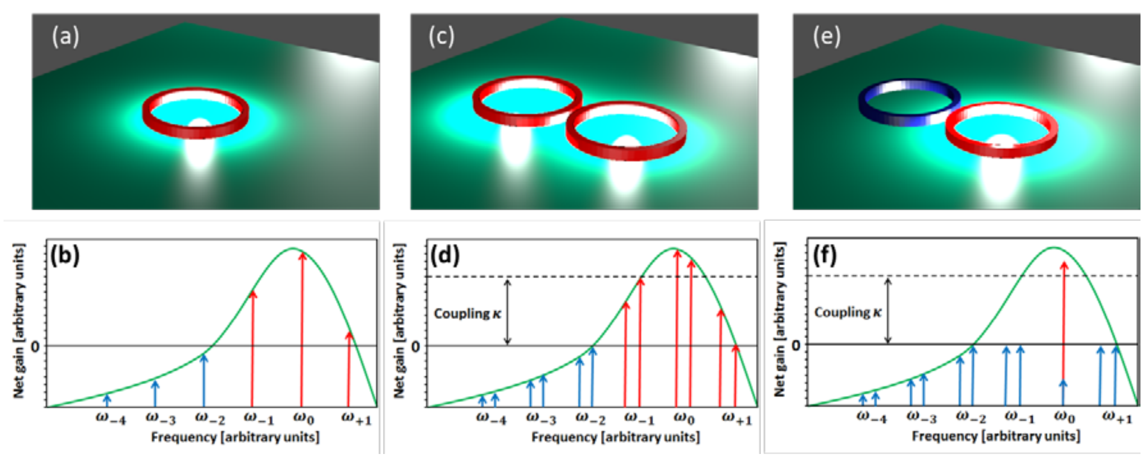

Fig. 1. Schematic illustration of the lasing process in PT lasers. (a) A single microring laser and (b) its modes (arrows) within and exemplary gain bandwidth (green curve). The solid black line depicts the lasing threshold meaning that modes with a positive net gain (red arrows) can lase while those remaining below this threshold cannot lase. (c) Two coupled ring lasers and (b) their lasing spectrum. (e) PT-symmetric laser is composed of a gain ring (red) coupled to a lossy ring (blue). (f) The spectrum of the PT laser where the dashed black line shows the coupling strength between the gain and loss cavities. Modes with a gain/loss higher than the coupling level can break the PT symmetry and lase.

In our experiment, we utilize InGaAsP microrings partially buried in SiO_2. Each ring, having a width of 500nm and a height of 200nm, exhibits an external radius of 10μm and the separation between the two coupled resonators is 200nm. Active regions in the rings are achieved by relying on six InGaAsP quantum wells. The quantum well layer can provide gain in a large spectral window centered around 1550 nm and ranging from 1350 nm to 1600 nm, while the pump laser operates at 1064nm. Note that in principle each ring is associated with an intrinsic loss due to absorption, scattering and radiation. As a result a PT pair of coupled microring resonator can be obtained by selectively pumping only one of the two rings.

Figures 2 shows the experimental results of the spectrum measurements for a single lasing ring (a), two coupled lasing rings (b), and finally a PT-symmetric pair of rings. In each case the insets depict the intensity profiles observed through scattered light. According to Fig. 2(a) a single ring resonator exhibits four prominent longitudinal modes within the gain bandwidth. When two coupled rings are pumped equally, their lasing spectrum forms a set of doublets each corresponding to a longitudinal mode within a single ring (Fig. 2(b)). Finally in the PT-symmetric arrangement, only one longitudinal mode lases (Fig. 2(c)). This shows that only a pair of supermodes falls into the broken PT-symmetry regime, with one being amplified while the other one is decaying. On the other hand the strong coupling between the gain and loss rings keeps all the other supermodes below their PT symmetry breaking threshold, thus eliminating them from the lasing spectrum.

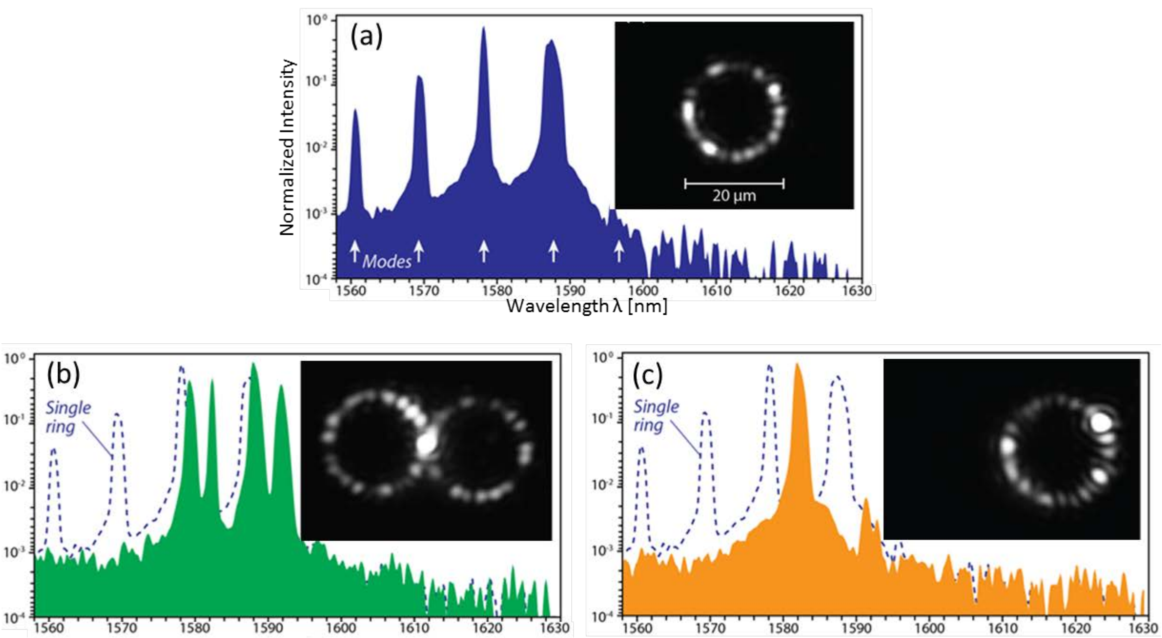

Fig. 2. Experimental demonstration of longitudinal mode selection in PT-symmetric microring lasers. (a) The lasing spectrum of a single microring laser, (b) two coupled microring lasers and (c) PT-symmetric microring laser. In each case the inset depicts the corresponding intensity pattern obtained from the scattered light.

In conclusion we have demonstrated, for the first time, single mode operation in PT-symmetric laser arrangements. Our approach is simple and versatile and can be applied to other types of dielectric laser cavities to achieve single longitudinal or transverse mode operation.

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