Drak-State Microring Lasers: Using Exceptional Points for Mode Management

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Abstract: A semiconductor microring laser based on a dark state configuration is demonstrated. Single mode lasing is achieved by judiciously exploiting non-Hermitian exceptional points.

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Microring resonators are one of the main building blocks of photonic integrated circuits [1]. Their small foot-print, high quality factor, and modularity make them ideal candidates for on-chip laser applications [2]. However, up until recently, the utilization of ring structures as laser cavities has remained largely out of reach due to their inherent multimode behavior dictated by their size, and the lack of a simple yet versatile technique that is capable of suppressing unwanted resonances. Here we present experimental results regarding a new approach to enforce single mode lasing in microring systems based on the physics of non-Hermitian exceptional points [3]. This is accomplished by exploiting the recently proposed class of dark state lasers [4].

Fig. 1(a) provides a schematic of the dark state laser configuration used in our experiments. This arrangement is comprised of two dissimilar microring resonators (same widths, different radii), indirectly coupled to each other via a central waveguide. Fig. 1(b) depicts an SEM image of such a laser, implemented on an InP based semiconductor wafer. The central waveguide as well as the microrings are composed of InGaAsP multiple quantum well structures surrounded by low index dielectrics (SiO_2 and air).

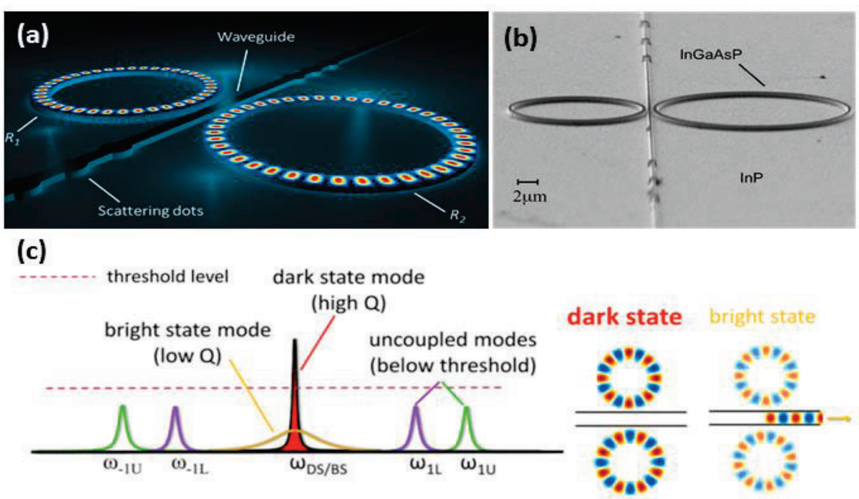

Fig. 1 (a) Schematic of the dark state laser. Two active microring resonators of different radii are coupled through a bus waveguide. The scattering dots on the bus waveguide are used to detect light coupled to the waveguide.(b) An SEM image of the InP based dark state laser system. (c) In the absence of a bus waveguide, when the two microring resonators are directly coupled, any coinciding modes form a pair of bonding and anti-bonding supermodes. The dark state mode, is virtually uncoupled to the central waveguide and hence has the highest Q-factor and will be the first to lase with large mode discrimination margin.

In the dark state configuration, the presence of the central waveguide, provides a channel for irreversible power loss and therefore introduces an exceptional point (Fig. 1). Clearly, in this arrangement, any light coupled to the intermediate channel eventually escapes the system. Analysis indicates that in such a system, at frequencies where the resonances of the upper and lower rings are close enough, two temporal supermodes emerge, with corresponding field distributions that are approximately in-phase and π-out-of-phase within the coupling region. Given that the symmetric in-phase mode strongly excites the central waveguide through constructive interference, a considerable

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amount of energy is expected to be irreversibly lost through this channel. On the other hand, the anti-symmetric π-out-of-phase mode (dark state) does not inject light into the middle channel and hence experiences minimum attenuation. In this latter scenario, the mode remains well-confined within the two rings as shown in the inset of Fig. 2c. The non-coinciding resonances associated with the two dissimilar rings endure a significant amount of loss since they are strongly coupled to the central waveguide by design (Fig. 1c). As a result, in the presence of gain, the anti-symmetric dark state mode is the first in line to lase with a large margin for mode discrimination.

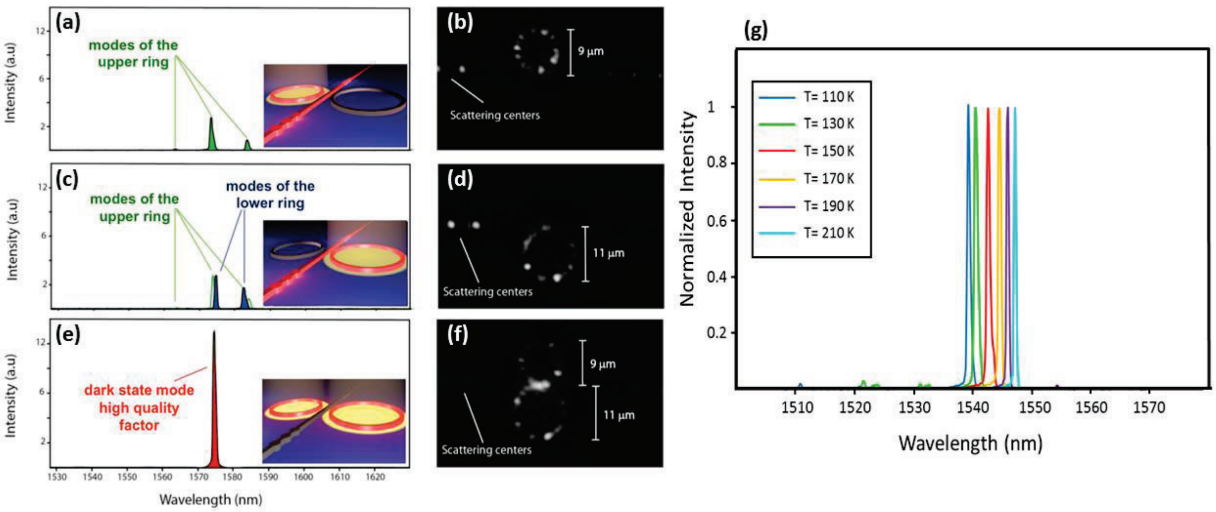

Fig. 2 (a) Emission spectrum of the upper microring when illuminated by the pump beam (peak pump power: 12mW). In this regime, several longitudinal modes are lasing within the gain bandwidth. (b) Corresponding intensity pattern as obtained from scattering. The presence of light ir the central bus waveguide is observed from the bright scattering centers. (c) and (d) Same as in (a) and (b) when the lower ring is pumped (e) When both rings are pumped at the same power densities as in (a) and (c), the double ring system lases in a dark mode emerged from two coalescing longitudinal frequencies (f) In this case, no emission is seen from the scattering dots, indicating absence of light in the central waveguide. (g) Over 8 nm wavelength tuning is demonstrated under dark state lasing conditions by varying the ambient temperature. The radii of the two rings are 10 and 9 µm,

Fig. 2 shows the emission spectra of a dark state structure comprising of two microrings with radii of 9 µm and 11 µm (width: 500 nm, height: 210 nm) separated by a waveguide of an identical cross section, centered at a distance of 200 nm from each of the two rings. The pump is coupled through the top surface and the output is collected through the scattering off the structures. Single mode lasing is achieved at room temperature under optical pumping conditions (pump wavelength: 1064 nm). In order to ensure the observation of a dark state mode, the spectrum of this two-ring configuration (Fig. 3e) is compared to that obtained from the lower and upper rings when they are pumped individually (Figs. 3a,c). As expected, independently, each ring exhibits lasing in a multiple number of modes. However, when a resonance from the upper microring happens to be in close proximity to another one of the lower ring, a dark state mode emerges as the fundamental oscillation in this coupled system (Fig. 3e). In addition, to directly observe the lasing modes, a set of scattering dots has been intentionally embedded in the middle channel away from the coupling region as shown in Figs. 1a,b. The brightness of these defects is an indication of the light present in the middle waveguide (Fig. 3b,d,f) . The scatterers in the middle channel light up when the individual rings are pumped. Conversely, these same centers appear dim when only a dark state mode is present. The free spectral range in such a resonator system can be substantially increased by appropriately designing the relative radii of the two rings. Thus, over one free spectral range of hop-free tuning is achieved by adjusting the ambient temperature. Fig. 2 shows the spectral tuning of a dark state laser (having rings with radii 9 and 10 µm).

4. References

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