Self-injection locking to a photonic crystal ring-microresonator with synthetic back-reflection is demonstrated for the first time. The on-chip system permits deterministic generation of exclusively single-soliton microcombs and does not rely on random backscattering from defects or imperfections.

1 Introduction

Dissipative Kerr solitons (DKSs) in continuous-wave (CW) laser-driven microresonators provide access to low-noise ultrashort pulses and frequency combs (microcombs) with repetition rates from GHz to THz. They have found applications in sensing, communication, and signal processing [1]. Major practical challenge for DKS sources emerge from the requirement that the pump laser detuning must remain controlled and stable. This is particularly challenging during DKS initiation, when thermooptic effects cause an abrupt change in resonance frequency. An elegant method addressing this challenge is laser self-injection locking (SIL)[2]. It is based on resonant Rayleigh scattering from random defects inside the microresonator. The scattering results in a resonant backward-wave, that propagates in the direction opposite to the pump wave and hence back to the pump laser providing critical feedback to the laser (injection) and effectively locking the laser frequency to the microresonator resulting in a stable detuning. Previous works have used SIL to narrow the linewidth of laser diodes [3] and recently SIL-based DKS generation has been demonstrated [4, 5]. However, the random defects in the microresonators that currently form the basis for SIL are neither wanted nor can they be used to achieve predictable SIL; careful sample selection to achieve stable SIL is usually required.

Here we demonstrate for the first time SIL utilizing a photonic crystal ring resonator (PhCR) [6–8] with programmable synthetic reflection (independent of random defect). In addition, we demonstrate that such PhCRs can be used for deterministic SIL-based initiation and stable operation of DKS (single-DKS regime). Both applications are demonstrated experimentally in such a system.

2 Results

To gain independence from backscattering random defects, we use PhCRs that enable synthetic reflection. The reflection is controlled by periodic nano-patterned corrugations of the ring-resonators’ inner wall. The PhCRs used...
in our experiments have a single-period corrugation pattern (Fig. 1a). Notably, the induced backward coupling can significantly exceed the internal linewidth for one select resonance, while the other resonances remain unaffected (Fig. 1b). Fig. 1c shows examples of coupling rate distributions measured in microresonators without (blue) and with corrugation (colors from red to olive) of different amplitudes. PhCR enables control over the backscattering rate by design and, as shown by the experimental data, provides robust access to backreflection rates that are difficult or impossible to access for conventional microresonators.

To demonstrate SIL, a semiconductor distributed feedback laser diode (DFB) is coupled to a Si$_3$N$_4$ PhCR (free-spectral range 300 GHz) with a designed backreflection (Fig. 1a) at approximately 1560 nm wavelength. The microresonator is critically coupled with an internal linewidth of $\kappa_0^2/\pi \approx 55$ MHz and backward coupling $\gamma/2\pi \approx 150$ MHz. The DFB laser diode emission can be scanned across the resonance by changing its driving current. The resonant backreflection is injected into the laser diode and provides frequency-selective optical feedback. In this way, deterministic SIL across a wide range of laser-diode currents is achieved (see Fig. 2a).

Importantly, the system readily generates exclusively single DKS deterministically without the need for any external feedback or a stabilization mechanism (Fig. 2b). Turing patterns, noisy comb-states and multi-DKS regimes are absent in stark contrast to previous SIL-based microcomb generation, but consistent with spontaneous single-DKS formation in conventionally-driven (non-SIL) PhCR [8].

3 Conclusion

In summary, we demonstrate an integrated optical microresonator with synthetic resonant-backreflection for robust and predictable SIL, as well as, deterministic and stable generation of single-DKS based on SIL. This novel approach addresses a long-standing challenge in microcomb technology and permits leveraging the advantages of SIL without relying on random defect-based backreflection.

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References