Kerr solitons in high-Q integrated Fabry-Pérot microresonators

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Abstract. Disspative Kerr Solitons are generated in an integrated standing wave Fabry-Pérot microresonator. Enabled by synthetic anomalous dispersion provided by a pair of Photonic Crystal Reflectors (PCR) forming a high-Q cavity, the generated soliton pulses exhibit a unique spectral profile extending beyond the PCRs' bandgap.

1 Introduction

High-Q microresonator frequency combs (*microcombs*) have emerged as light sources complementing mode-locked lasers when high-repetition rates (10 GHz to 1 THz) are desired. Usually travelling wave resonators, whispering gallery mode or ring-type, are used which can also be integrated on chip and represent a major technological building block of novel photonic technologies from the ultraviolet to the mid-infrared regime [1, 2]. Microcombs have also been demonstrated in fiber-based standing-wave Fabry-Pérot (FP) resonators [3] and recently also in integrated geometries [4], with new opportunities for dispersion engineering.

Here, we report on the generation of disspative Kerr solitons (DKSs) within integrated Fabry-Pérot microresonators. Composed of two photonic crystal reflectors (PCRs) spaced by a straight waveguide, the high-Q microresonator supports ultra-short (300 fs) solitonic pulses under continuous wave pumping.

2 Results

The high-Q Fabry–Pérot microresonators were fabricated from thick-film (800 nm) Si_3N_4 in SiO_2 cladding; a platform which has gained considerable interest in the field of nonlinear integrated photonics in recent years due to its high $\chi^{(3)}$ nonlinearity and low propagation losses [2]. Made of a straight waveguide section terminated by two 1 D photonic crystal reflectors, the 20 GHz free spectral range microresonators have an intrinsic quality factor of $Q_0 = 4.0 \times 10^6$ (median linewidth $\kappa_0/2\pi = 47$ MHz) a value comparable to state-of-the-art ring-resonators and only limited by the waveguide propagation losses inherent to the Si_3N_4 platform. Owing to the absence of frequency degenerate counter-propagating modes in the FP configuration, the resonances are free of back-scattering induced mode-splitting, a fact which is evident when comparing the resonance lineshapes between ring and FP configurations (Fig. 1a and b). Additionally, the resonator is also free of avoided mode crossings due to the single mode nature of the PCRs.

3 Dissipative Kerr Soliton Generation

In order to generate dissipative Kerr solitons a microresonator is pumped using 150 mW of continuous wave on-chip power in the anomalous dispersion regime at a wavelength of approximately 1587 nm. The pump laser is swept across the targeted resonance with decreasing optical frequency until reaching an effectively red-detuned regime, upon which one or more soliton are observe to form. The single DKS spectra is displayed in Fig. 1c from which we estimate the soliton pulse duration to be ~300 fs. The soliton exhibits a strong dispersive wave owing to the symmetric dispersion profile provides by the PCRs and interestingly, extend far beyond their nominal bandwidth (i.e. bandgap of the main section of the PCRs). We attribute this to the reflection sidelobes the PCRs (Fig. 1d), and confirm this through numerical simulation based on a frequency domain implementation of the Lugiato–Lefever equation, which enables straightforward inclusion of arbitrary frequency-dependent dispersion and linewidth profiles. The simulated intracavity and outcoupled spectra as well the experimentally recorded spectrum are compared in Fig. 1c showing excellent match between simulation and experiment. We also note that the out-coupled spectrum is much flatter than the intracavity spectrum due to multiplication by the output PCR transmission.

To further confirm soliton formation we record the phase-to-amplitude response of the system under phase-modulation of the pump laser as a function of detuning (Fig. 1e). In soliton operation one expects to observe both the so-called S- and C-resonances corresponding to the response of the soliton and CW background respectively. In our case, owing to a relatively low pump detuning, the S- and C-resonances overlap in frequency while having opposite phase, leading to a destructive interference clearly

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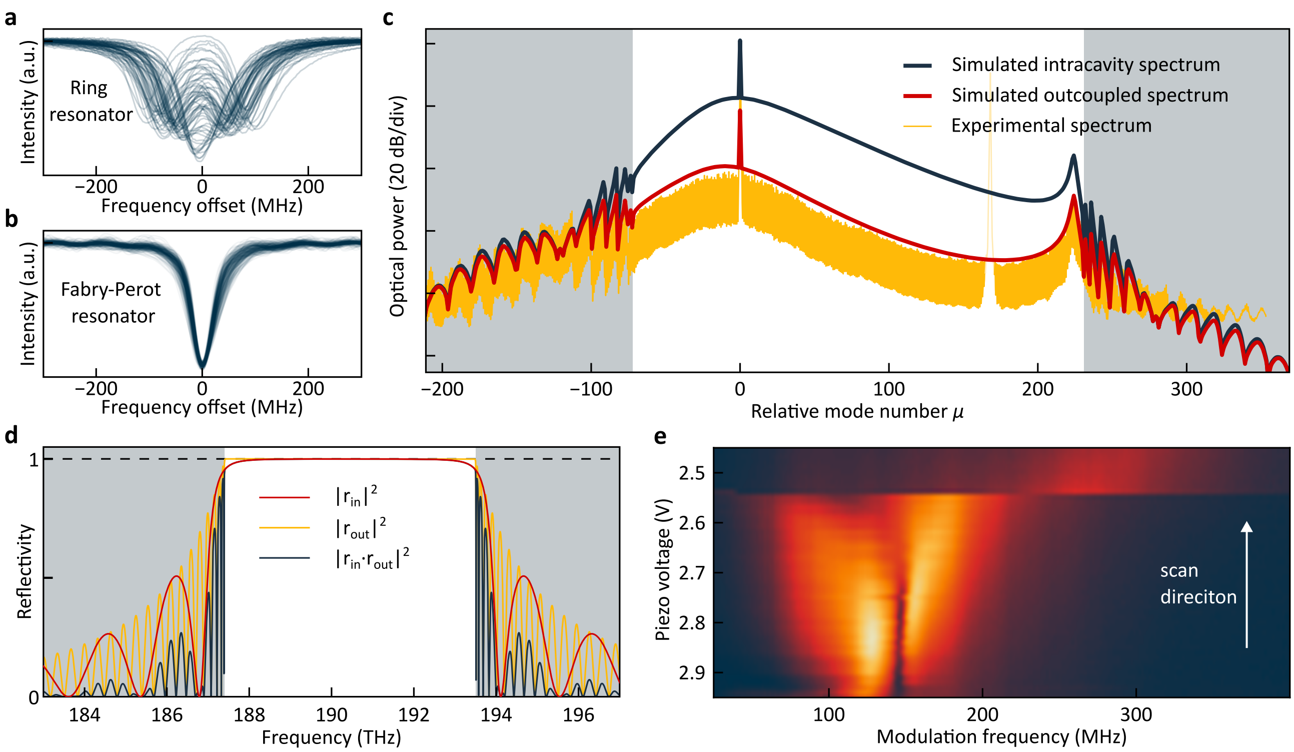

Figure 1. **a** and **b**, Superposed normalized line shapes of 150 GHz ring and Fabry-Pérot microresonators respectively. No mode-splitting can be observed in the latter due to the absence of frequency degenerate couter-propagating modes. **c**, Simulated intracavity (blue), simulated outcoupled (red) and experimentally measured (orange) spectra. **d**, Magnitude of the reflection coefficients of the Fabry-Pérot microresonator's input PCR (red), output PCR (orange) and combination thereof (blue) used for the simulation in **d**. **e**, Experimental VNA response obtained by gradually increasing (decreasing) detuning (piezo-voltage). When reaching 2.55 V, the detuning exceeds the soliton existence range for the given pump power and the DKS vanishes, esulting in only the C-resonance and an increased detuning due to the cavity cool-down.

visible at ~150 MHz in Fig. 1e. Upon reaching a detuning exceeding the soliton existence range, the DKS vanishes and only the *C*-resonance remains.

4 Conclusion

Continuous wave driven dissipative Kerr soliton inside integrated Fabry–Pérot microresonators with detectable microwave repetition rates of 20 GHz are demonstrated. Based on a pair of highly reflective photonic crytal mirrors, the integrated Fabry–Pérot platform offers synthetic dispersion through the conception of the PCRs. Our findings are also relevant to a more recent extension of our observation of photonic crystal microresonator DKS to a higher-index contrast platform [7]. With new degrees of freedom in design not available in ring-type resonators, new opportunities are opened for integrated photonics and applications including spectroscopy and frequency synthesis.

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