Simulation of Electrically-Controlled Mode Interaction for Adiabatic and Deterministic Single Soliton Generation

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Abstract: We demonstrate numerically the deterministic generation of a dissipative Kerr soliton in coupled Si_3N_4 microrings resonators using electrically-controlled mode interactions. We use a constant pump power and linearly sweep frequency. © 2021 The Author(s)

Kerr combs generated in integrated microresonators have recently attracted a lot of attention in the photonics research community; they have applications in areas such as communications, metrology, optical clocks, and, more recently, artificial intelligence. Singles solitons are commonly used to generate Kerr comb with microrings. Single solitons are ultra-short pulses of light that keep their shape while they propagate. Single solitons depend on a double balance between loss and pump power as well as Kerr nonlinearity and dispersion [1, 2]. The generation techniques include paths in the pump power and detuning parameter space such us back-detuning and chaos-avoiding trajectories. These techniques are challenging to implement in experiments due to the required fast change of power and wavelength of the pump laser. Other approaches use thermal control, pulse-triggered, multiple laser pumps, and engineered spatial mode interactions, among others [1, 3, 4, 7]. These approaches also involve difficult and expensive experimental setups. In this report, we demonstrate numerically the generation of a single soliton using a straightforward constant pump power with a slow frequency sweep in a dual-ring structure in which the longitudinal mode interactions are electrically controlled.

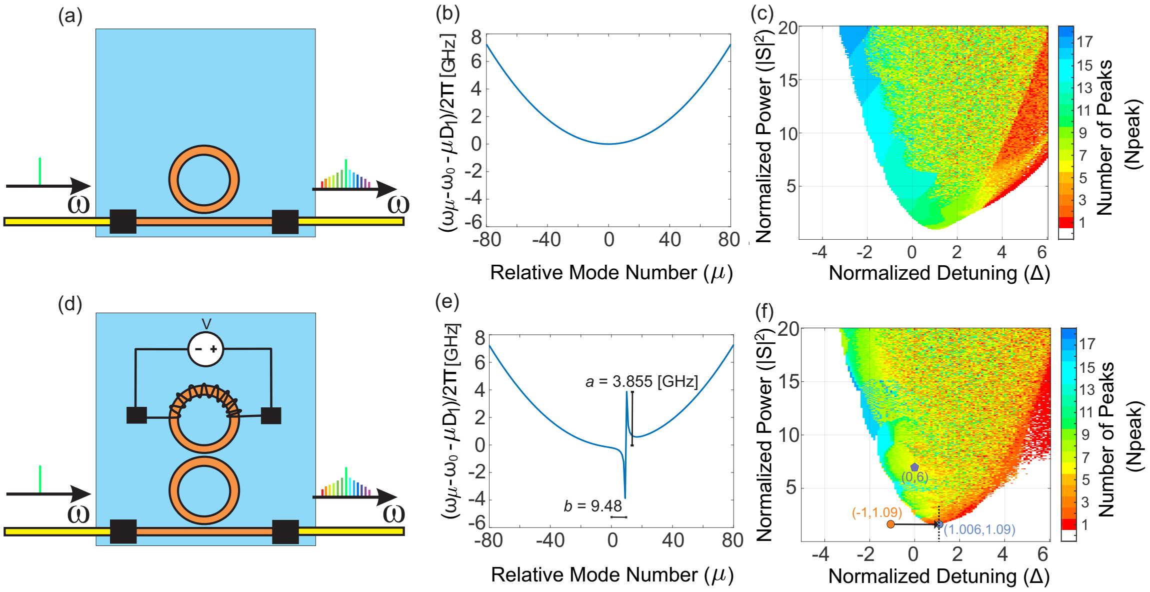

Fig. 1. (a) Microring resonator structure. (b) Dispersion profile of single microring in anomalous regime. (c) Npeak $(\Delta, |S|^2)$. (d) Two coupled microring resonators structure with heater. (e) Dispersion with mode interaction. (f) Npeak $(\Delta, |S|^2)$ with a two-coupled-microring structure. The blue point in (f) shows the initial point of the simulations.

First, we studied the different regions of Kerr comb operation in the pump power and detuning parameter space on a single Si_3N_4 microring resonator with a free spectral range of 227 GHz shown in Fig 1 (a). For this study, we

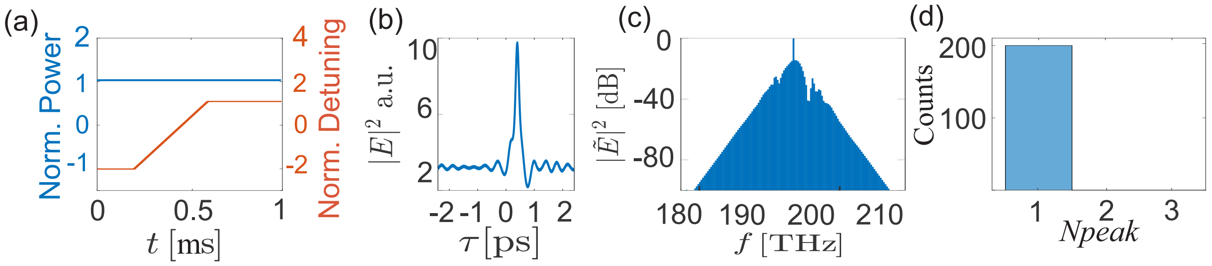

Fig. 2. (a) Pump power (blue) and Detuning (red) vs slow time. (b) Intensity figure. (C) Spectrum figure. (d) Histogram of the number of peaks (Npeak) for 200 simulations with different realizations of the initial noise with the pump power and detuning values of Fig 2. (a)

use the Lugiato-Lefever equation (LLE) solved numerically with the split-step Fourier method. We used the same parameters as in [3]. In Fig 1 (c), we show the results of these simulations. Here, we want to highlight the red thin single soliton region, which appears on the right side of the figure. The position of this region in this parameter space makes the single soliton region challenging to access.

Next, we introduce a slightly smaller second microring resonator with a microheater on top coupled with the microring previously described shown in Fig 1 (d). The change of the voltage applied to the heater results in a variation of the waveguide effective refractive index. This variation is due to the thermo-optic effect and leads to a change in the frequency resonances. Given the slight difference of the free spectral range of the microrings, an interaction between longitudinal modes appears periodically in the frequency domain. Here, we take into account only the nearest mode interaction to the pump wavelength. To take into account this interaction, we model the longitudinal mode frequencies ω_μ in the LLE with the following equation [5,6]:

$$\omega_\mu = \omega_0 + D_1\mu + \frac{1}{2}D_2\mu^2 + \frac{a/2}{\mu - b} \tag{1}$$

Where, μ is the relative mode number, ω_0 is the frequency of the pump, D_1 is the free spectral range, D_2 is the dispersion coefficient, and a and b are the strength and the frequency of the mode interaction, respectively. In the simulations, we chose $a = 2\pi \cdot 3.855$ GHz and $b = 9.48$, as shown in Fig. 1 (d). In Fig. 1 (e), we present the power ($|S|^2$) and detuning parameter space taking into account this mode interaction. Here, we highlight the shift of the single soliton region to the bottom of the comb generation. This new position of the single soliton region makes it accessible in a straightforward path at constant power and sweeping detuning from blue to red, as shown by the black arrow. To demonstrate the deterministic behavior of the single soliton region, we repeated 200 times a simulation with different initial random fields. The normalized power is constant 1.09 and the normalized detuning sweeps from -1 to 1.006. Additionally, we use an adiabatic path with a slow varying detuning shown in Fig. 2 (a) for a total simulation time of 1 ms. The histogram of Fig. 2 (d) shows that we obtain a single soliton state in every simulation, and Fig. 2 (b) and (c) present its temporal shape and spectrum, respectively.

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