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## Active Feedback Stabilization of Super-efficient Microcombs

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In the past years, major scientific and technological progress has been made in the field of dissipative Kerr solitons (DKS) frequency combs on microresonators (microcombs) [1]. The generation of microcombs in  $Si_3N_4$ microresonators exhibit broad bandwidth, high repetition rate, and low power consumption. These capabilities have opened a venue for applications within optical communication [2]. However, continuous operation and high power per comb line are needed in order to address the demands of system-level applications. Recent works have demonstrated the generation of bright solitons with unprecedented high power conversion efficiency using photonic molecules [3]. In this work, we report the continuous operation of a super-efficient DKS microcomb over 25 hours using a packaged module. The soliton state is maintained by the stabilization of thermal drifts and the onchip optical power in the cavity. Our photonic molecule is composed of two coupled cavities with heaters placed on top. The fabricated device has been robustly packaged into a fiber-connectorized module to prevent random variations of the power coupling (Fig. 1 (a)). The experimental setup used for the feedback control is shown in Fig. 1. (b). The comb is generated with 20 mW of on-chip optical power covering a bandwidth of  $\sim 100$  nm, see Fig. 1 (c). The power conversion efficiency of the bright soliton corresponds to 32 percent. The long-term operation is achieved by harnessing the thermal drifting of the main resonance via a feedback loop implemented on an FPGA board. The soliton power is used as a control parameter to maintain a fixed pump detuning. This indicates that the coupling between these parameters holds in the super-efficient configuration of the photonic molecule as in [4]. Fig. 1 (d) shows the spectral envelope of the microcomb with constant power over 25 hours. Since the pump laser is free-running, the active control forces the cavity to follow in order to maintain a fixed pump detuning. As a result, the frequency of the repetition rate of the microcomb drifts over 800 kHz towards higher frequencies (Fig. 1 (e)). The frequency drifting of the pump laser (Toptica CTL) was monitored over the last 5 hours of the soliton existence by beating versus a frequency comb (Menlo FC1500), see Fig. 1 (f). During the first 100 minutes of recording the resulting beat note drifts, increasing the frequency until it leaves the set span window. As the drifting continues, the beating with a neighboring line of the frequency comb is observed. The soliton power is stabilized as the photo-detected converted power remains constant (Fig. 1 (f)). Nevertheless, the drifts exhibited are very minor, and we expect increased stability by feeding back into the laser piezo-control.



Fig. 1 Long-term operation of a bright soliton. (a) Photonic molecule packaged into a single module. (b) Experimental setup of the active thermal control. (c, d) Measured optical spectrum over 25 hours. (e) The repetition rate of the microcomb using electro-optic down-conversion. (f) Measured pump frequency drifting and photo-detected converted power of the comb.

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