Microresonator soliton frequency combs

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ABSTRACT

Microresonator frequency combs provide access to compact, photonic-integrated optical comb with large mode spacing operating in a soliton regime. We will discuss the physics of such solitons and their applications in telecommunication and distance measurements.

Keywords: Integrated photonics, nonlinear optics, optical frequency combs, microresonators, optical solitons.

1 INTRODUCTION

Optical frequency combs [1], [2] provide equidistant markers in the IR, visible and UV and have become a pivotal tool for frequency metrology and constituted the underlying principle of optical atomic clocks. They are also finding use in other areas, such as broadband spectroscopy or low noise microwave generation. In 2007 a new method to generate optical combs was discovered based on high-Q optical microresonators[3], [4]. Such microresonator frequency combs have since then emerged as a new and widely investigated method with which combs can be generated via parametric frequency conversion of a continuous wave (CW) laser inside a high-Q resonator via the Kerr nonlinearity.

Over the past years the detailed understanding of the microresonator-based comb formation process has been gained, and regimes where such nonlinear driven dissipative microresonator system can support the formation of intracavity pulses - dissipative Kerr solitons (DKS), that not only provide low-noise optical frequency combs, but moreover give access to femtosecond pulses. Such DKS have unlocked the full potential of soliton microcombs by providing access to fully coherent and broadband combs obtained via soliton broadening effects. Dissipative Kerr solitons have now been generated in a wide variety of resonators, including crystalline microresonators and planar platfroms which are compatible with photonic integration based on silicon or silicon nitride (Si_3N_4). We will discuss the regime of dissipative Kerr solitons (DKS), first discovered in crystalline resonators [5], and our current understanding including its formation dynamics and behaviour under different effects, such as the impact of Raman scattering of the microresonator medium [6] and higher-order dispersion effect, including the emission of soliton dispersive waves (soliton-induced Cherenkov radiation)[7]. We also demonstrate a rich panel of instabilities available for DKS states due to their nonlinear origin, which includes the observation of different types of breathers [8], the influence of avoided mode crossings on breather and the repetition rate [9], [10], as well as methods to deterministically access the single soliton regime[11]. Taken together this has enabled to reliably access single soliton states in photonic-chip-based resonators, in particular those utilizing the photonic Damascene process [12].

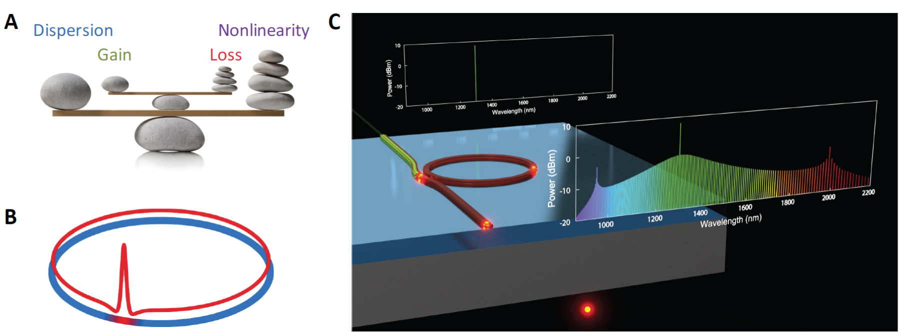

Figure 1. **Dissipative Kerr solitons** (a) Double balance between dispersion, nonlinearity, pump and cavity losses that is achieved for stable dissipative Kerr solitons generated in nonlinear Kerr cavity. (b) Intracavity waveform of the dissipative Kerr soliton. (c) Dissipative Kerr soliton formation in CW-driven on-chip nonlinear microresonator.

Dissipative Kerr solitons enable optical frequency combs that can span more than a full octave using soliton-induced Cherenkov radiation, which extends the combs bandwidth and power in the spectral wings via dispersive waves. Such DKS have been enabled to count the cycles of light[13], allow 2f-3f self referencing [14]. Using such soliton Kerr optical frequency combs in a SiN microresonator we have recently demonstrated with the group of C. Koos (KIT) massively parallel coherent communication, with dual combs for both the source and as massively parallel LO for the coherent receiver[15]. Moreover, using a pair of photonic-chip-based frequency combs, we have demonstrated dual-comb distance measurements, with record acquisition rates due to the combs large mode spacing (100 GHz). Our recent work moreover has shown that DKS can be extended to the biological imaging window at 1 micron, relevant for e.g. Raman spectral imaging or OCT [16]. Soliton microcombs have the potential to advance timekeeping, metrology or telecommunication by providing a technology amenable to full photonic integration, low power consumption and large comb bandwidth with high repetition rates.

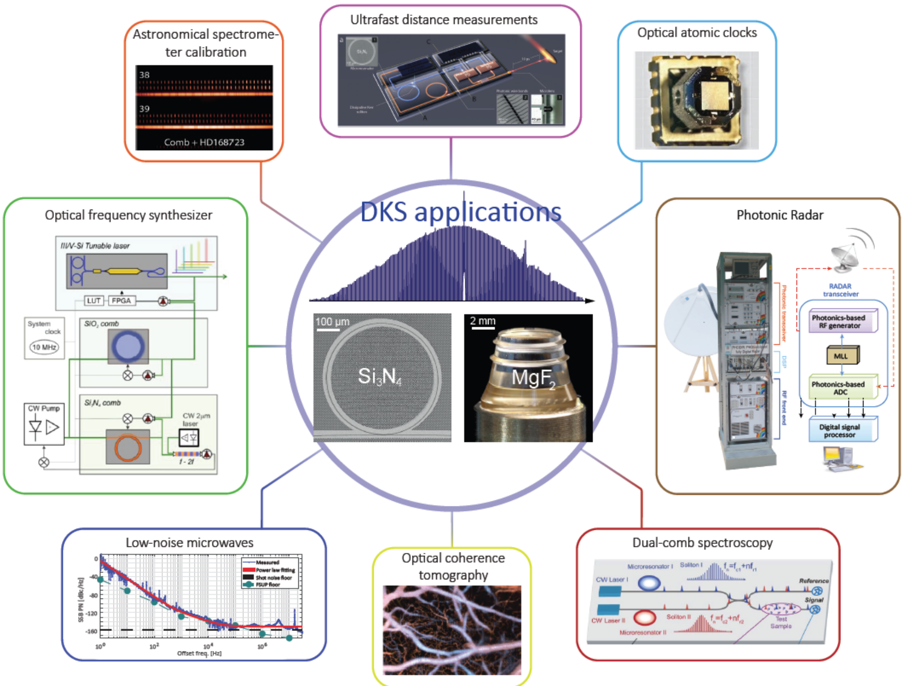

Figure 2. **Application of dissipative Kerr solitons**

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