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Optical Division of an Octave-Spanning Comb on an All-Silicon Nitride Platform

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***Abstract*—We demonstrate optical frequency division of an octave-spanning large repetition rate microcomb to an electronically-detectable frequency in an all-silicon nitride dual microcomb platform**

Keywords— frequency combs, photonic integration

I. INTRODUCTION

The recent demonstration of octave-spanning microcombs has opened the door to a number of exciting applications requiring extreme frequency stability, including RF-to-optical frequency synthesis and atomic clocks [1,2]. Prior to these broadband devices, on-chip self-referencing of a microcomb was difficult at best, limiting the potential of integrated combs. However, the progress of octave-spanning solitons on chip has still been hampered by a significant problem: they have only been demonstrated with repetition rates on the order of a THz, far outstripping the capabilities of current electronics for detection. In 2019, NIST reported a measurement of the repetition rate of a THz octave-spanning soliton in a silicon nitride (SiN) microring via the beat signal with a 22 GHz narrow bandwidth soliton in a silica whispering-gallery-mode (WGM) microresonator (the latter provides an ultrahigh Q that compensates for the drop in intracavity power associated with large cavity volume) [2]. This frequency division scheme provided a route for an on-chip stable frequency source. However, the different platforms for the two microresonators significantly increase the complexity of integration. In this work we report, to the best of our knowledge, the first use of a low repetition rate soliton microcomb to read out the repetition rate of an octave-spanning soliton fully based in silicon nitride (SiN). This work is enabled by the recent realization of ultrahigh Q low-free spectral range (FSR) SiN microresonators [3] to overcome the requirement for high pump power to excite low repetition rate solitons. Additionally, both resonators are integrated with microheaters allowing for precise comb line placement, and are fabricated on wafers with identical thickness, suggesting promise for convenient integration. We believe this is a significant step toward the goal of realizing fully on-chip RF-to-optical and optical-to-RF links.

II. DEVICE DESIGN

Images of our two high-Q microresonators (FSRs of ~900 GHz and 25 GHz, respectively) fabricated on 740-nm thick SiN films are shown in Fig. 1a. To achieve octave-spanning comb generation, the film thickness and ring width of Device 1 need to be carefully designed. We target low local dispersion at the pump frequency as well as dispersive wave excitation around 1000 nm and 2000 nm to enhance the signal to noise ratio for f-2f self-referencing. The low repetition rate comb need only span the C band, which is easy to realize with thick films that result in anomalous dispersion, provided that sufficiently high Q is available. Therefore, the target thickness of the SiN film is dictated by dispersion engineering considerations for Device 1; for the thickness of Device 2 the primary requirement is simply to have anomalous dispersion. Accordingly, the film thickness of 740 nm is selected based on dispersion simulations using the measured refractive index of the SiN waveguide core and silicon oxide cladding with the aim of optimizing the spectrum of the ~900 GHz comb. The ring waveguide width of Device 1(2) is 1640 (1900) nm. To minimize the propagation loss as well as the mode coupling between the fundamental and higher-order modes, Device 2 utilizes a bending transition design [3] to achieve 14 million intrinsic Q. Due to the planar structure of microring resonators, microheaters are relatively easy to fabricate on the SiN platform compared to WGM resonators. Here we include platinum integrated heaters on both of the devices to add extra tunability of both solitons.

III. EXPERIMENTAL RESULTS

We implement a rapid pump frequency tuning method to generate solitons faster than resonator thermal effects, as in [4]. We split the pump power equally into two arms and route each to an erbium-doped fiber amplifier (EDFA) followed by a SiN microring. Using our on-chip heater structure, we thermally shift our octave comb to spectrally overlap the pump resonances of the two rings.

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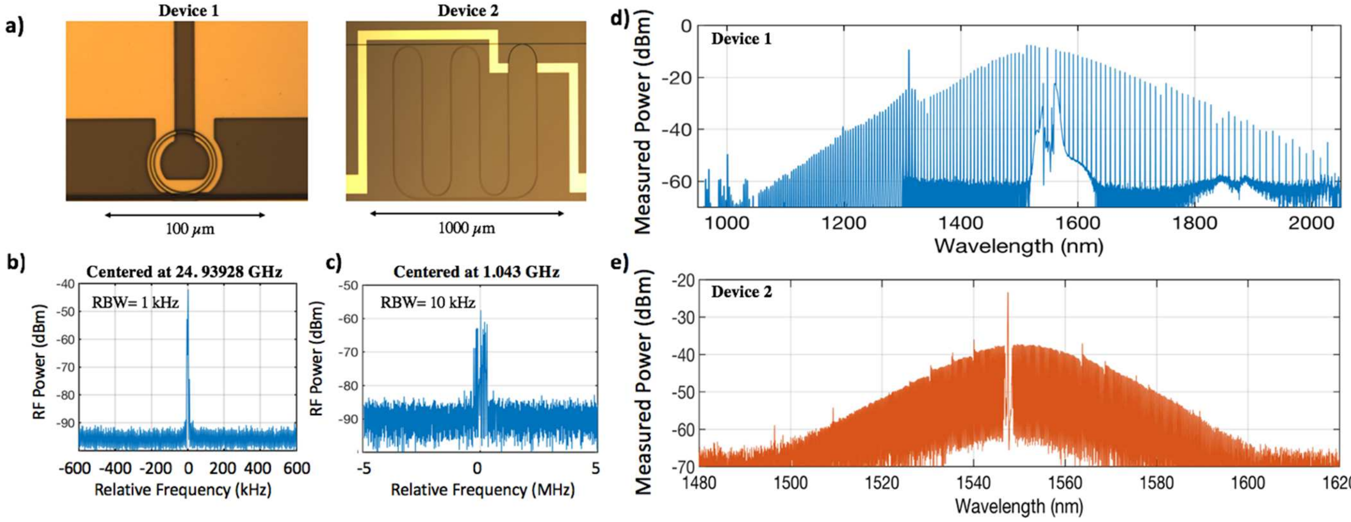

Figure 1 a) Optical Images of Devices b) Repetion Rate of low FSR soliton c) 2nd Spectral Overlap Beat d) Octave-spanning comb spectrum generated on Device 1 e) Optical spectrum of soliton generated on Device 2

The pump is scanned over multiple GHz in ~10 ns and generates solitons simultaneously in both resonators. The optical spectra are shown in Figs. 1d and 1e, respectively. Due to the low power levels of the 25 GHz soliton comb, we amplify the comb with an EDFA before optically combining with the octave comb and detecting with a high-speed photodiode. We record the RF spectrum on an electrical spectrum analyzer (ESA), revealing the repetition rate of the 25 GHz comb (Fig. 1b) and the optical beat notes between the 25 GHz and octave combs at their spectral overlap points (second overlap beat shown in Fig. 1c). The relatively broad beat in Figure 1c is presumed to be caused by the drifting of the unlocked combs' repetition rates. An optical spectrum analyzer shows how many 25 GHz comb lines fall between successive octave comb lines. Using this information combined with the measured beat frequencies, we compute an estimate of the octave comb repetition rate as 897.292 GHz. We note that as with any optical heterodyne measurement, there is a +/- ambiguity in the overlap beat. We resolve this ambiguity by dithering the repetition rate of the 25 GHz comb via pump power control. Finally, we validate the repetition rate measurement via the EO comb method described in [5]; the two measurements agree at ~1 MHz level.

IV. Conclusion

We have demonstrated the use of a SiN soliton microcomb with electronically-detectable repetition rate to optically sample an octave-spanning microcomb. We expect this will help pave the way forward for future microcomb integration efforts. We anticipate future work will focus on performing higher precision measurements of the repetition rate and on optimizing the 25 GHz comb coupling condition to improve the comb output power in order to eliminate the need for an EDFA post-chip.

Acknowledgment

The Si_3N_4 samples were fabricated at Myfab Chalmers.

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