Ultra-Low Threshold Broadband Soliton Frequency Comb Generation

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AJA sputter deposition, mask writer, furnace, Oxford 82 etcher

Abstract:

We measure a record-low threshold power down to 73 µW for parametric oscillation using resonators with intrinsic *Q* of 31.8 ± 4.4 million and demonstrate a broadband single soliton comb spectrum spanning 1097 nm-2040 nm (126 THz). The resonator compact profile is designed to minimize higher order modes excitation.

Summary of Research:

Microresonator-based frequency comb generation has recently attracted interest due to potential applications in spectroscopy, precision metrology and biomedical imaging [1-8]. However, the thresholds for these broadband frequency combs are limited by loss due to surface scattering [9,10].

Here we demonstrate an ultra-low threshold broadband single soliton frequency comb. It is generated with a resonator based on highly multimode Si_3N_4 waveguides for decreasing loss due to surface scattering and adiabatic bends to suppress higher order modes excitation.

Figure 1(a) shows the schematic of the device. The microresonator has a free spectral range (FSR) of 174 GHz and a cross section of 730 nm × 2600 nm which supports more than 8 modes (Transverse electric (TE) modes are shown in Figure 1 inset). A bus waveguide with the same dimension is used to couple to it. In the coupling section, the bending radius starts large (~ 900 µm) and then gradually reduces to a small value (~ 80 µm). The bending radius changes adiabatically, which allows us to have a small bending radius and also suppress excitation of higher order modes. Full 3D finite-difference time-domain (FDTD) simulations (Lumerical FDTD) depicted in Figure 2 show that higher order modes in our adiabatic bends design are suppressed compared with a regular ring resonator with constant bending radius.

We achieve a broadband single soliton comb spectrum spanning 1097 nm-2040 nm (126 THz) and measure a record-low threshold power down to 73 µW for parametric oscillation using resonators with intrinsic

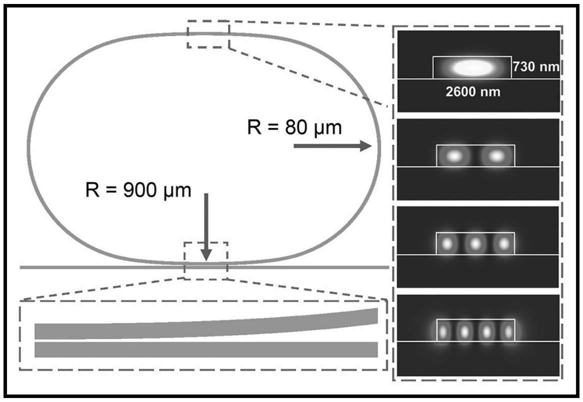

Figure 1: Schematic of our microresonators with adiabatic bends design. The bending radius starts large (~ 900 µm) and then gradually reduces to a small value (~ 80 µm). Inset shows the transverse electric (TE) modes supported by the waveguide and only the fundamental mode is excited in the adiabatic bends design.

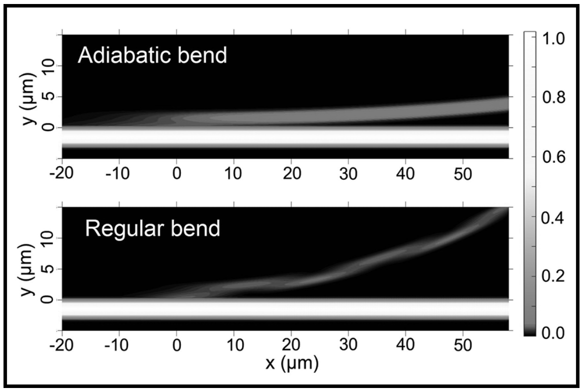

Figure 2: FDTD simulations of the adiabatic bends design (top) and the regular ring resonator with constant bending radius (bottom). Note that higher order modes have been excited in the regular ring and not in our adiabatic bends design.

Q of 31.8 ± 4.4 million. One can see that despite the large waveguide dimensions, we can still engineer the dispersion. In order to test the devices, we launch a laser source transmitted through a fiber polarization controller into the inverse nanotaper of our chip using a lensed fiber and collect the output through another inverse nanotaper using a collimating lens. We then split the collected light such that one of the outputs is used to monitor the generated comb spectrum and the other one is sent to a fast photodiode (> 12.5 GHz) to monitor transmission. We measure the output power in the first generated four-wave-mixing sidebands for different pump powers to determine the threshold for parametric oscillation.

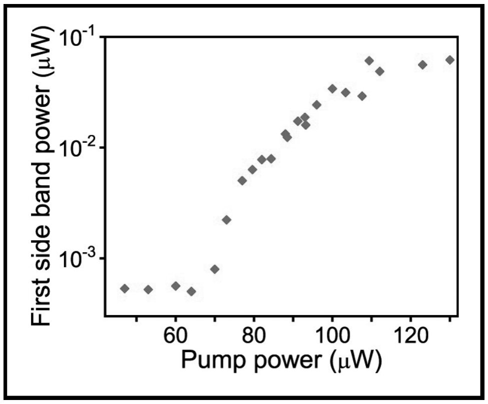

Figure 3: Output power in the first generated side band as a function of pump power. In this device, parametric oscillation is observed for pump power down to 73 μW.

Figure 3 shows the data for a device with an intrinsic Q of 32.8 million pumped at the resonance near 1560 nm. Parametric oscillation is observed with pump power down to 73 μW which is close to the theoretical limit of 70 μW. We generate a soliton-mode locked comb with the thermal tuning method as demonstrated in [11]. A narrow wavelength division multiplexing (WDM) filter centered at the pump wavelength is used to increase the dynamic range of the optical spectrum analyzer (OSA). Limited by the wavelength range of a single OSA, we obtain the spectrum in two shots under the same experimental condition (shown in Figure 4). Soliton state is maintained the same throughout the experiment.

In conclusion, we measure a record-low threshold power down to 73 μW for parametric oscillation using resonators with intrinsic Q of 31.8 ± 4.4 million.

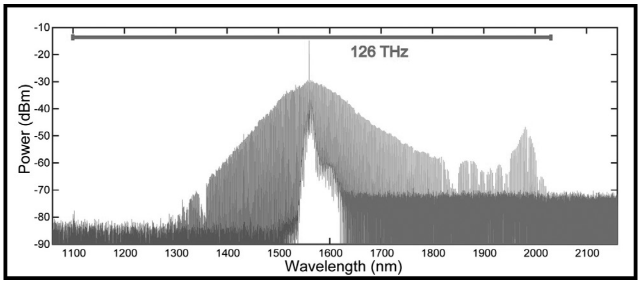

Figure 4: Broadband single soliton frequency comb spanning 1097 nm-2040 nm (126 THz) using highly multimode microresonators. Note that blue and red parts are the same single soliton state measured by two OSAs and dips in the spectrum (at 1350 nm and 1850 nm for example) are due to the WDM filter defects.

We achieve a broadband single soliton comb spectrum spanning 1097 nm-2040 nm (126 THz) using highly multimode waveguides by suppressing excitation of higher order modes with adiabatic bends. Utilizing highly multimode structures, we have more flexibility in the waveguide design (i.e. dispersion engineering). This work provides a method for using ultra high-Q multimode microresonators for applications such as spectroscopy and precision metrology.

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