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micro-Comb NTF

FNSNF

Planar SiN frequency comb generators for spectroscopy and communication

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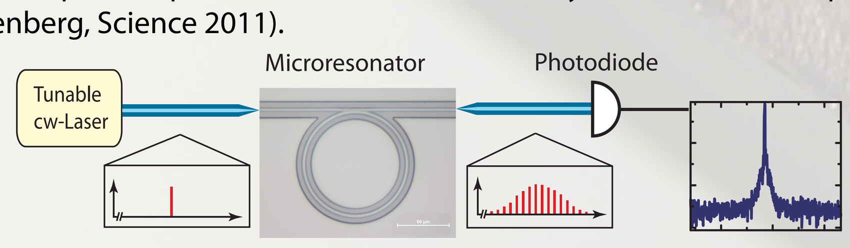
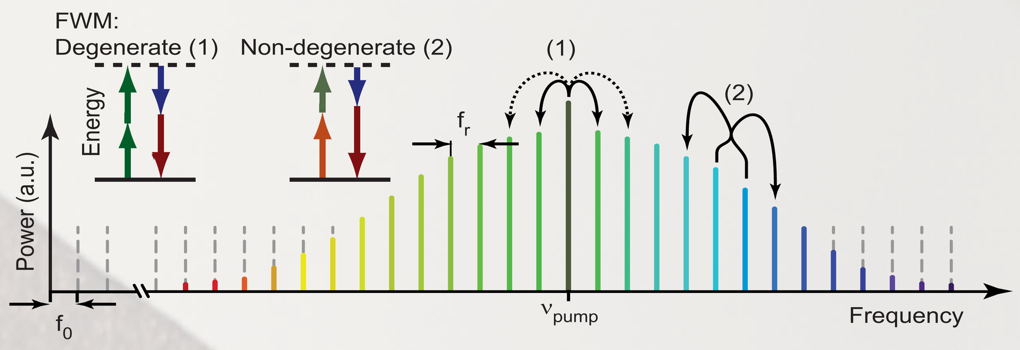
MPQ

Frequency Comb Generation in Micro-resonators via the Kerr Nonlinearity

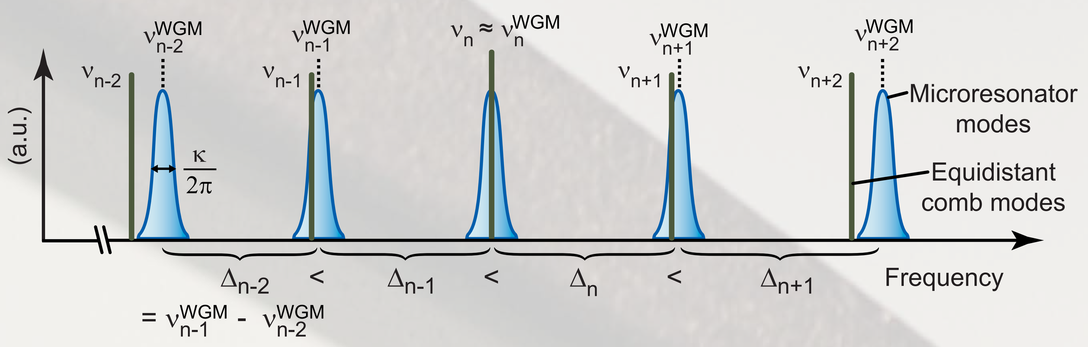
In 2007 our laboratory demonstrated a new way for optical frequency comb generation based on parametric frequency conversion in high-Q resonators (Del'Haye, Nature 2007). This technology allows to bring optical frequency comb technology into a planar chip scale setting and allows efficient, unprecedentedly compact combs sources with large mode spacing in the GHz domain. Such integrated comb generation has a variety of applications, notably in telecommunication as channel generators, as chip scale spectrometers and in astronomy to calibrated astrophysical spectrometers (Kippenberg, Science 2011).



The equidistance is comparable to conventional frequency combs from mode-locked lasers[1]. The repetition rate (fr) is determined by the Free Specral Range(FSR) of the microresonator.



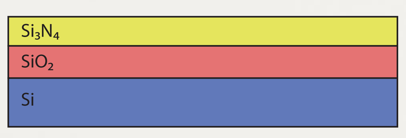
The cutoff frequency of the frequency comb is defined by absorption and resonator dispersion leading to a walk off between eqidistant comb modes and resonator modes.



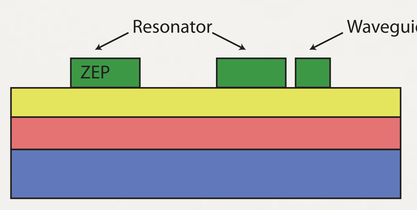
We employ Fully Vectorial FEM Simulations to optimize the dispersion in our microresonators.

Nanofabrication of integrated high-Q Ring Resonators

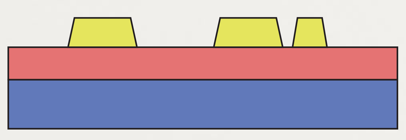
We use Wet Oxidation and Low Pressure Chemical Vapor Deposition (LPCVD) to prepare a Si_3N_4 on SiO_2 slab waveguide on a Silicon wafer



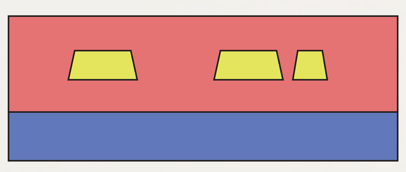
The ring resonators and the coupling wavegiudes are defined via Electron Beam Lithography.

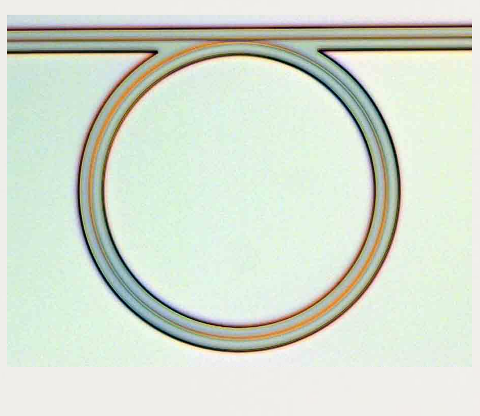


We perform a Reactive Ion Etching (RIE) step to transfer the layout into the resist. The sidewalls are slighty angled after the etching.



The resonators are then clad in with LPCVD SiO_2. The devices are now fully integrated and well isolated from the environment.





On the left you see an optical microscopy picture of the finished structures.

All the Nanofabrication steps are performed at the Center of Micronanotechnology at EPFL.

CMi EPFL Center of MicroNanoTechnology

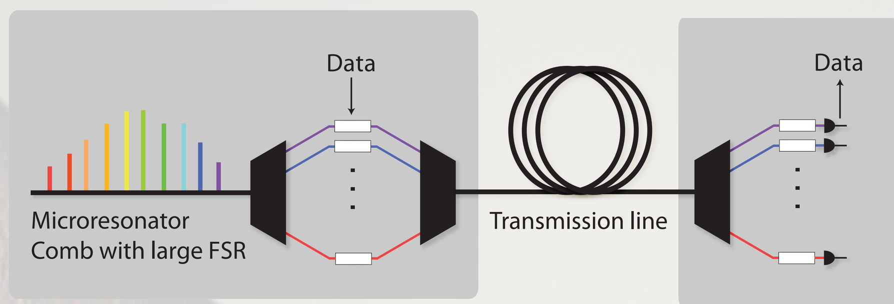
Outlook

- Further optimize the fabrication process to produce resonators with quality factors of the order of millions
- Achieve low phase-noise combs by advanced dispersion engineering
- Achieve octave spanning frequency combs
- Extend approach to other wavelengths and materials
- Proof of Principle for true on chip multi-heterodyne spectroscopy

Applications in Optical Communications and Sensing

Multi Wavelength Source for Wavelength Division Multiplexing:

Fully integrated on-chip Kerr combs with large FSR are very promising candidates for stable and low cost pump sources for WDM optical communication schemes.



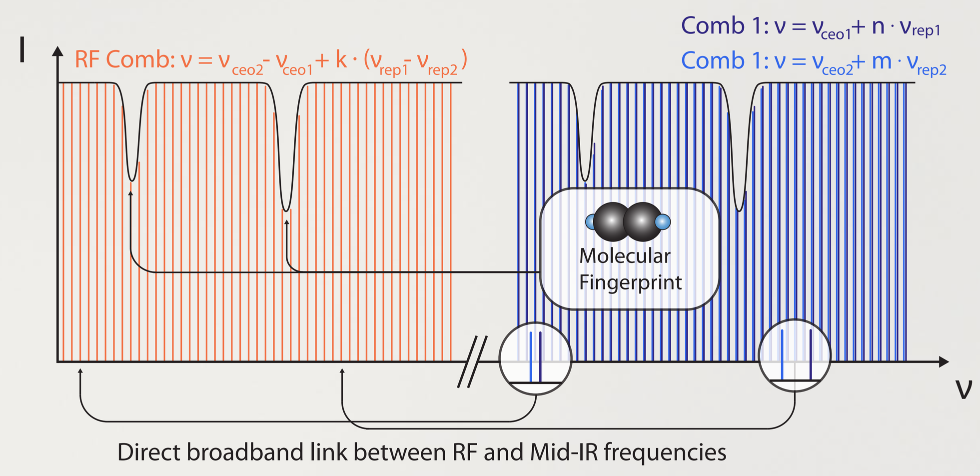
Recently, Orthogonal Frequency Division Multiplexing(OFDM) has been shown with mode-locked lasers[3]. Kerr combs with low FSR can increase the long term stability of those systems and decrease the cost.

Advantages:
- High power per comb line[1]
- Stable without external or internal stabilization scheme or reference because of thermal-self-locking mechanism[1]

Further applications range from arbitrary optical waveform generation to on-chip optical clocks and astronomical spectrometer calibration.[2]

On Chip Multi-Heterodyne Spectrocopy:

We employ two Kerr combs with slightly different FSR. The first resonator serves as a multi-frequency reference while the second one probes the medium of interest. This results in an RF beat note between the two combs whose frequency is measurable with a fast photo diode.[4]



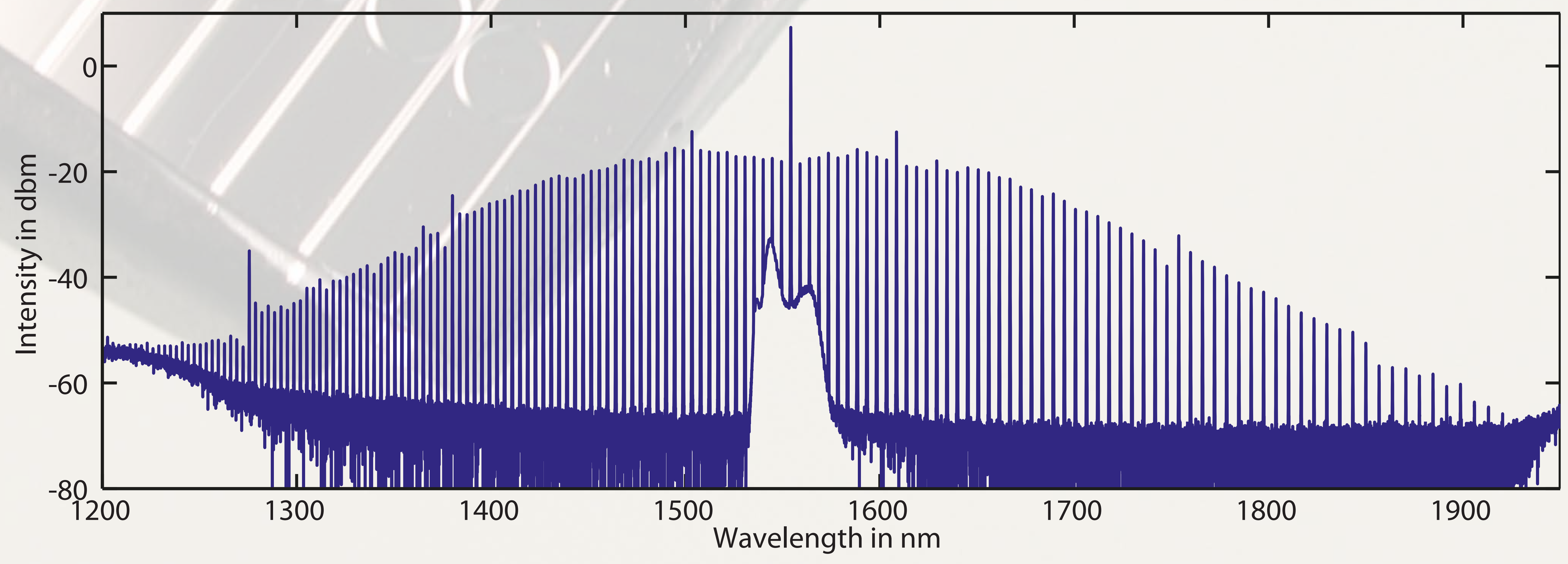
Advantages:
- Use an open resonator with cavity-enhanced evanecent field for true on-chip spectrocopy
- Large bandwidth of Kerr Combs
- No f-2f interferometry or frequency stabilization needed for incoherent detection of absorption spectra and trace gas sensing

Generated Combs

Our efforts of producing high quality SiN resonators were fruitful when we achieved the first combs. Nowadays we routinely fabricate samples with different properties such as repetition rate, coupling and even dispersion. The repetition rates achieved start at around 17 GHz and go up to over 1 THz.
These combs span not yet an octave but very broad combs such as the one shown below with a repetition rate of around 1 THz have been generated.

The current challenge of these combs is their high phase noise which indicates that the lines do not have a fixed phase relationship. This prevents us right now from exploring the multiple applications listed above. The phase noise is clearly visible in broad beat notes of the comb repetition rate which we can measure directly.

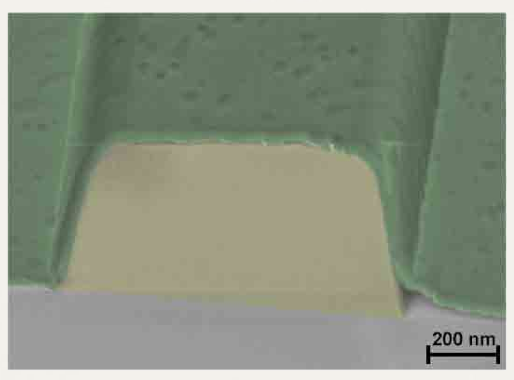
Reaching the octave with low phase noise can be considered as the Holy Grail of frequency combs. We are currently working towards this goal. Although it should be pointed out that an octave is not always necessary.



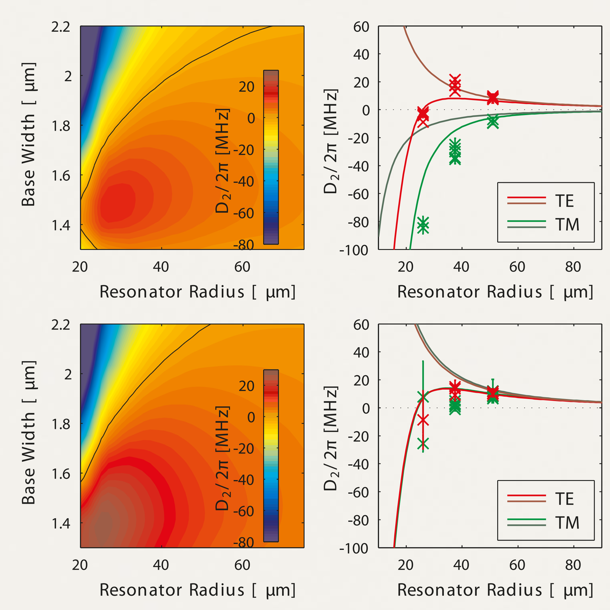
Dispersion Simulation, Measurement and Engineering

In the course of our research and comparing the results from the presented SiN combs with combs generated in crystalline resonators we found that dispersion plays an important role in the evolution of the comb[5]. Here we want to increase the dispersion in our resonators.

A SiN waveguide is covered with 55nm of hafnium dioxid (HfO_2, shown in green). This increases dispersion and smoothes the roughness of the SiN waveguide sidewalls caused by the etching. The deposition of these thin films is possible via Atomic Layer Deposition (ALD).



The upper two panels show simulations and measurements for uncoated SiN resonators, the lower panels show the same for sets for a resonator coated with 55nm of HfO_2. Simulations are FEM based and are carried out in Comsol Multiphysics. A paper with details is in preparation[6].



References:
1) Del'Haye et al., Optical Frequency Comb Generation from a monolithic microresonator, Nature 450, 1214-1217 (2007)
2) Kippenberg et al., Microresonator-Based Optical Frequency Combs, Science 332, 555 (2011)
3) Hillerkuss et al., Simple all-optical FFT scheme enabling Tbit/s real-time signal processing, Opt. Express 18, 9324-9340 (2010)
4) Coddington et al., Coherent multiheterodyne spectroscopy using optical frequency combs, Phys. Rev. Lett. 100, 13902 (2008).
5) Herr et al, Universal Dynamics of Kerr-Frequency Comb Formation in Microresonators, accepted for publication at Nature Photonics
6) Riemensberger et al, Dispersion Engineering and Measurement of Silicon Nitride based Ring Resonators coated with Atomic Layer Deposition, in preparation