Frequency comb generation in whispering gallery mode silica microsphere resonators

Inga Brice[1], Karlis Grundsteins[1], Arvids Sedulis[1], Toms Salgals[2,3], Sandis Spolitis[2,3], Vjaceslavs Bobrovs[3], Janis Alnis[1]

[1]Institute of Atomic Physics and Spectroscopy of the University of Latvia, Riga, Latvia
[2]Institute of Telecommunications of the Riga Technical University, Riga, Latvia
[3]AFFOC Solutions Ltd., Riga, Latvia

SPIE.
UNIVERSITY OF LATVIA INSTITUTE OF ATOMIC PHYSICS AND SPECTROSCOPY
NATIONAL DEVELOPMENT PLAN 2020
EUROPEAN UNION European Regional Development Fund
INVESTING IN YOUR FUTURE

Introduction

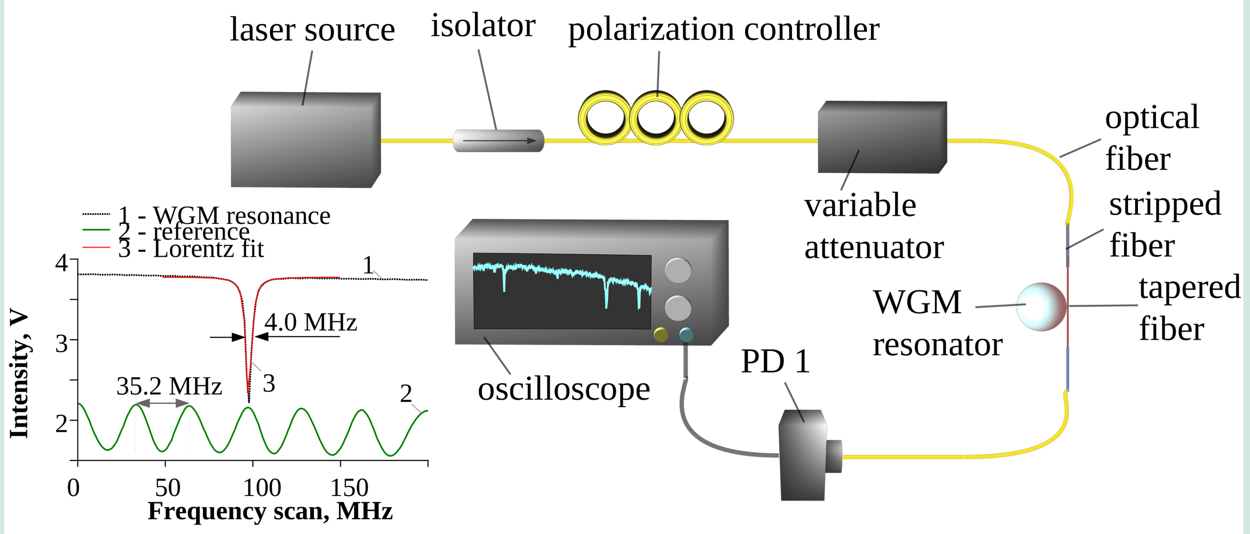
An optical frequency comb (OFC) can be generated using third-order Kerr-nonlinearity induced four wave mixing (FWM) generating the equidistant optical side-bands in the whispering gallery mode (WGM) microresonators. The microresonators are a suitable platform for nonlinear interactions due to their ultra-high quality (Q) factors, which requires low-power pumping for high efficiency of FWM.

OFCs using different kinds of whispering-gallery-mode (WGM) microresonators have already shown various applications. We are especially interested in the applications of WGM resonator OFCs in a fiber optical communication systems as replacements of laser-arrays. For this application the free spectral range (FSR) matches the ITU-T spectral grid is desirable. Besides the fabrication material for microspheres the resonator radius can be modified to change the FSR.

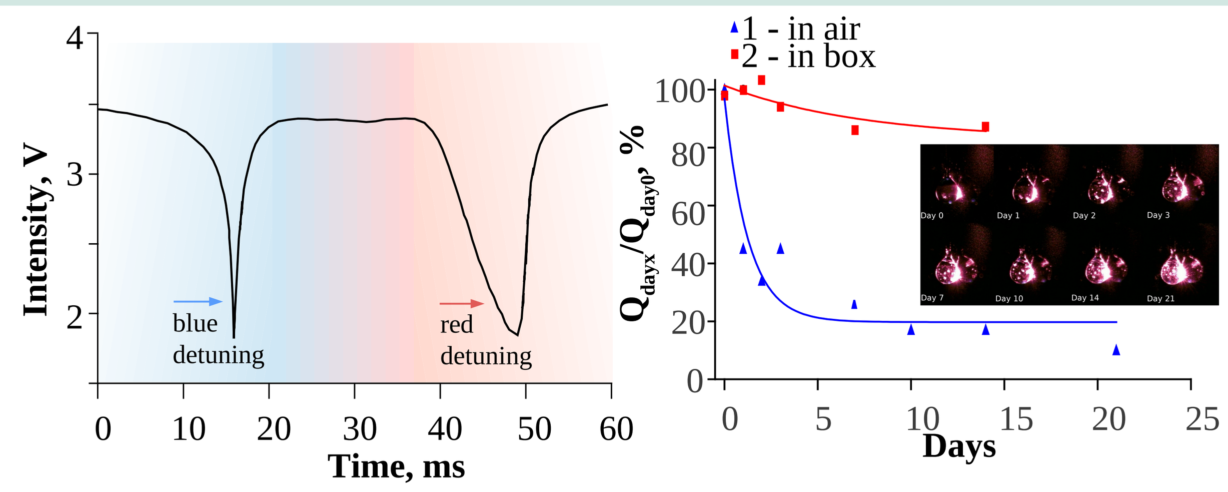
In the paper use of silica microspheres for OFC represents a cheap alternative over the other microcombs: microring, microdisk, and microtoroid. We experimentally research the microsphere fabrication process from different kind of silica (SiO_2) fibers by use of the Hydrogen-Oxygen melting technique. We experimentally review the OFC generation process the main microresonator parameters as FSR, Q-factor and evaluate resulting WGMR-OFC comb light source for further applications. An OFC was excited inside a 166 µm silica microsphere WGM resonators using a 1548 nm laser light. The obtained broadband OFC spanned from 1400–1700 nm with FSR of (3.17 ± 0.08) nm.

WGM Resonances

WGM Resonators. The light waves inside a WGM resonator are almost perfectly guided round by repeated optical total internal reflection. To couple the light inside the microsphere a coupling element like a prism or tapered fiber is necessary.

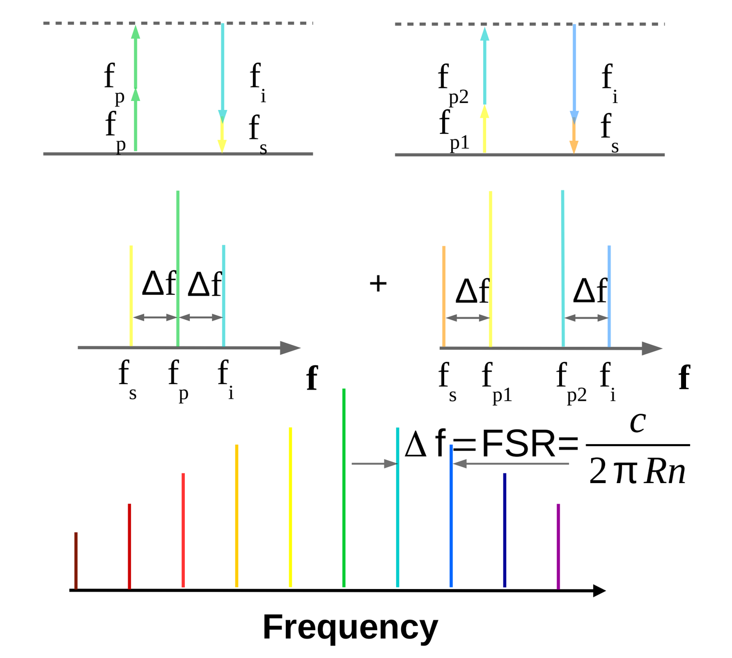


Characterizing WGM Resonators. The resonators were characterized by measurement of the Q factor. The measurement system was set up using a 1550 nm laser which was scanned to excite the WGM resonances. A photo-diode was used to record the transmission dips which corresponded to the resonances. Additionally, interferometer fringes from a 3 m long optical fiber were used as a reference signal.

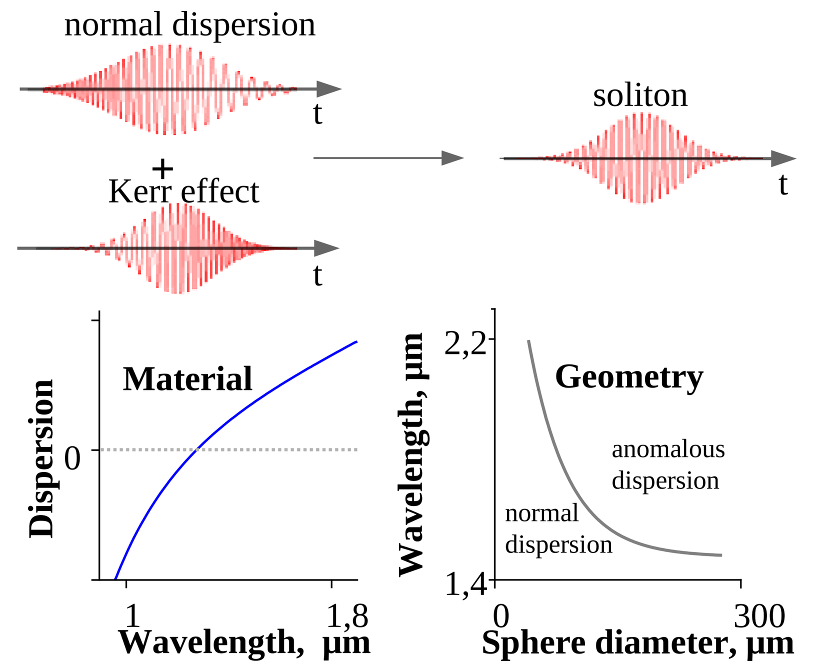


Non-linearity and Q degradation. In silica WGM microresonators it was possible to observe nonlinear effects while measuring the Q factor. Depending on the scanning direction of the laser the WGM resonance dips were compresses for blue detuning or broadened for red detuning due to the nonlinear effects. The effects are dependent on the Q factor. If the resonator aged the nonlinear effects became less pronounced.

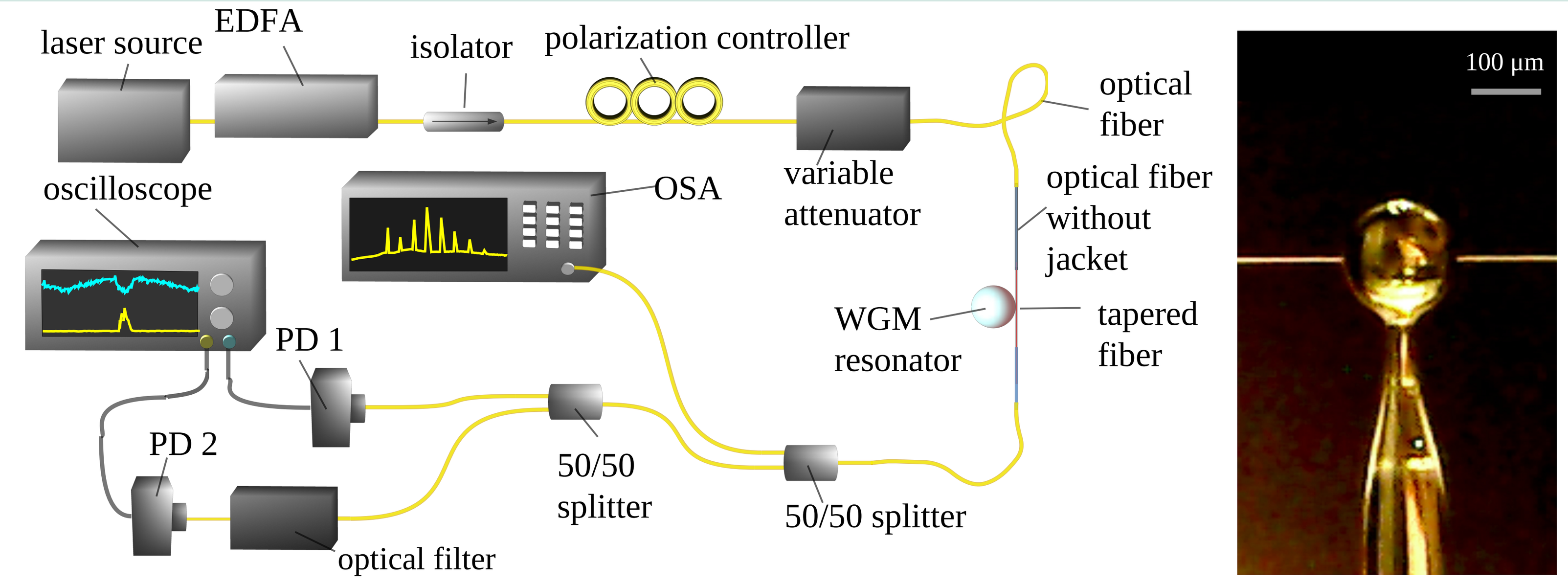
Generating Kerr Comb



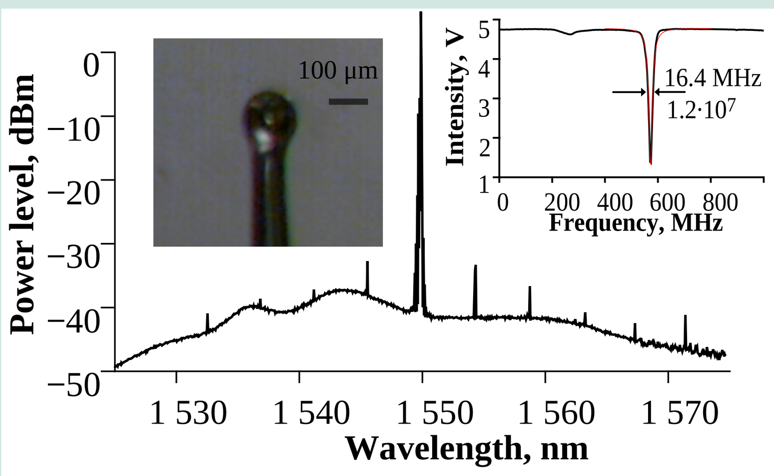
FWM VS losses. The degenerate FWM excites an equidistant signal and idler lines and both regular and degenerate FWM generate new comb lines.



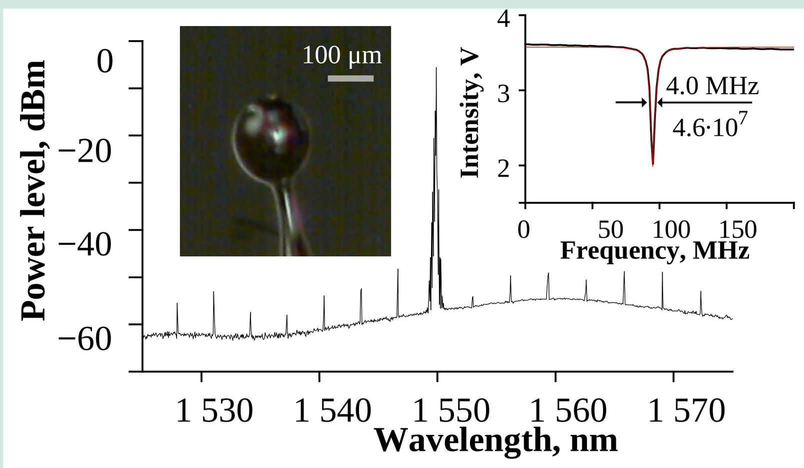
Dispersion VS Kerr effect. Both the material and geometry dispersion of the WGM microresonator contribute to the total dispersion.



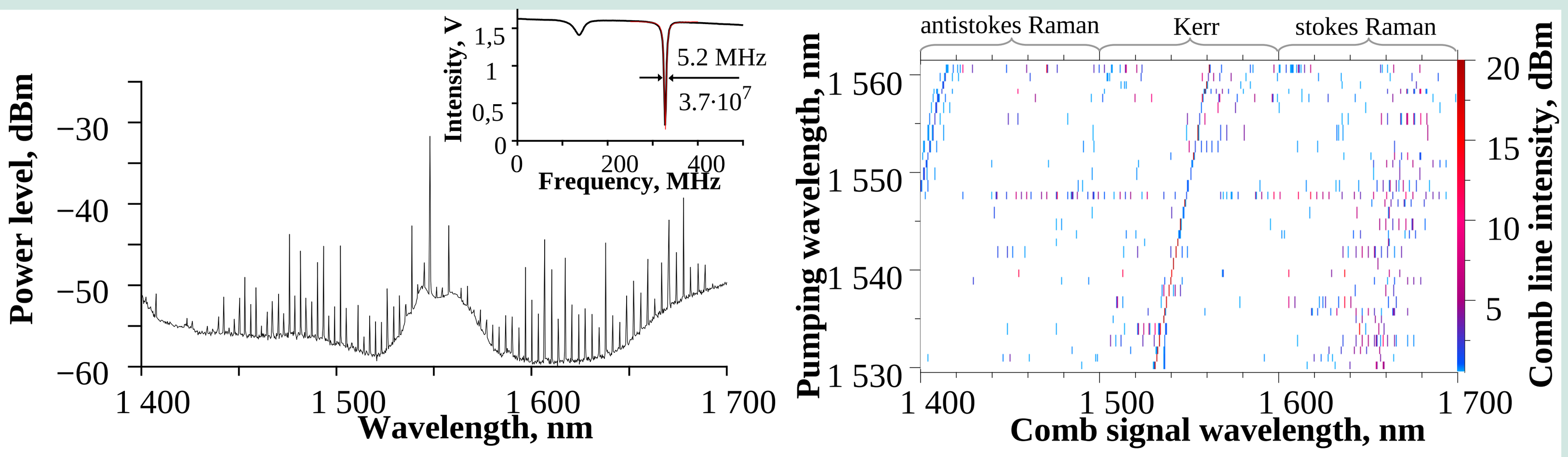
The figure shows a basic set-up scheme for Kerr Frequency comb generation. A tunable 1550 nm laser was and amplified and coupled inside a silica microsphere using a tapered fiber. Two photo-diodes were used: one to monitor the transmission signal and detect the WGM resonances and other to identify which WGM resonances generated the frequency comb. OSA was used to record the generated comb signal.



Kerr comb generated with 120 µm sphere. A comb like structure with comb spacing (4.31 ± 0.10) nm was observed, the radius of the resonator was calculated as (61 ± 1) µm.

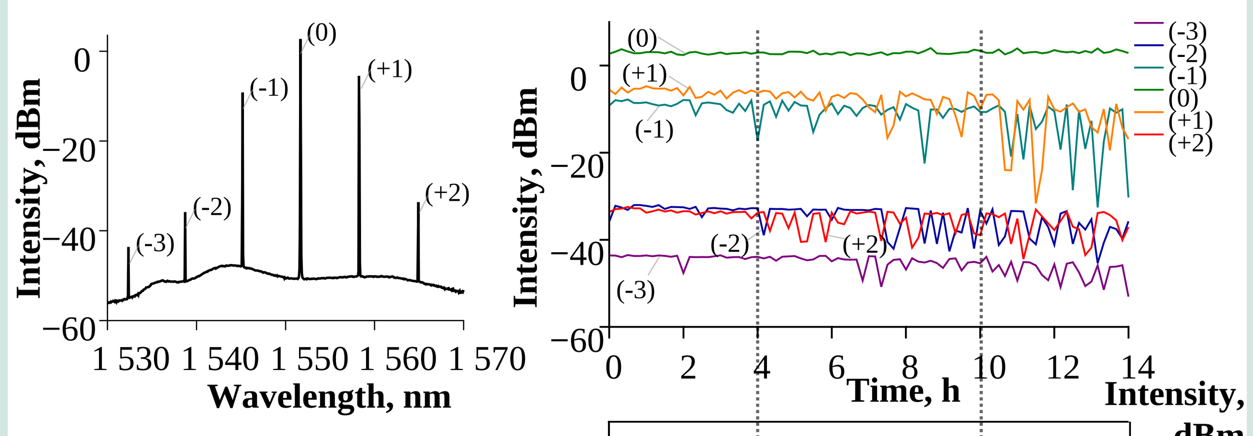


Kerr comb generated with 170 µm sphere. A comb like structure with comb spacing (3.14 ± 0.04) nm was observed, the radius of the resonator was calculated as (84± 1) µm.



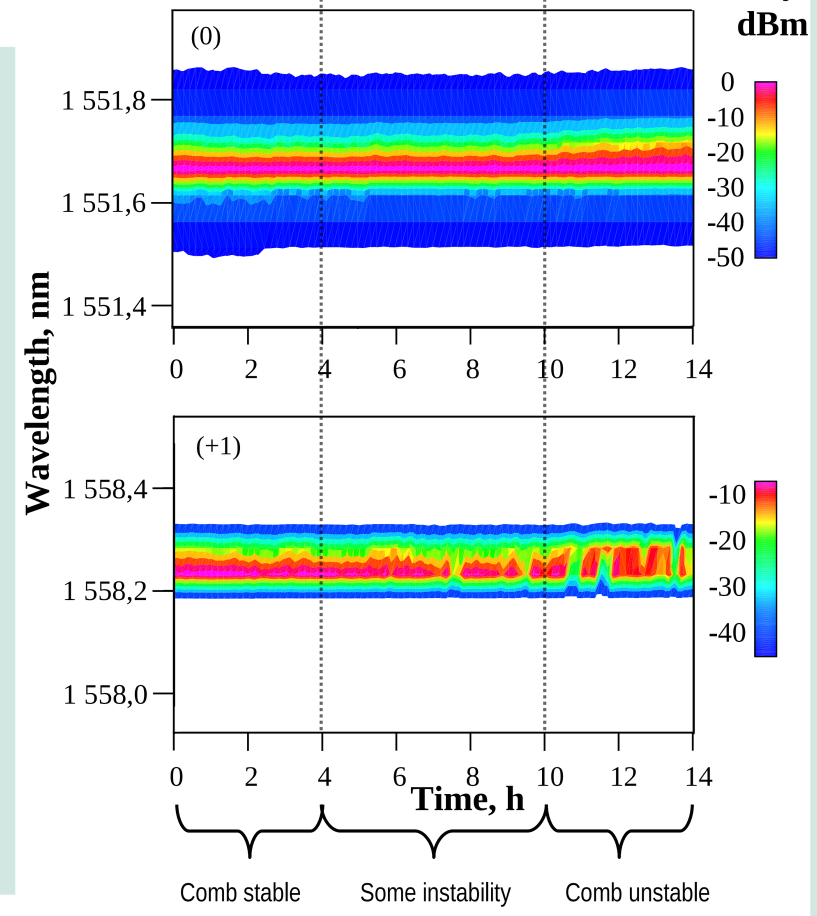
Kerr comb generated with 166 µm sphere. 32 different C-Band channel frequencies were pumped inside the WGM microsphere. Only 12 Channels generated Kerr comb lines. Using a 1547.72 nm laser light a comb was obtained spanning from 1400 – 1700 nm with FSR of (3.17±0.08) nm.

Comb Stability



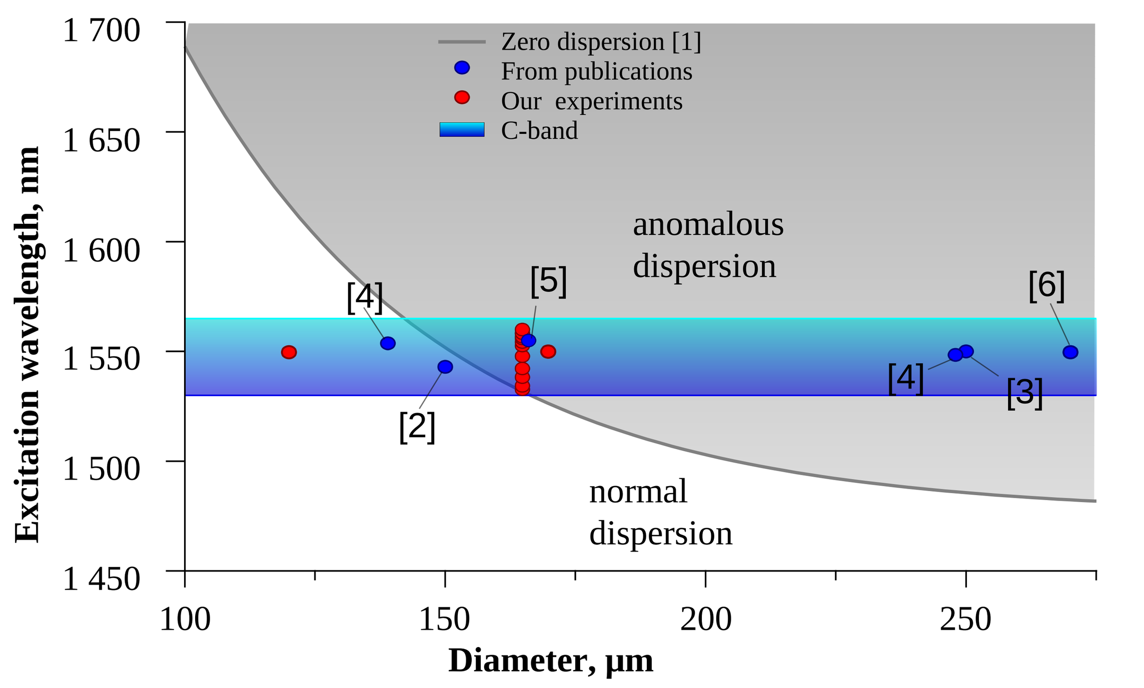
Vital parameters to monitor for stable Kerr Comb generation:

- Resonance excitation wavelength – temperature may shift resonance position.
- Coupling conditions – temperature may change the resonance and taper positioning.
- Pumping laser polarization – temperature may change optical fiber length.



Temperature control important for long term stability. An important parameter that could impact the long term stability is the temperature as it can impact multiple factors. The increase in instability observed from 4 to 10 h could be explained by the slight change of coupling conditions. Observing the intensity profile in time for the excitation laser (0) the signal broadened after 10 h due to the polarization changes. This broadening corresponds with the increase in instability. Eliminating the causes of instability will improve both the stability and the suitability of the system for WGM data transmission.

Application



Application in telecommunications. Demonstrated results show that the WGM resonator generated OFC in silica microsphere have the potential to replace individual laser arrays as a multiple laser source for data communication solutions. The telecom C-band region is 1530 – 1565 nm. The zero-dispersion wavelength depends on the material and size of for microsphere [1]. The publication with microspheres mostly feature resonators operating in the anomalous dispersion regime close to the zero-dispersion: [2-6].

References:

[1] N. Riesen et al., Material candidates for optical frequency comb generation in microspheres, Optics Express. 23 (2015).
[2] I.H. Agha et al., Four-wave-mixing parametric oscillations in dispersion- compensated high- Q silica microspheres, Physical Review A - Atomic, Molecular, and Optical Physics. 76 (2007).
[3] K.E. Webb et al., Murdoch, Experimental observation of coherent cavity soliton frequency combs in silica microspheres, Optics Letters. 41 (2016).
[4] S. Zhuet al., Controllable Kerr and Raman-Kerr frequency combs in functionalized microsphere resonators, Nanophotonics. 8 (2019).
[5] A.V. Andrianov, E.A. Anashkina, Single-mode silica microsphere Raman laser tunable in the U-band and beyond, Results in Physics. 17 (2020).
[6] J. Braunfelds et al, Frequency comb generation in WGM microsphere based generators for telecommunication applications, Quantum Electronics. 50 (2020).

Acknowledgements:

This research was funded by the **ERDF project No. 1.1.1.1/18/A/155**: "Development of optical frequency comb generator based on a whispering gallery mode microresonator and its applications in telecommunications" and by the Riga Technical University's Doctoral Grant programme.