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R. Suzuki et al.,
J. Opt. Soc. Amer. B. 35, 933-938 (2018)

Raman comb generation through broadband gain in a silica microresonator

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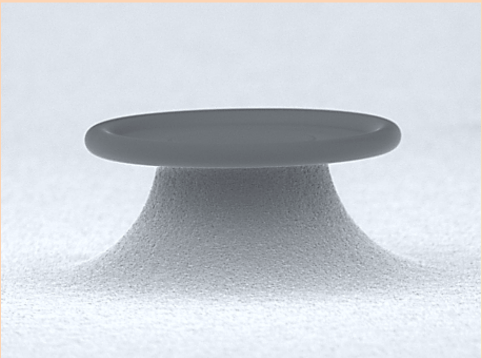
Microcombs

Laser light having a comb-like spectrum, which is generated from a microresonator.

"Microcombs"

"Frequency combs"

Microresonator

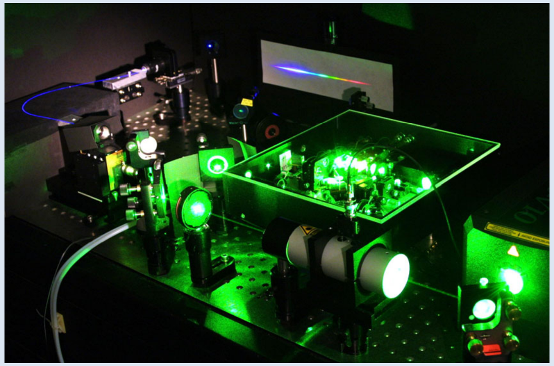


- Compact size
- Low consumption energy
- Large mode spacing (10-1000GHz)

Applications

- Optical communications
- Dual-comb spectroscopy
- Dual-comb LIDAR
- Microwave oscillators
- Optical frequency synthesizers

Ti:Sapphire laser

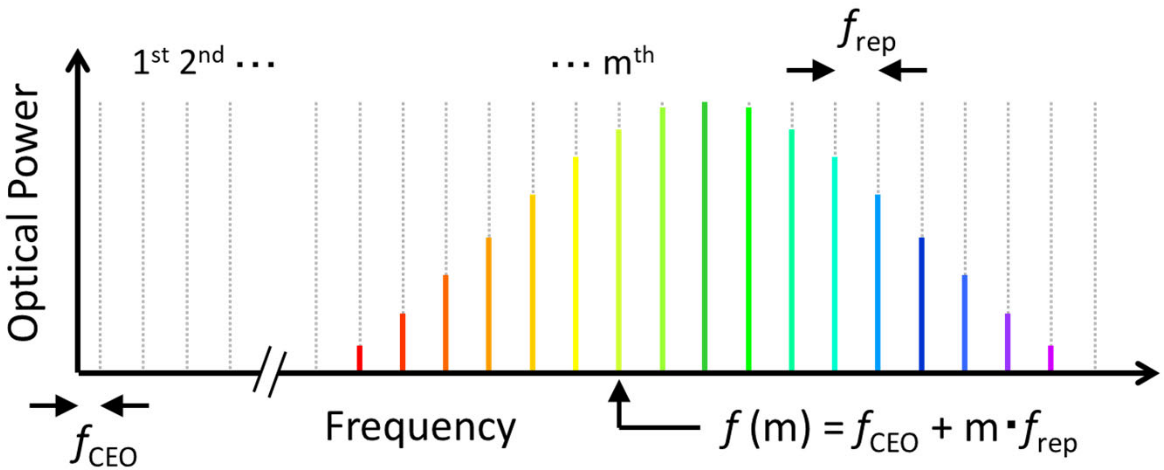


http://www.mpq.mpg.de/~haensch/comb/index.html

Fiber laser

https://www.aist.go.jp/index_ja.html

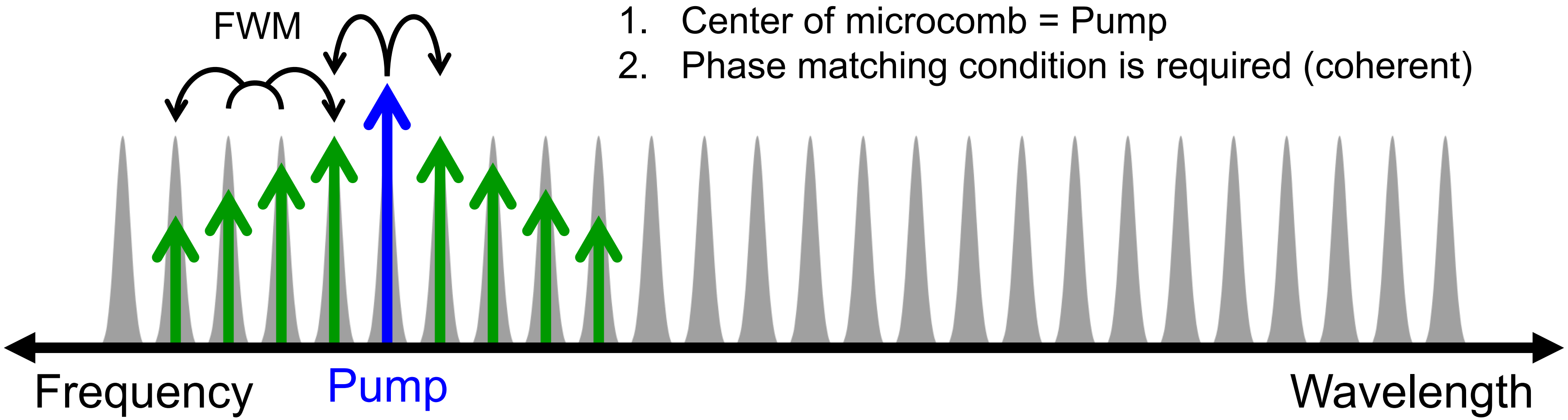
Comb spectrum



Microcomb generation via FWM/SRS

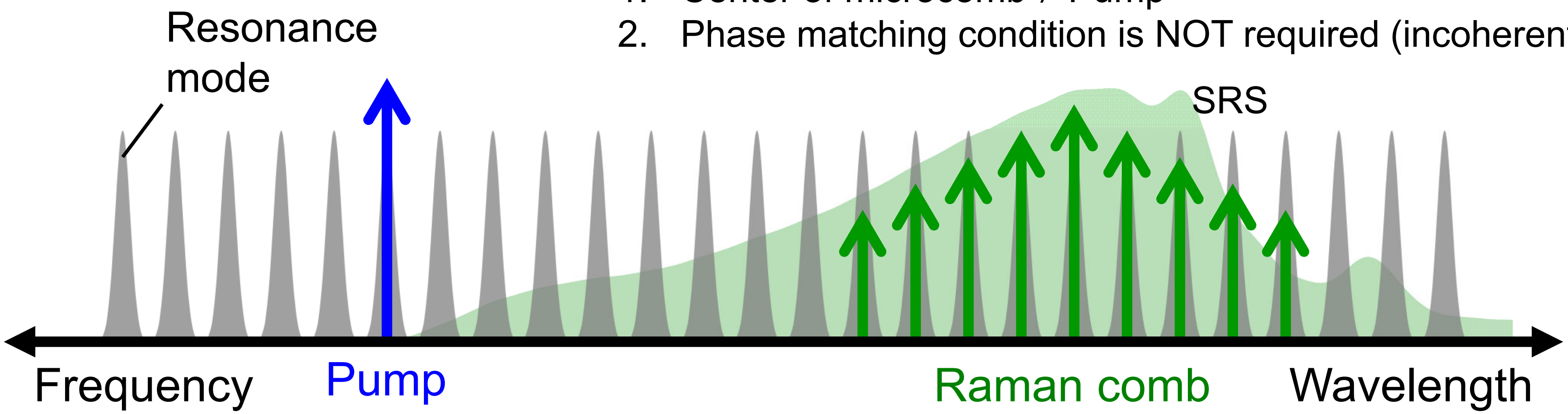
Microcomb via four-wave mixing (FWM)

1. Center of microcomb = Pump
2. Phase matching condition is required (coherent)



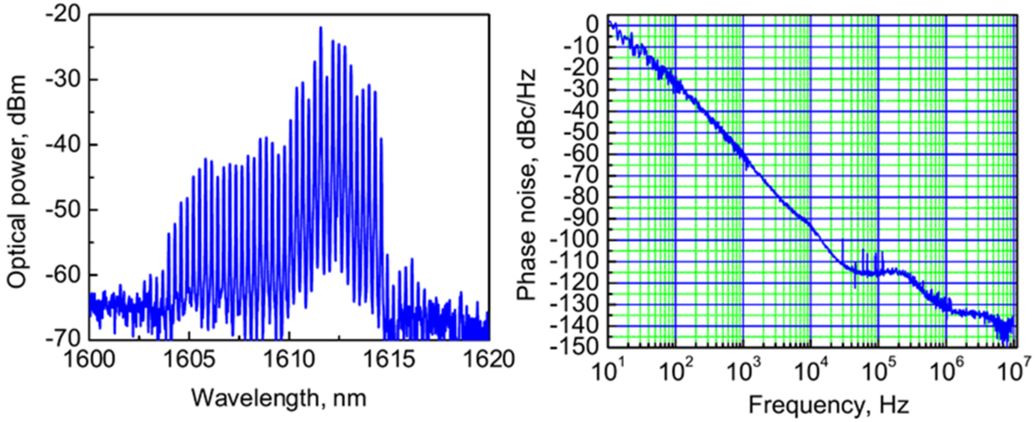
Microcomb via stimulated Raman scattering (SRS)

1. Center of microcomb ≠ Pump
2. Phase matching condition is NOT required (incoherent)



Stimulated Raman scattering in a microresonator

Coherent Raman comb generation



Phys. Rev. Lett. 105, 143903 (2010).

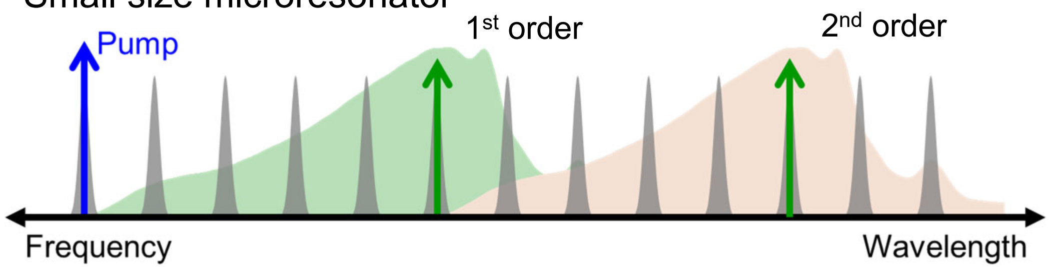
Coherent Raman comb generation has been demonstrated using CaF_2 and BaF_2 microresonators.

[1] W. Liang et al., Phys. Rev. Lett. 105, 143903 (2010).
[2] G. Lin et al., Opt. Lett. 41, 3718-3721 (2016).

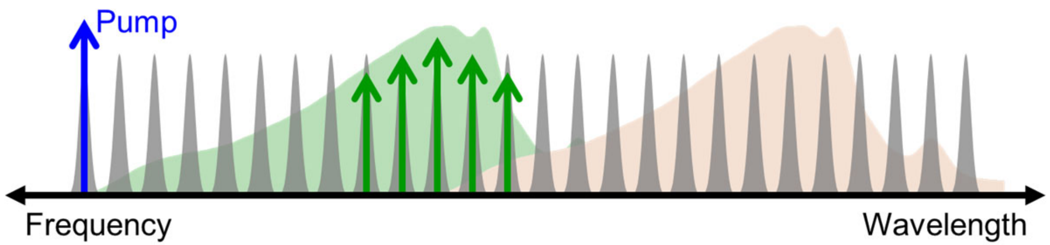
⇒Potential for coherent comb sources, which are generated via SRS in wide wavelength regieme.

SRS dynamics inside a microresonator

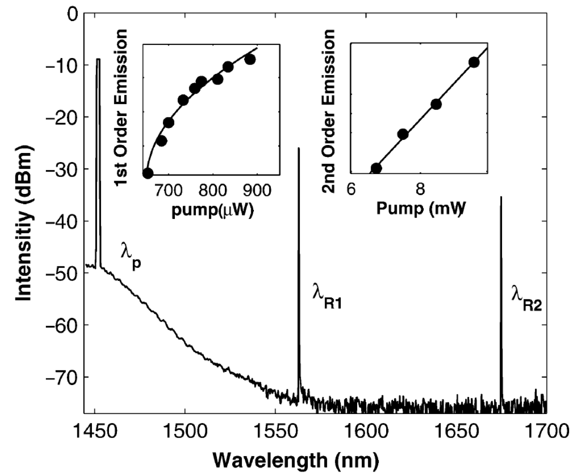
Small size microresonator



Large size microresonator [this work]



SRS formation in a small microresonator has been well studied (e.g. cascaded Raman)



IEEE J. Sel. Top. Quantum Electron. 10, 1219-1228 (2004)

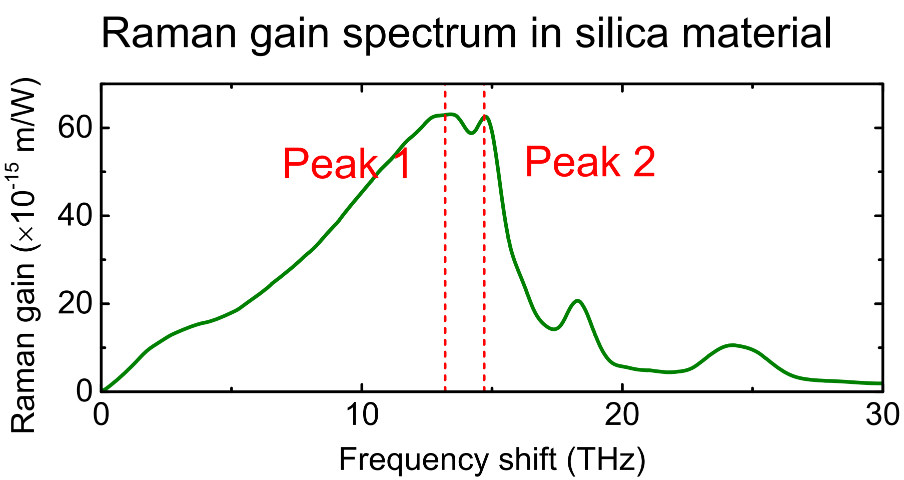
Motivation of this research

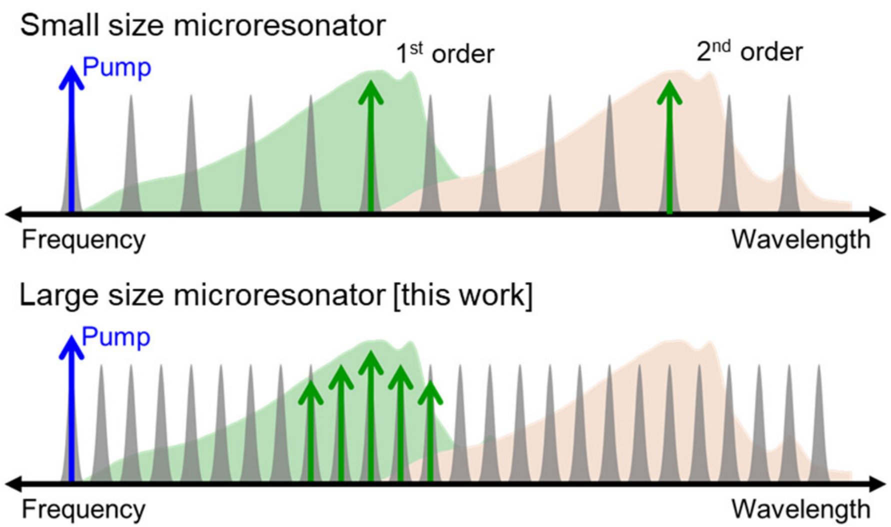
Motivation

To study the dynamics of Raman comb formation in mm-scale microresonators.
To focus particularly on the frequency shift within the Raman gain with two large peaks at 13.2 THz (Peak 1) and 14.7 THz (Peak 2).

Methods

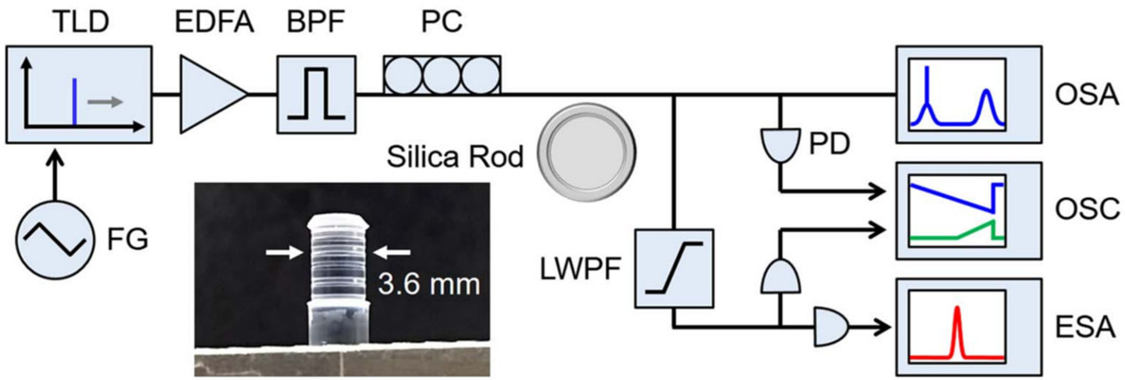
We used silica rod microresonators with cavity FSRs in microwave rates.
Silica material has broadband Raman gain spectrum.





Experimental setup & Raman comb generation

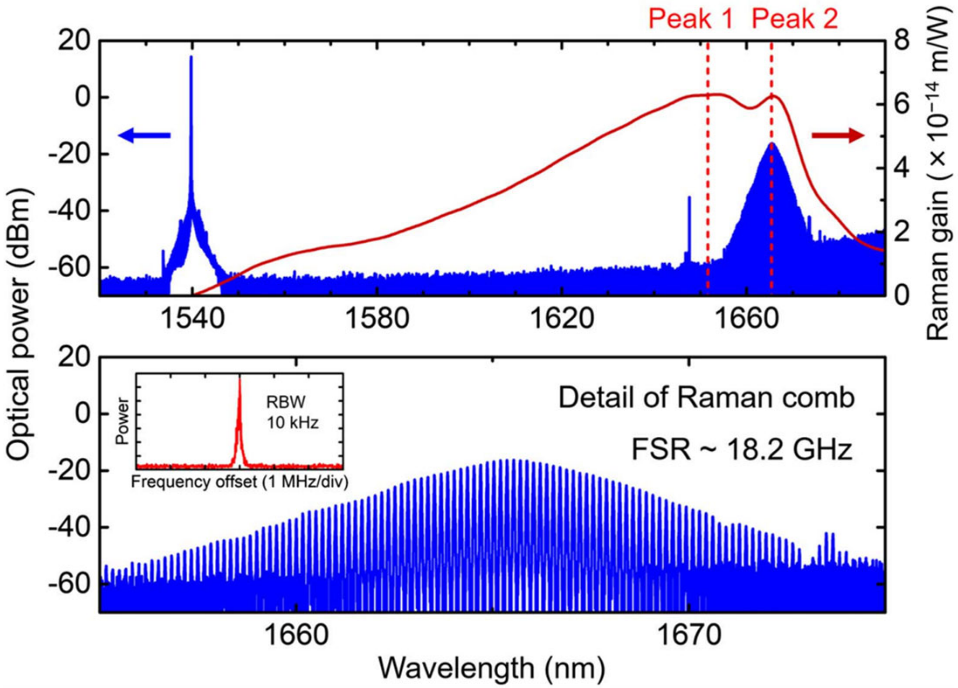
Experimental setup



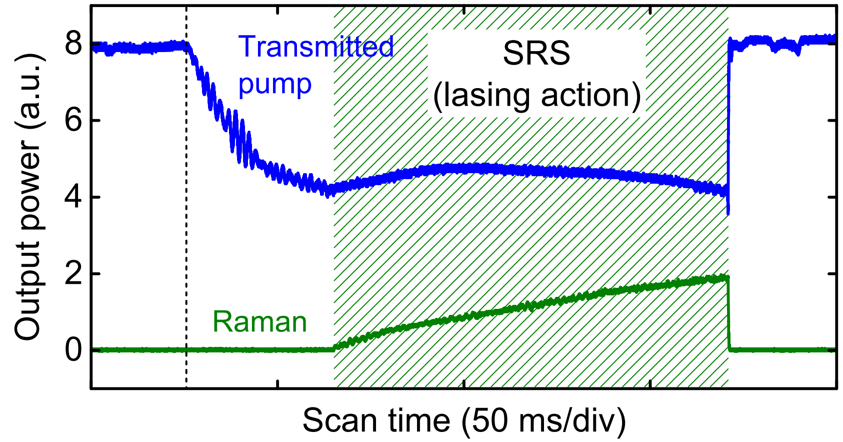
Cavity FSR: 18.2 GHz
Q factor: ~10^8
Pump power: 100 mW
Pump wavelength: 1540 nm

TLD: tunable laser diode, FG: function generator,
EDFA: erbium-doped fiber amplifier,
BPF: band pass filter, PC: polarization controller,
LWPF: long wavelength pass filter, PD: photodetector,
OSA: optical spectrum analyzer, OSC: oscilloscope,
ESA: electrical spectrum analyzer

Raman comb generation

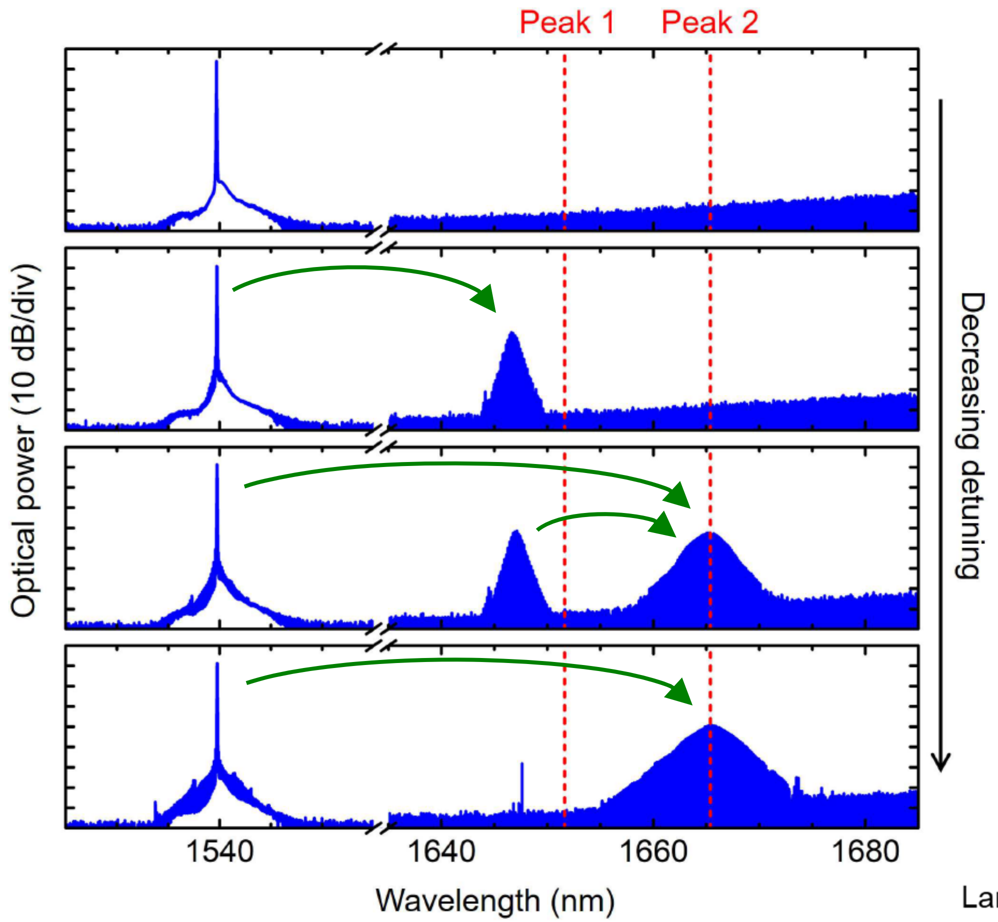


Output power during pump scanning

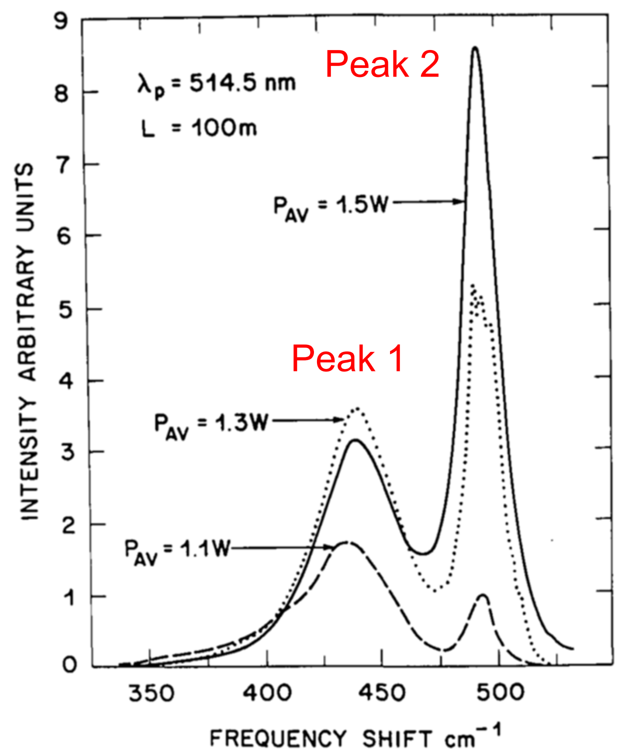


Detuning dependent Raman comb formation

Raman peak transition in a microresonator (depending on detuning) [This work]



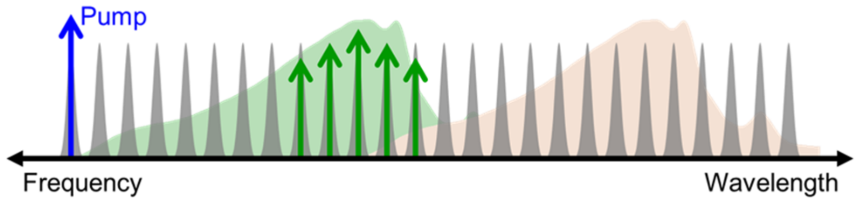
Raman peak transition in optical fibers (depending on input pulse power) [Ref]



J. Opt. Soc. Am. B 1, 652-657 (1984)

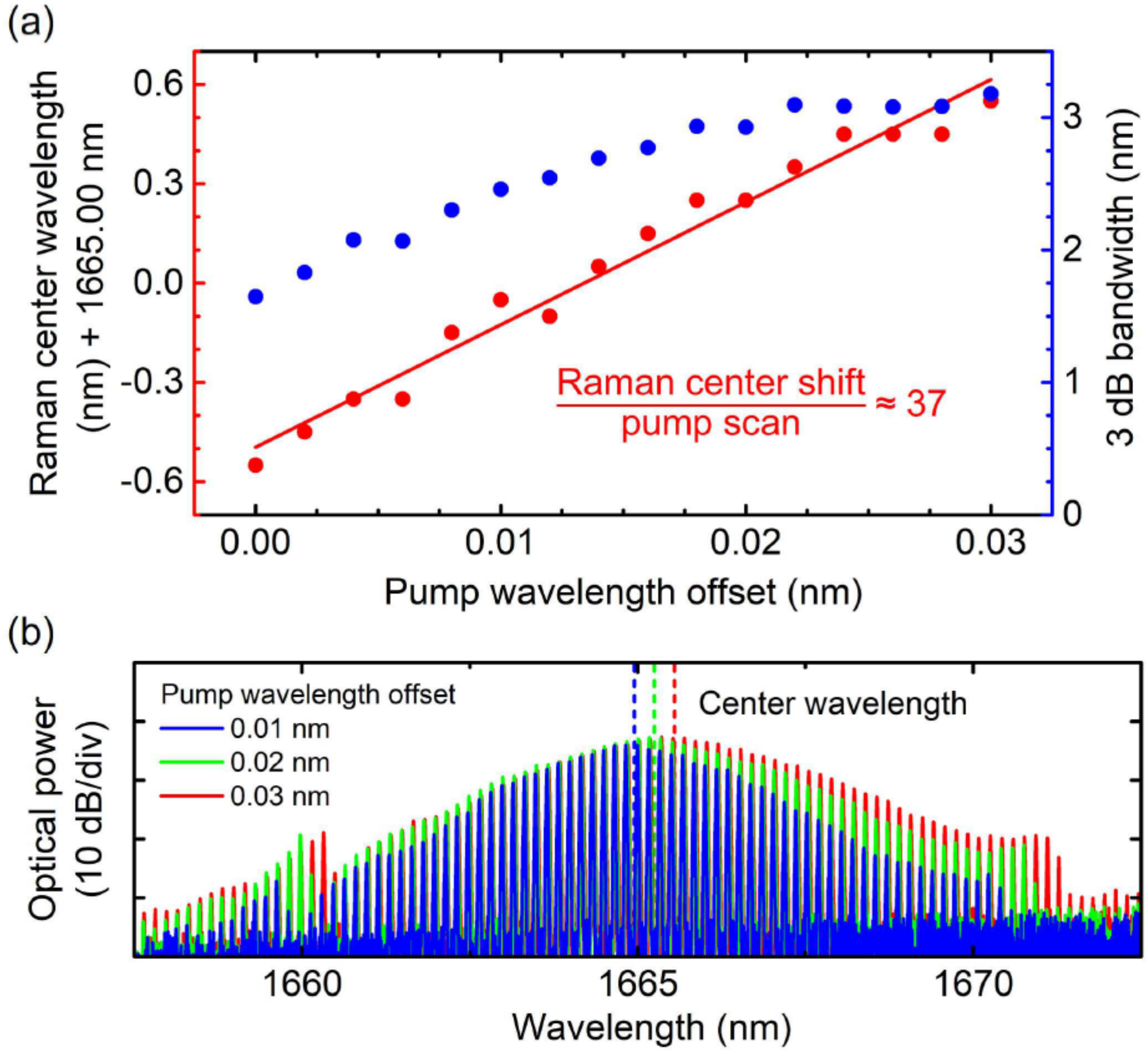
Energy transition via SRS
Larger detuning: Pump → Peak 1
Smaller detuning: Pump + Peak 1 → Peak 2

Large size microresonator [this work]



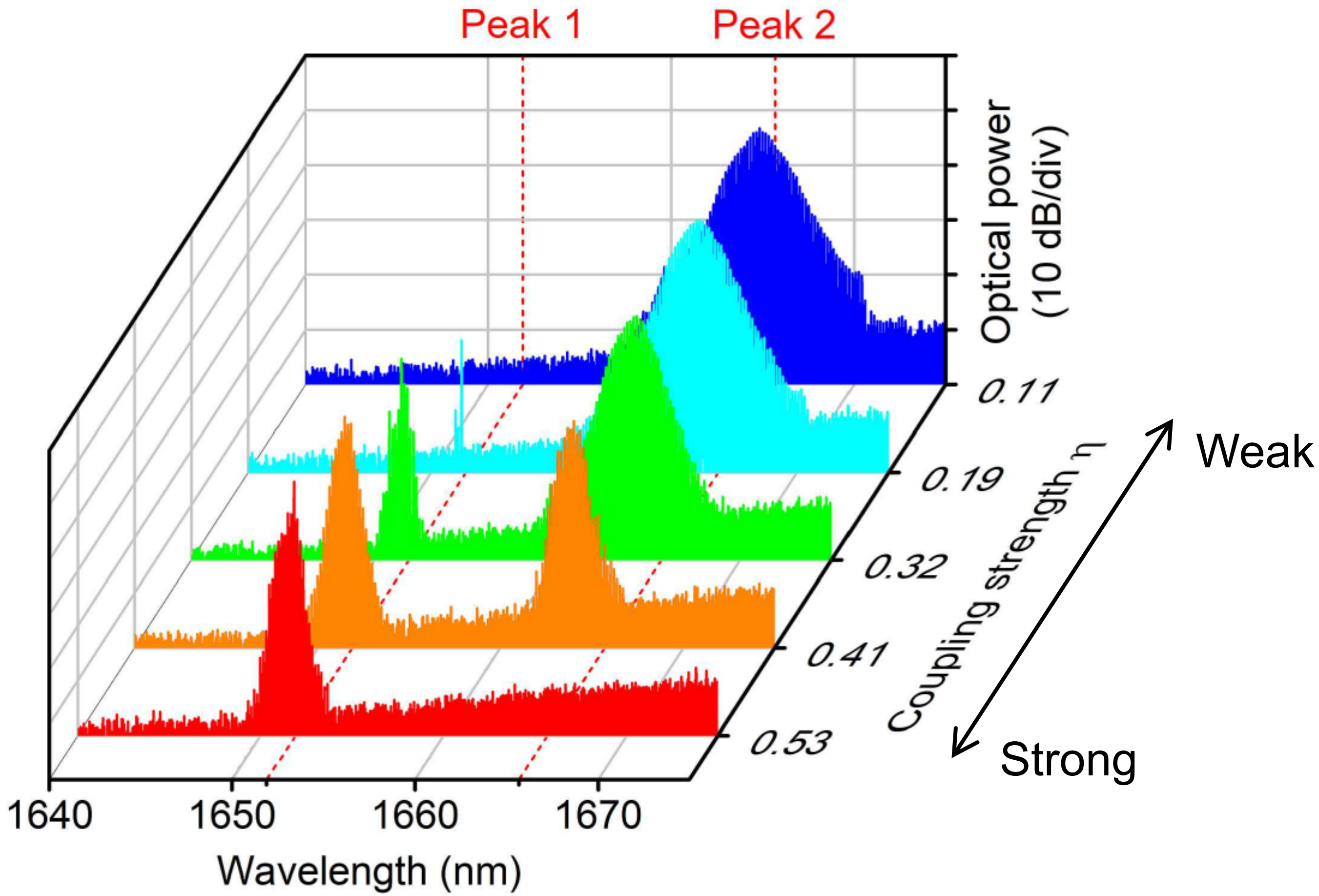
Detuning dependent center wavelength shift

Center wavelength transition in a Raman comb depending on detuning



Coupling dependent Raman comb formation

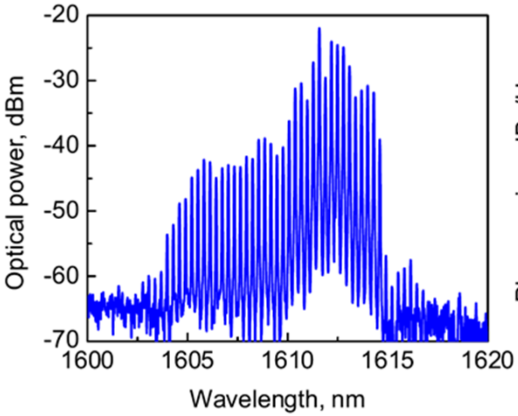
Raman comb spectra depending on coupling strength
(detuning values were close to zero)

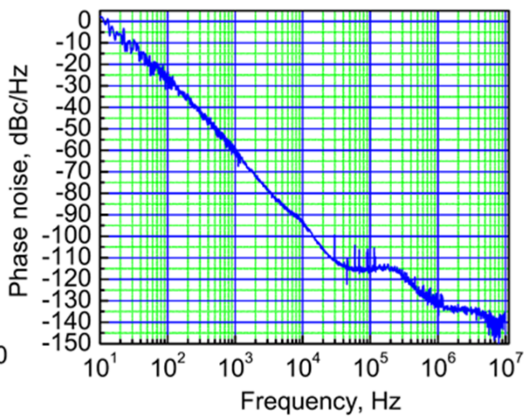


Weaker coupling condition causes efficient SRS.

Towards coherent Raman comb generation

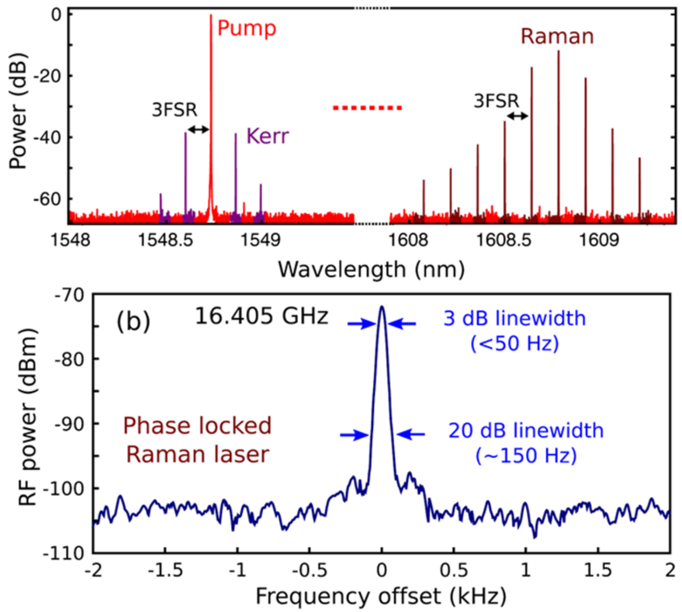
35 GHz CaF_2 microresonator





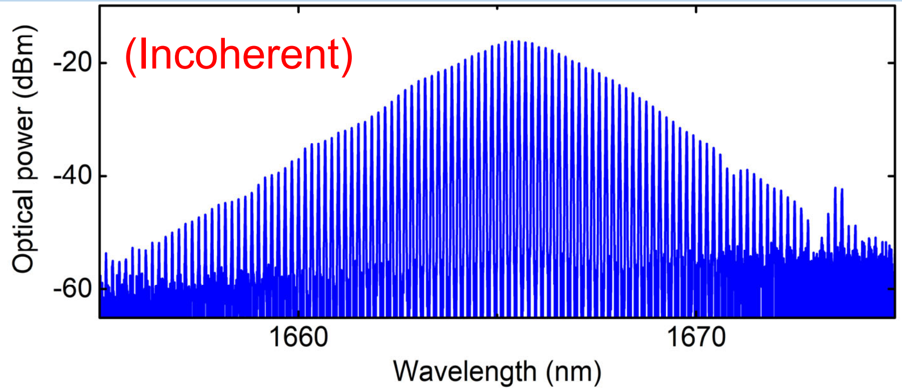
W. Liang et al., Phys. Rev. Lett. 105, 143903 (2010).

5.5 GHz BaF_2 microresonator



G. Lin et al., Opt. Lett. 41, 3718-3721 (2016).

18 GHz SiO_2 microresonator [this work]



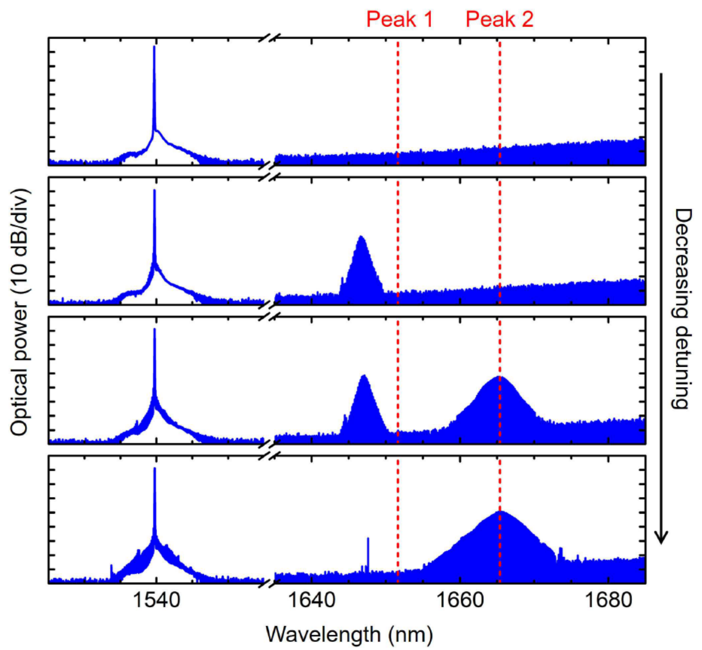
Future work

For coherent Raman combs, we will perform experiments in shorter wavelength regime with weak normal dispersion.

Conclusion

- Generated Raman combs from a silica rod microresonator with an 18.2 GHz FSR.
- Controlled the Raman energy transition between Peak 1 and Peak 2 by controlling the detuning and coupling strength.
- Observed the center wavelength shift of a Raman comb, with a shift that is 37 times larger than that of pump scanning.

Detuning dependence



Coupling dependence