Raman comb generation through broadband gain in a silica microresonator

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Funding
Microcombs

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

“Microcombs”

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

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

“Frequency combs”

Comb spectrum

http://www.mpq.mpg.de/~haensch/comb/index.html
https://www.aist.go.jp/index_ja.html
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

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Coherent Raman comb generation

Coherent Raman comb generation has been demonstrated using CaF$_2$ and BaF$_2$ microresonators.


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

SRS dynamics inside a microresonator

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

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: $\sim 10^8$
- Pump power: 100 mW
- Pump wavelength: 1540 nm

Raman comb generation

- 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

Output power during pump scanning

- SRS: stimulated Raman scattering (lasing action)
- Transmitted pump

Detail of Raman comb

- FSR: 18.2 GHz
- Frequency offset (1 MHz/div)
- RBW: 10 kHz

Scan time (50 ms/div)
Detuning dependent Raman comb formation

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

- Larger detuning: Pump $\rightarrow$ Peak 1
- Smaller detuning: Pump + Peak 1 $\rightarrow$ Peak 2

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

- Peak 1
- Peak 2

Energy transition via SRS

Detuning dependent center wavelength shift

Center wavelength transition in a Raman comb depending on detuning

(a) Graph showing the relationship between pump wavelength offset and Raman center wavelength shift. The graph includes a linear fit with a slope labeled as \( \text{Raman center shift \approx 37} \) for the pump scan.

(b) Diagram illustrating the optical power spectrum with different pump wavelength offsets (0.01 nm, 0.02 nm, 0.03 nm) and a marked center wavelength.
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

5.5 GHz BaF$_2$ microresonator

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.
- 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.