Kerr comb generation with suppressed cavity-optomechanical oscillation in toroid microcavity

Ryo Suzuki,
Takumi Kato, Akitoshi C. Jinnai, Takuma Nagano,
Tomoya Kobatake, Takasumi Tanabe

Faculty of Science and Technology,
Keio University
Kerr frequency comb

Kerr comb

Microcavity

- Small & Inexpensive
- High repetition rate (10GHz-1THz)
- Large bandwidth
- Low threshold pump

Threshold pump power for four-wave mixing

\[ P_{\text{threshold}} \propto \frac{V}{Q^2} \]

\( V \): Mode volume
\( Q \): Quality factor

Conventional frequency comb sources

Ti:Sapphire laser

Fiber laser

Large & Expensive

- Small & Inexpensive
- High repetition rate (10GHz-1THz)
- Large bandwidth
- Low threshold pump

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

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

\[ f(m) = f_o + m \cdot f_{\text{rep}} \]
Motivation

Mode-locked pulse

Microcavity

SiN microring

MgF₂ bulk

SiO₂ microtoroid

Mode-locked?

Microcavity

Strong nonlinear effect, but…

+ optomechanical noise

Background

Transmittance

Wavelength

Pump scan

Effective blue-detuning

Effective red-detuning

Cold resonance

Triangular

Mode locked state “soliton step”

Transmittance

Wavelength

Pump scan

w/o cavity optomechanics

w/ cavity optomechanics

T. Herr et al., Nat. Photon. 6, 480 (2012)
Cavity optomechanical oscillation

Can observe optomechanical oscillation by measuring RF signal.

SiO₂ microtoroid (cross section)

(Top view)

Red-detuning
Supress optomechanical oscillation

Blue-detuning
Amplify optomechanical oscillation
**Experimental setup & Dispersion**

**Kerr comb**

- TLD
- EDFA
- FPC

**Experimental results**

- TE mode
  - $\mathcal{Q}_i \sim 10^7$
  - $\mathcal{Q}_m = 2.5 \times 10^3$

- TM mode

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<thead>
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<th>199</th>
<th>196</th>
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<tbody>
<tr>
<td>$D_2/2\pi$</td>
<td>$-2 \text{ MHz}$</td>
<td>$14 \text{ MHz}$</td>
<td>$-33 \text{ MHz}$</td>
<td>$-46 \text{ MHz}$</td>
<td>$-1 \text{ MHz}$</td>
<td>$-52 \text{ MHz}$</td>
<td>$85 \text{ MHz}$</td>
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**Dispersion**

$\frac{\mathcal{D}_2}{2\pi} \gg 0 \text{ MHz}$

- Anomalous dispersion

**Graph**

- $\frac{\omega - \omega_0}{\mu D_1} / 2\pi$ (GHz) vs Relative mode number $\mu$

- Fitting
- Experiment
Kerr comb generation with single-FSR

Multiple of 60 MHz signals were caused by optomechanical oscillation.

RF signal disappeared.

In terms of cavity optomechanics, state-4 is into effective red-detuning.

Experiment
Transform limited pulse (TLP) of single-FSR comb was generated.

Linewidth of comb line

(same order as that of pump and reference lasers)
Transmittance affected by oscillation

Transmittance

Pump scan 350 mW pump

Resonance modulation by optomechanical oscillation

⇒ Chang transmittance?
Simulation of transmittance

Simulation model

Slowly varying field amplitude in microcavity \( a(t) \):

\[
\frac{da(t)}{dt} = -a(t) \left( \frac{\omega_0}{2Q_t} - i \left( \omega_p - \omega_0 + \omega_0 \frac{\omega_0}{R} \right) \right) + s_{\text{in}} \sqrt{\omega_0 Q_c \frac{\text{FSR}}{Q_t}}
\]

Displacement in radial direction \( x(t) \):

\[
\frac{d^2 x(t)}{dt^2} + \frac{\Omega}{Q_m} \cdot \frac{dx(t)}{dt} + \Omega^2 x(t) = \frac{2\pi n}{m_{\text{eff}} c} |a(t)|^2
\]

\( \omega_0 \): resonance frequency, \( \omega_p \): pump frequency, \( Q_t \): total Q, \( Q_c \): coupling Q, \( s_{\text{in}} \): input pump field, \( \text{FSR} \): cavity FSR, \( R \): cavity radius, \( n \): refractive index, \( c \): speed of light, \( \Omega \): mechanical frequency, \( Q_m \): mechanical Q, \( m_{\text{eff}} \): effective mass

Previous research


Optomechanical oscillation (resonance modulation)
Slowly varying field amplitude in microcavity $a(t)$:

$$\frac{da(t)}{dt} = -a(t) \left( \frac{\omega_0}{2Q_t} - i \left( \omega_p - \omega_0 + \Delta n_{\text{Kerr}}(t) \frac{\omega_0}{n} + x(t) \frac{\omega_0}{R} \right) \right) + s_{\text{in}}(t) \frac{\omega_0}{Q_c} \sqrt{FSR}$$

**Effective detuning & Transmittance with high power pump**

Not including FWM process

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**Simulation**

**Optomechanical oscillation**

Minimum transmittance at zero-detuning

Minimum transmittance at zero-detuning
A mode-locked pulse with a single FSR was generated from a toroid microcavity although no “soliton step” was observed.

A Kerr comb in a low noise state had a linewidth of 200 kHz, which is same order as that of a pump and a reference lasers.

We calculated the influence of optomechanical oscillation on transmittance by considering Kerr and optomechanical effects.
Acknowledgements

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