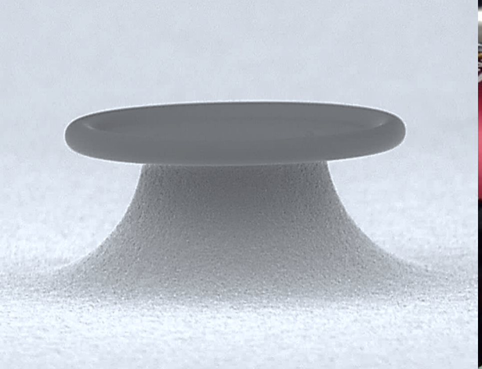


Keio University

APS March meeting 2016
A51.00008 (March 14, 2016)

Influence of cavity optomechanics on Kerr frequency combs

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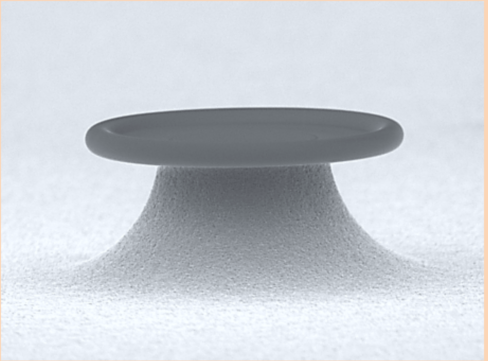
Tomoya Kobatake, Takumi Kato and Takasumi Tanabe

Faculty of Science and Technology,
Keio University

Kerr frequency comb

Kerr comb

Microcavity



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

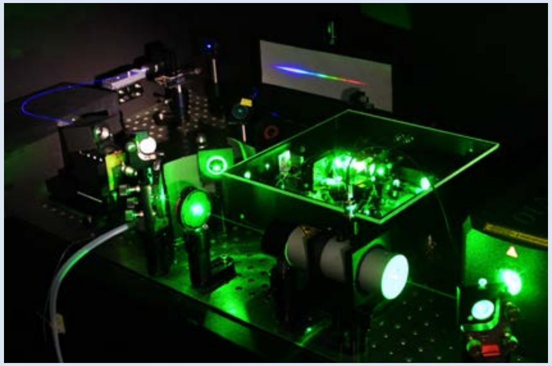
Threshold pump power of four-wave mixing

$$P_{\text{threshold}} \propto V/Q^2$$

V : Mode volume
Q : Quality factor

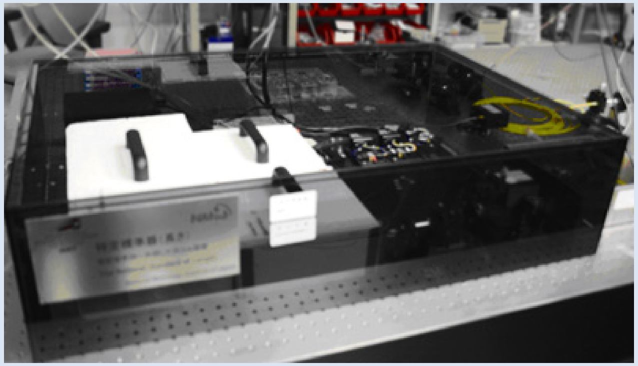
Conventional frequency comb sources

Ti:Sapphire laser



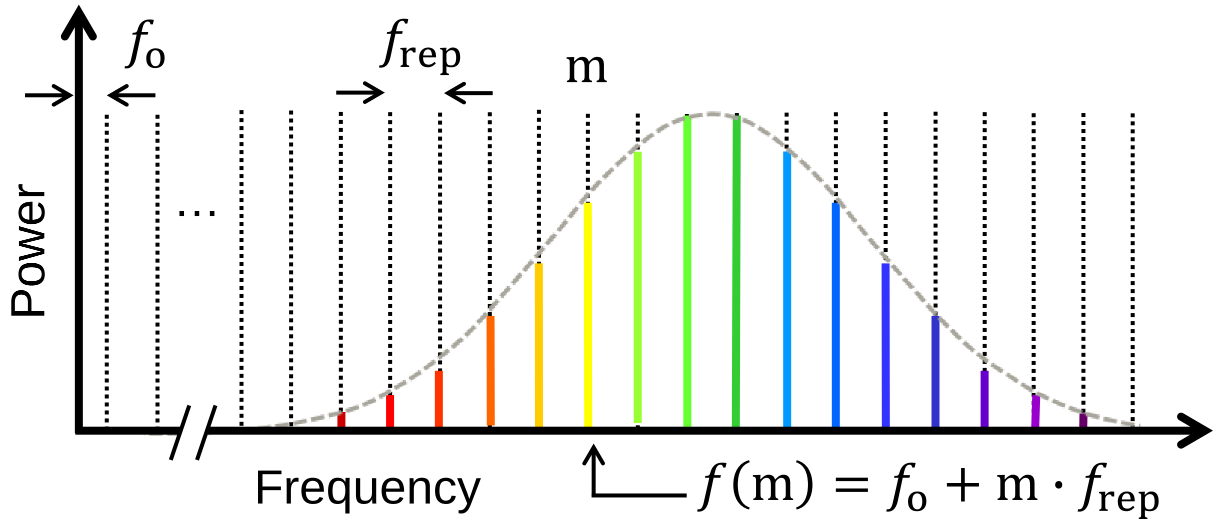
http://www.mpq.mpg.de/~haensch/comb/index.html

Fiber laser



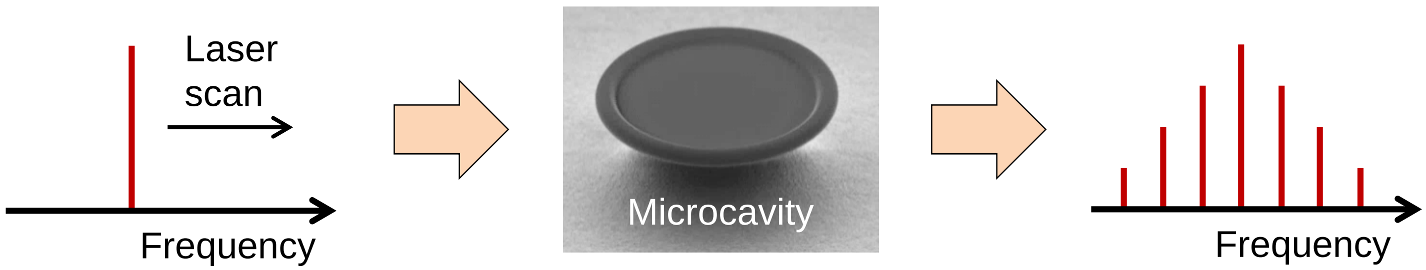
https://www.aist.go.jp/index_ja.html

Large size & Expensive



Mode locked pulse in microcavities

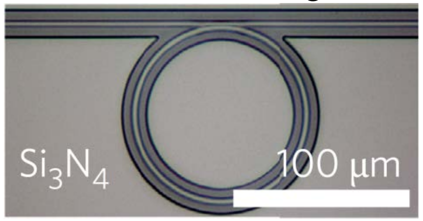
Cascaded FWM occurs by pumping the microcavity with CW laser



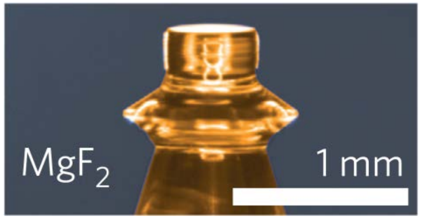
Mode locking was demonstrated using Si_3N_4 and MgF_2 microcavities

<u>Commonly used microcavities</u>

SiN microring

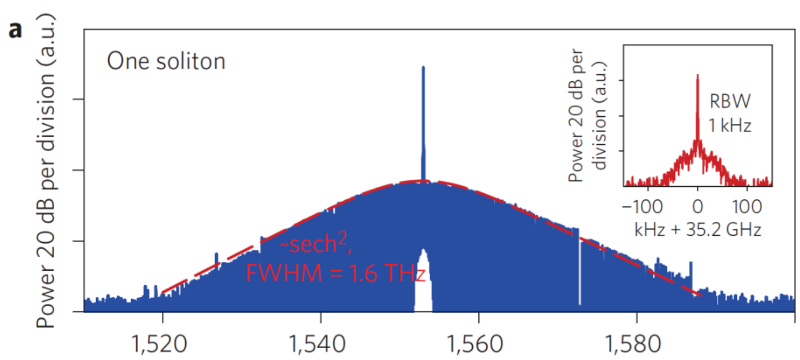


MgF_2 bulk

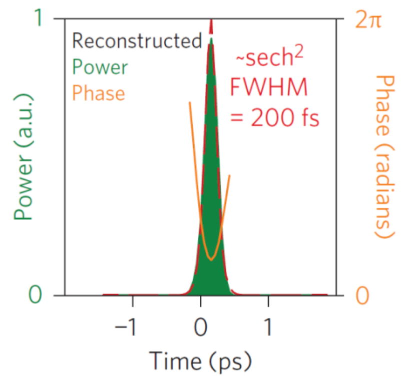


T. Herr et al., Nat. Photon. **6**, 480 (2012)

Frequency domain measurement

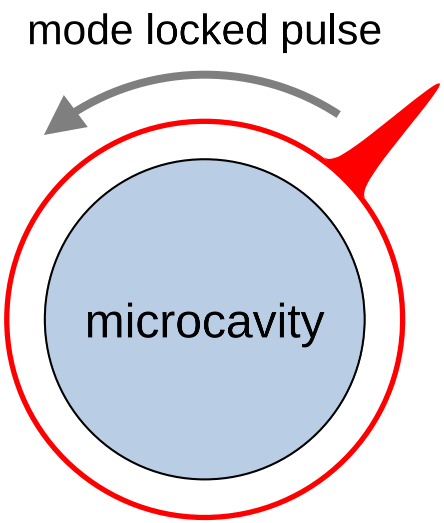


Time domain measurement

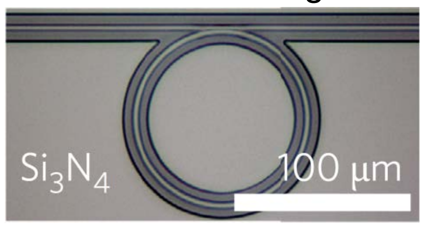


T. Herr et al., Nat. Photon. **8**, 145 (2014)

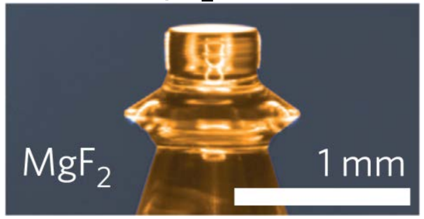
Motivation



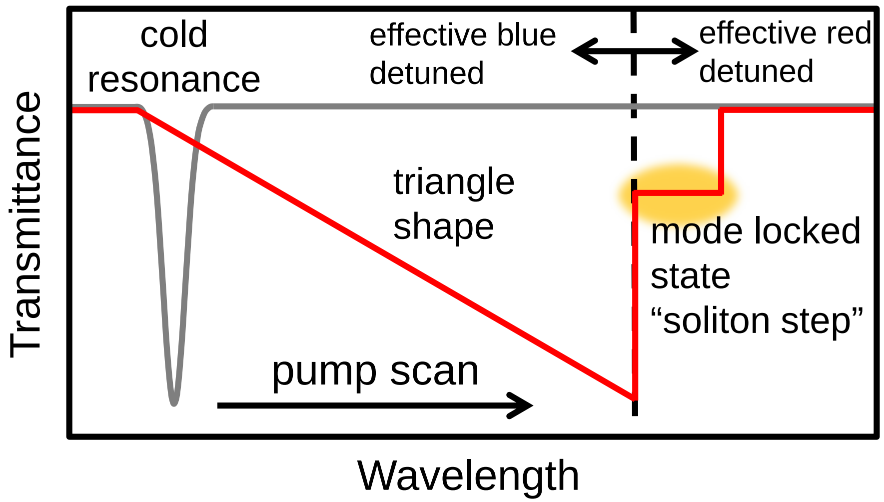
SiN microring



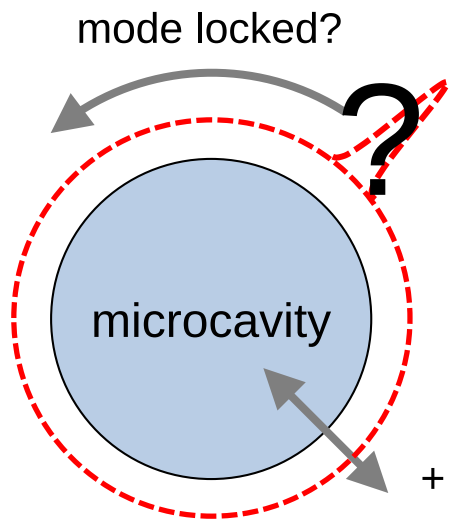
MgF_2 bulk



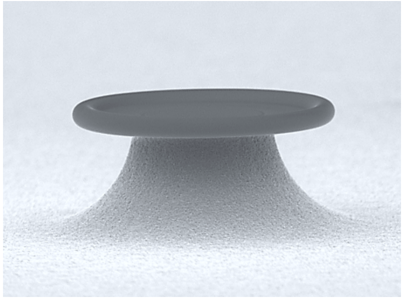
T. Herr et al., Nat. Photon. **6**, 480 (2012)



w/o cavity optomechanics

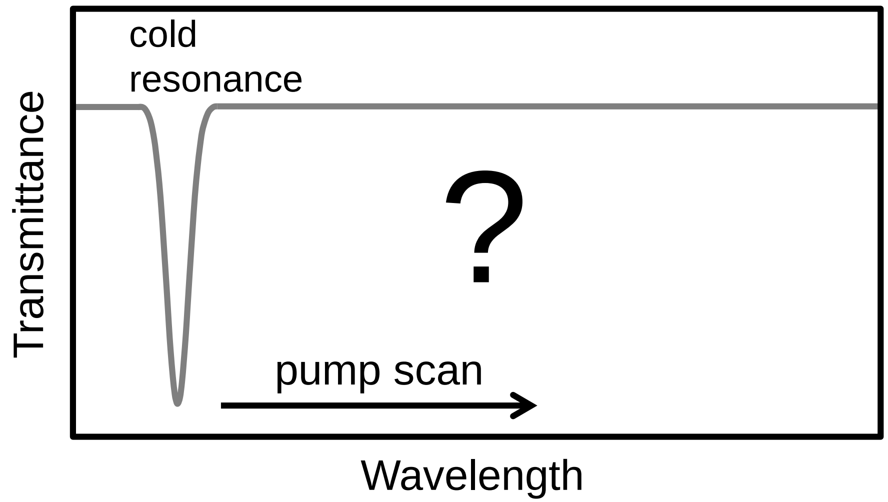


SiO_2 microtoroid



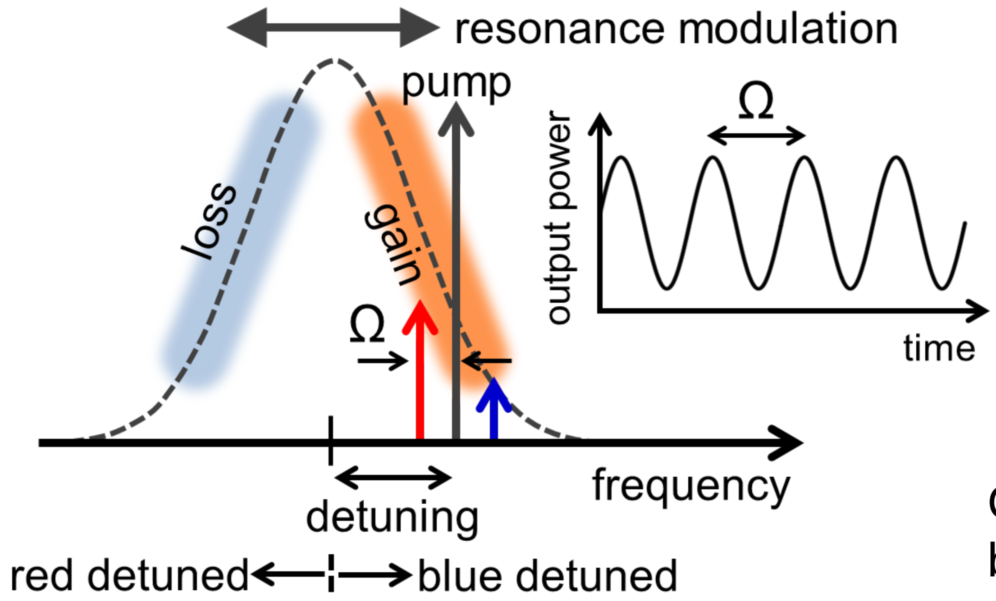
Strong nonlinear effect, but…

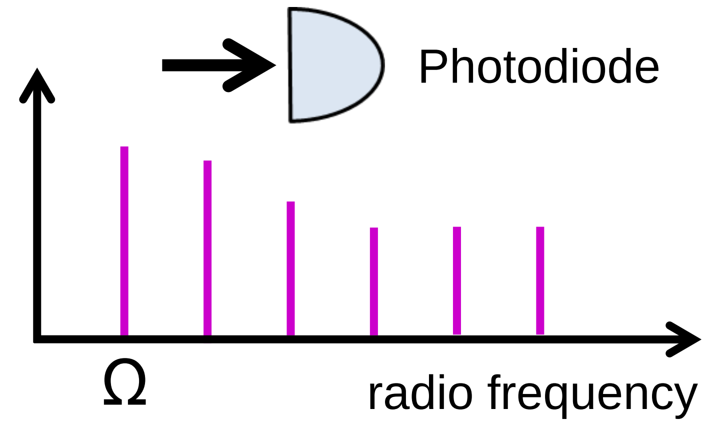
+ optomechanical noise



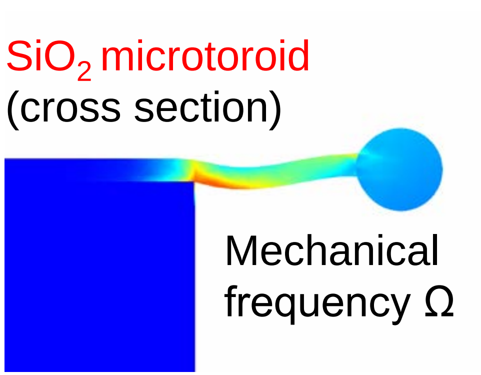
w/ cavity optomechanics

Cavity optomechanical vibration

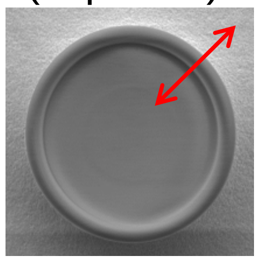




Can observe optomechanical vibration by measuring RF signal



(Top view)

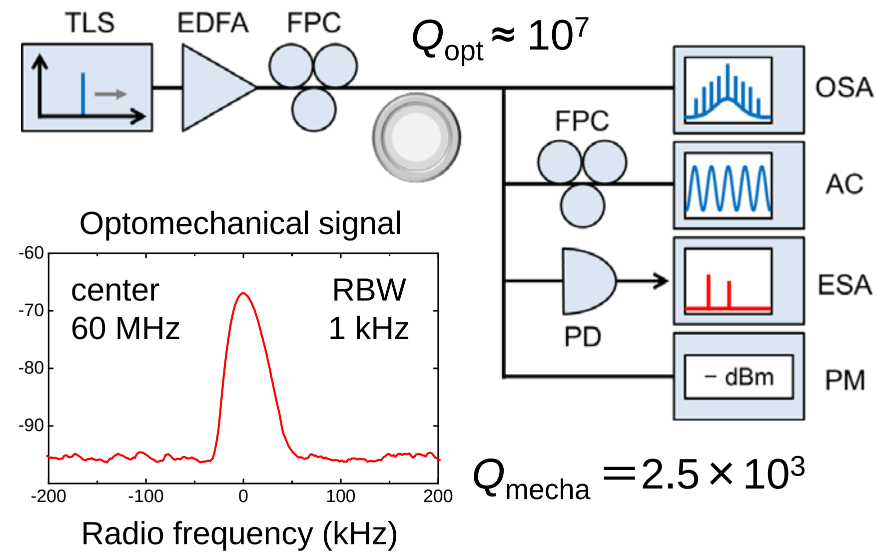


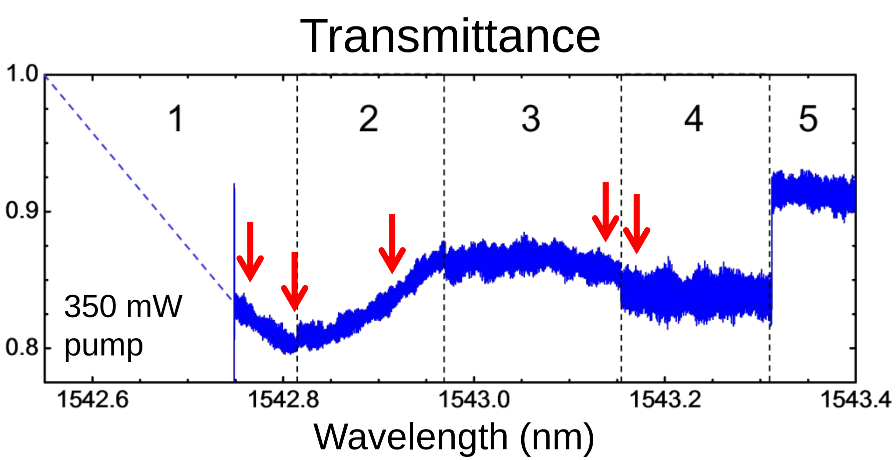
Blue detuning
Amplify optomechanical vibration

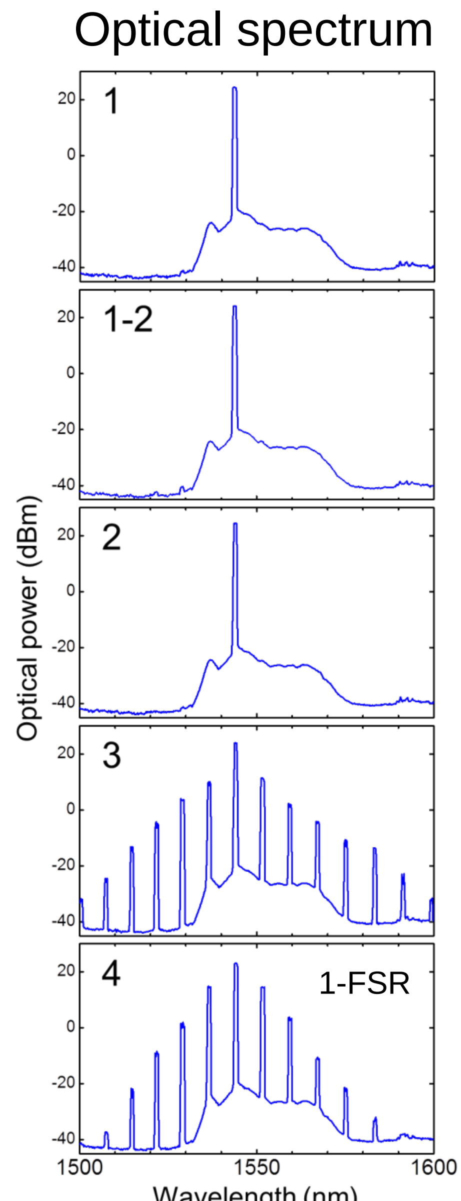
Red detuning
Suppress optomechanical vibration

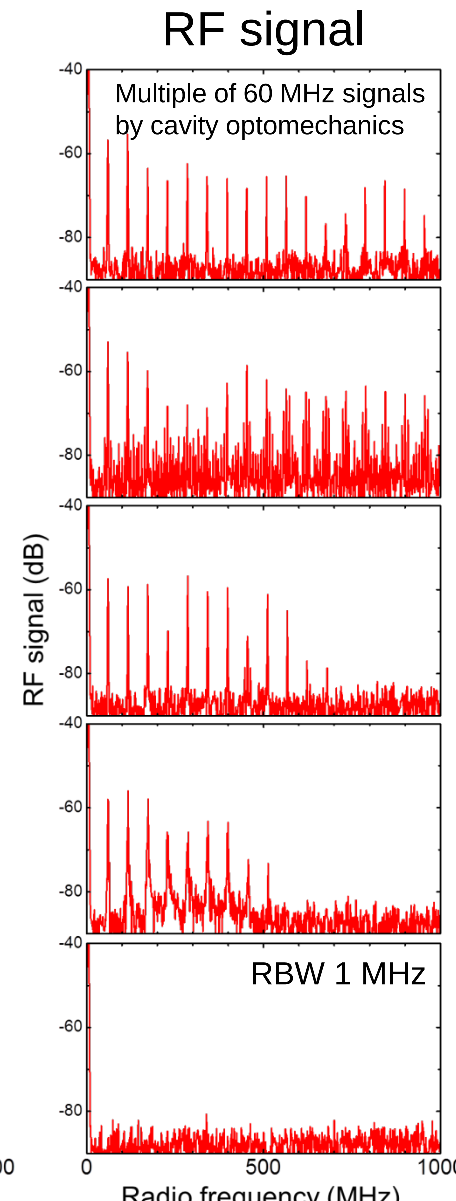
Kerr comb generation with single-FSR

Experiment setup



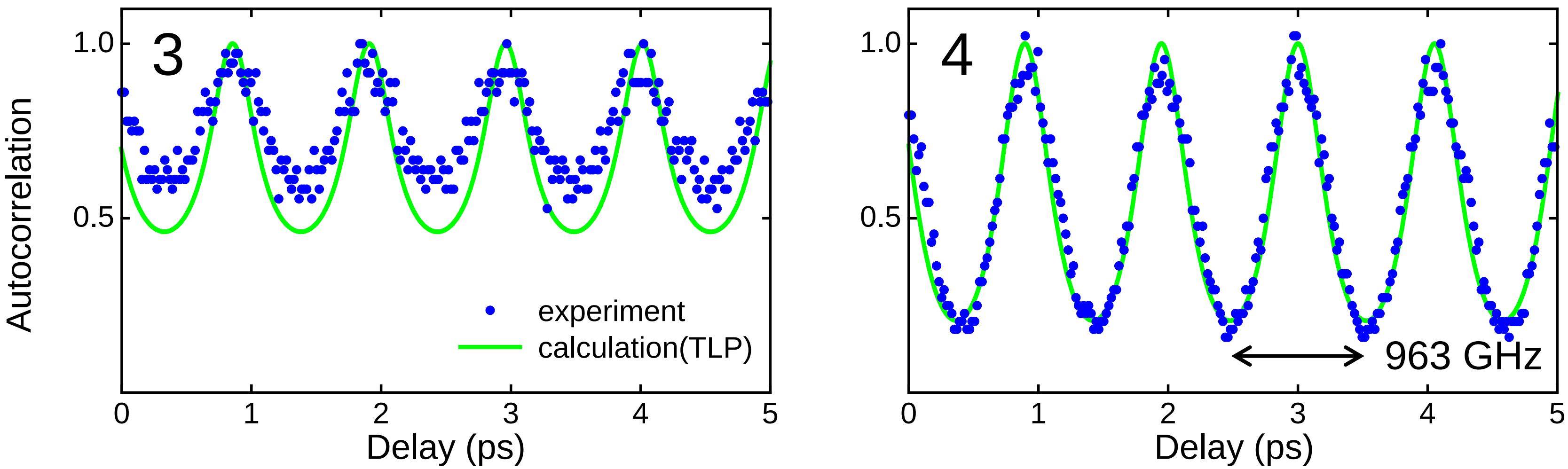






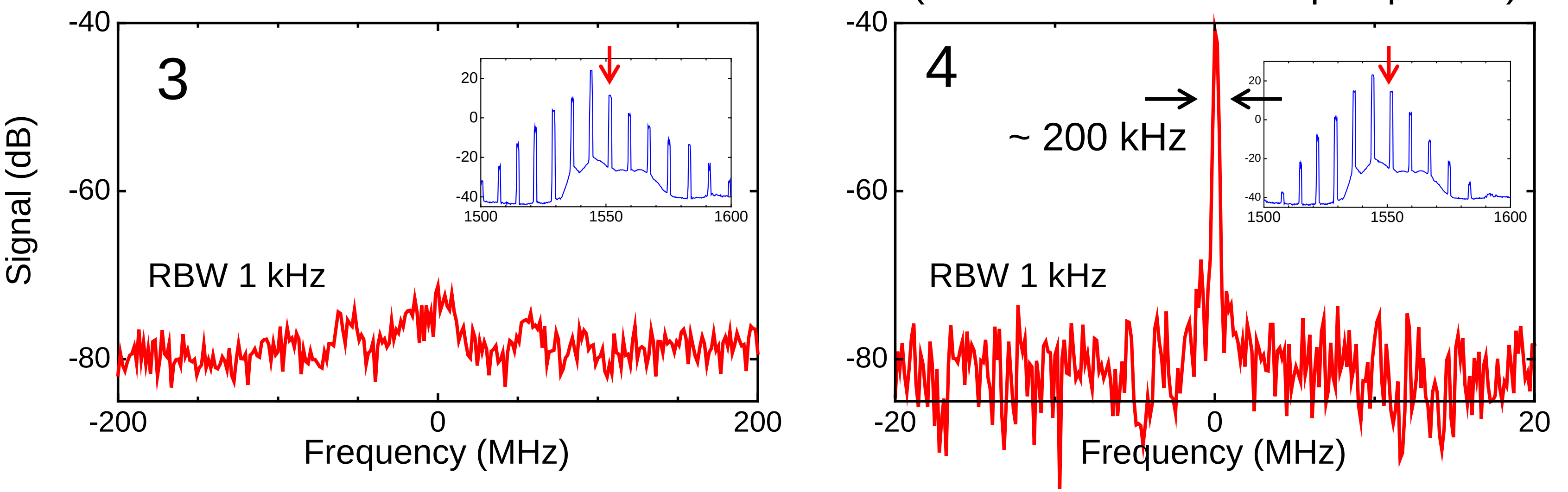
Mode locked pulse with single-FSR

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



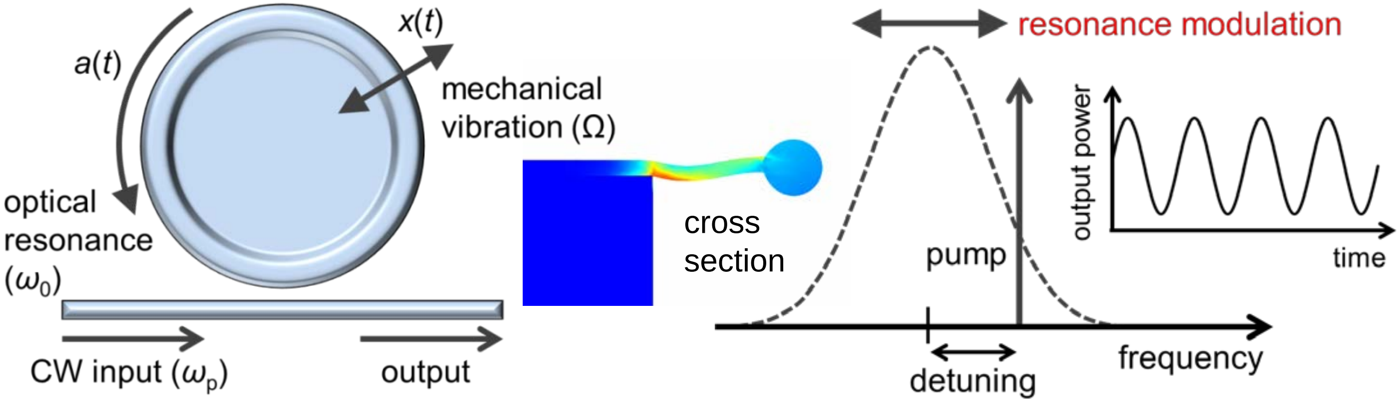
<u>Linewidth of comb line</u>

(same order as that of pump laser)



Simulation of temporal behavior

Simulation model



calculation

Amplitude ***a*(*t*)**

Displacement ***x*(*t*)**

Previous research

T. Carmon et al., Phys. Rev. Lett. 94, 223902 (2005).

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

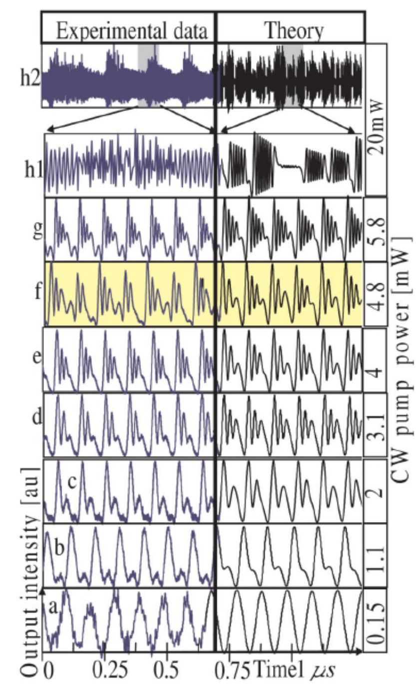
$$\frac{d\boldsymbol{a}(\boldsymbol{t})}{dt} = -\boldsymbol{a}(t)\left(\frac{\omega_0}{2Q_t} - i\left(\omega_p - \omega_0 - \boldsymbol{x}(\boldsymbol{t})\frac{\omega_0}{R}\right)\right) + s_{in}\sqrt{\frac{\omega_0}{Q_c}FSR}$$

resonance modulation

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

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

ω_0: resonance frequency, ω_p: pump frequency, Q_t: total Q, Q_c: coupling Q,
s_{in}: input pump field, *FSR*: cavity FSR, *R*: cavity radius, *n*: refractive index,,
c: speed of light, *Ω*: mechanical frequency, Q_m: mechanical Q, m_{eff}: effective mass



Transmittance with high power pump

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

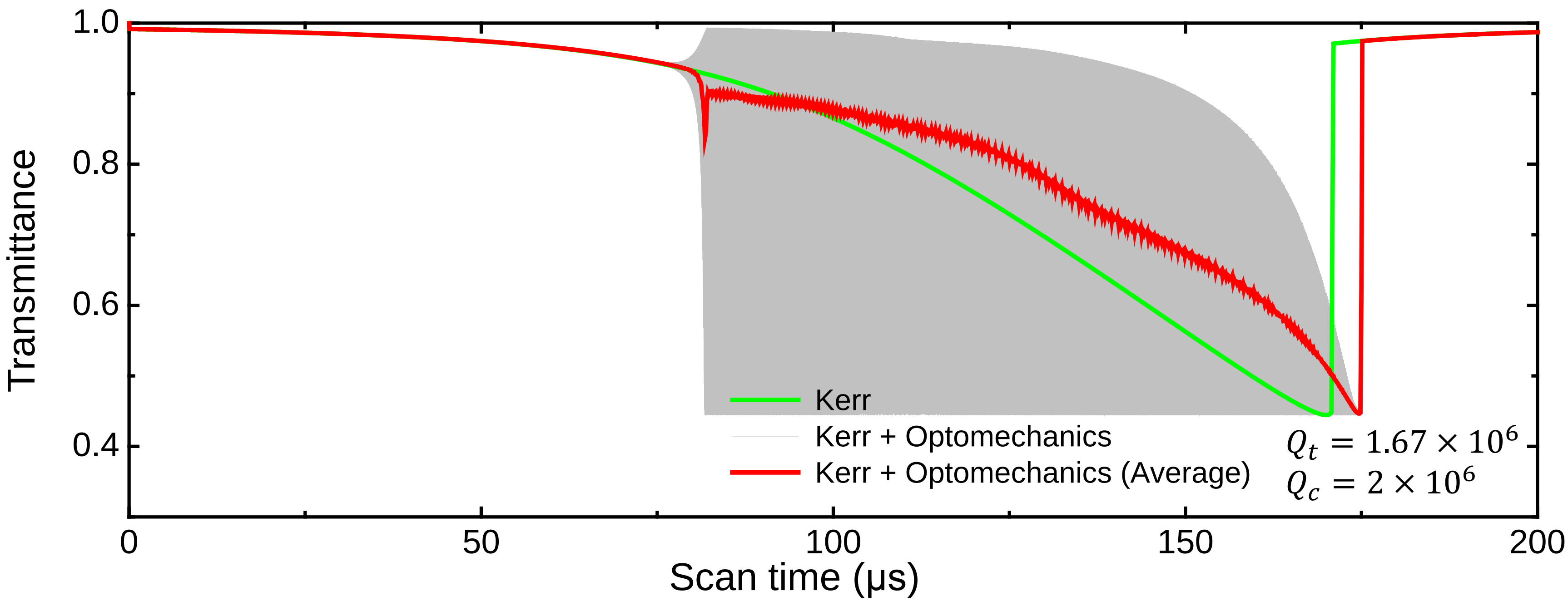
$$\frac{da(t)}{dt} = -a(t)\left(\frac{\omega_0}{2Q_\mathrm{t}} - i\left(\omega_\mathrm{p} - \omega_0 - \Delta n_\mathrm{Kerr}(t)\frac{\omega_0}{n} - x(t)\frac{\omega_0}{R}\right)\right) + s_\mathrm{in}(t)\sqrt{\frac{\omega_0}{Q_\mathrm{c}} FSR}$$

Kerr shift resonance modulation

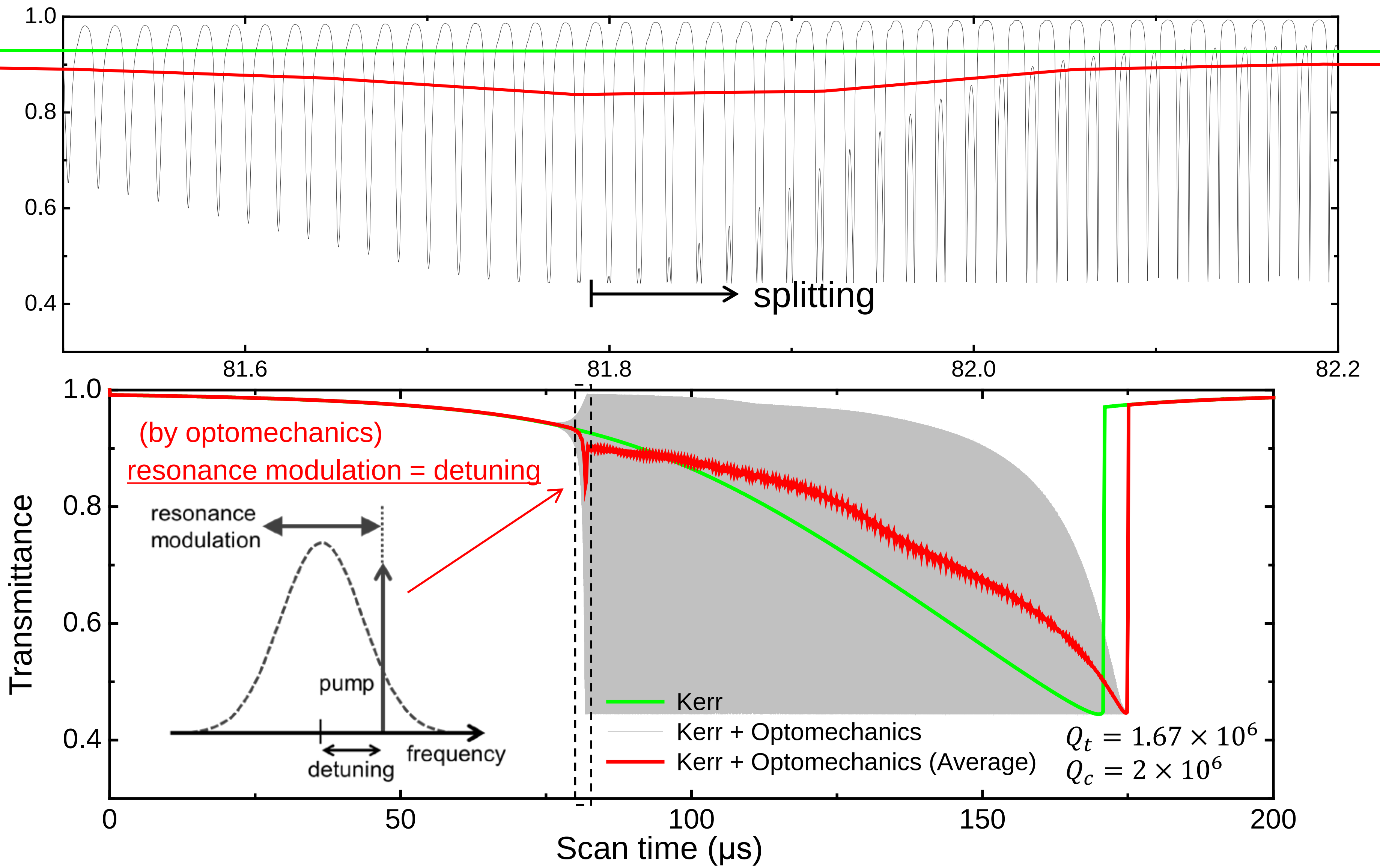
Displacement in radial direction *x*(*t*):

$$\frac{d^2x(t)}{dt^2} + \frac{\Omega}{Q_\mathrm{m}}\cdot\frac{dx(t)}{dt} + \Omega^2 x(t) = \frac{2\pi n}{m_\mathrm{eff}c}|a(t)|^2$$

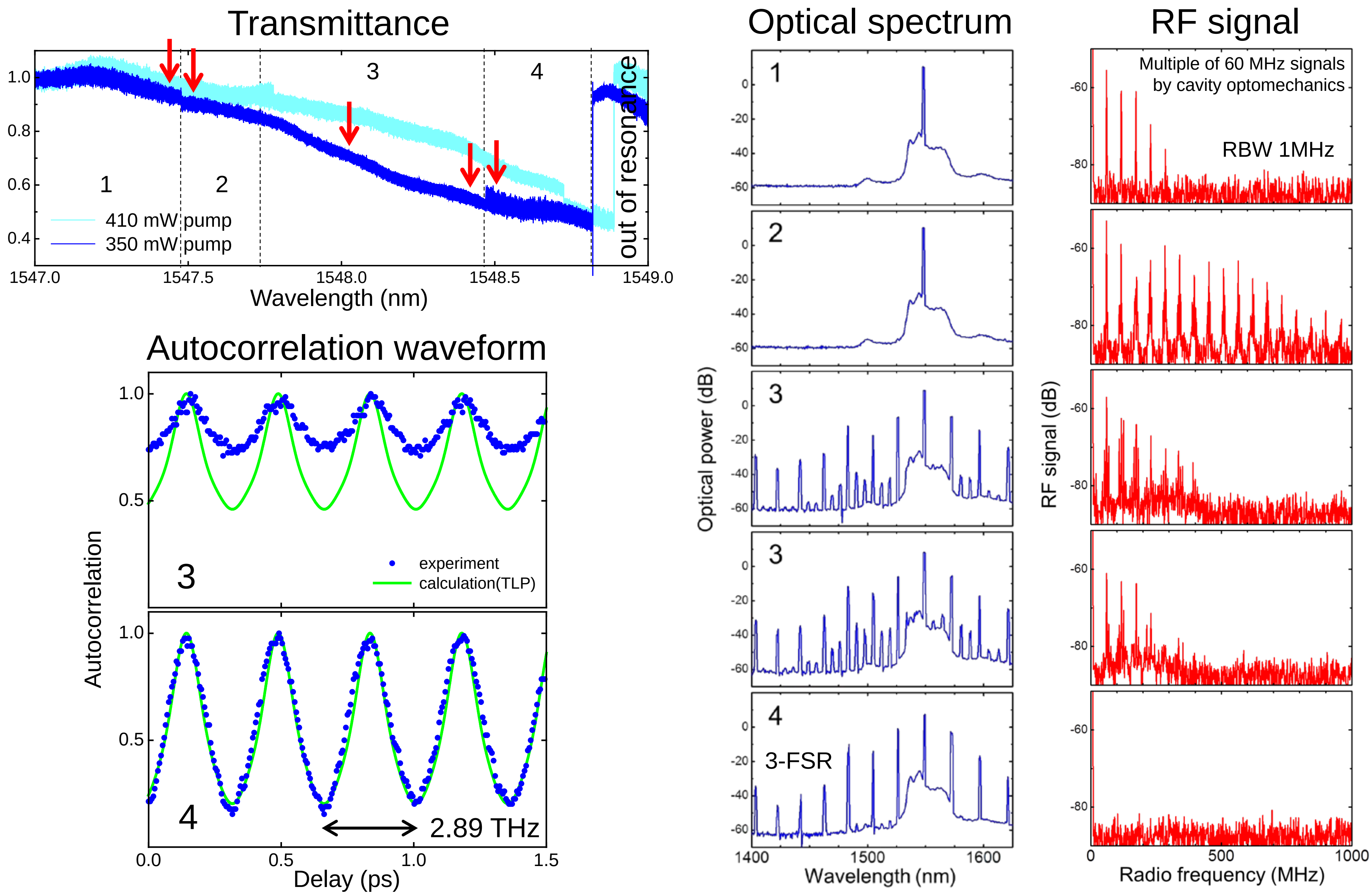
ω_0: resonance frequency, ω_p: pump frequency,
Q_t: total Q, Q_c: coupling Q, s_in: input pump field,
FSR: cavity FSR, *R*: cavity radius, *n*: refractive index,,
c: speed of light, Ω: mechanical frequency,
Q_m: mechanical Q, m_eff: effective mass



Transmittance with high power pump



Kerr comb generation with multi-FSR



Conclusion

- Mode locked pulse with single and multi FSR was generated from a silica toroid microcavity though “soliton step” was not observed.
- Kerr comb at low noise state had narrow linewidth of 200 kHz, which is same order as that of pump laser.
- Local minimum of transmittance shows that resonance modulation by optomechanical vibration gets over the detuning.

Acknowledgement

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- Ishii-Ishibashi Fund, Keio University, Japan