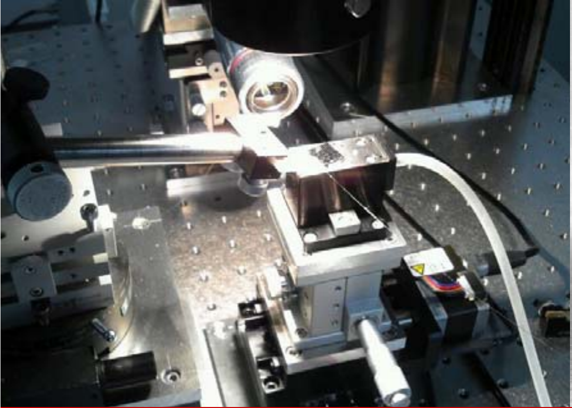
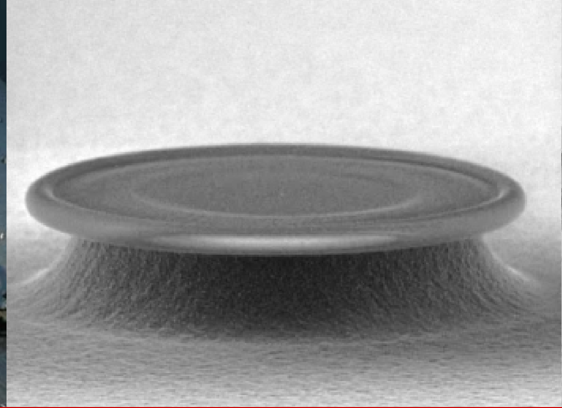

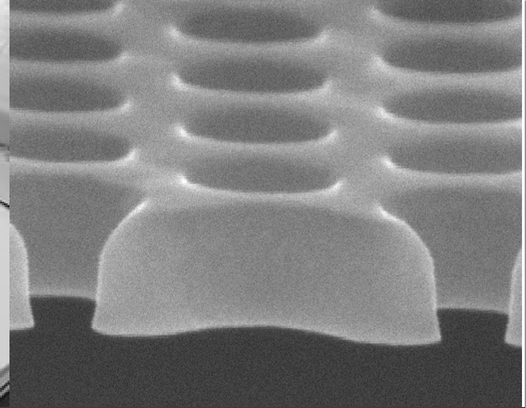

Frontiers in Optics / Laser Science 2014

FTu5D.6

Broad-bandwidth pulse transmission through an ultrahigh-*Q* nanocavity with a chirped pulse

Zhelun Chen, Wataru Yoshiki, and Takasumi Tanabe*

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Faculty of Science and Technology, Keio University
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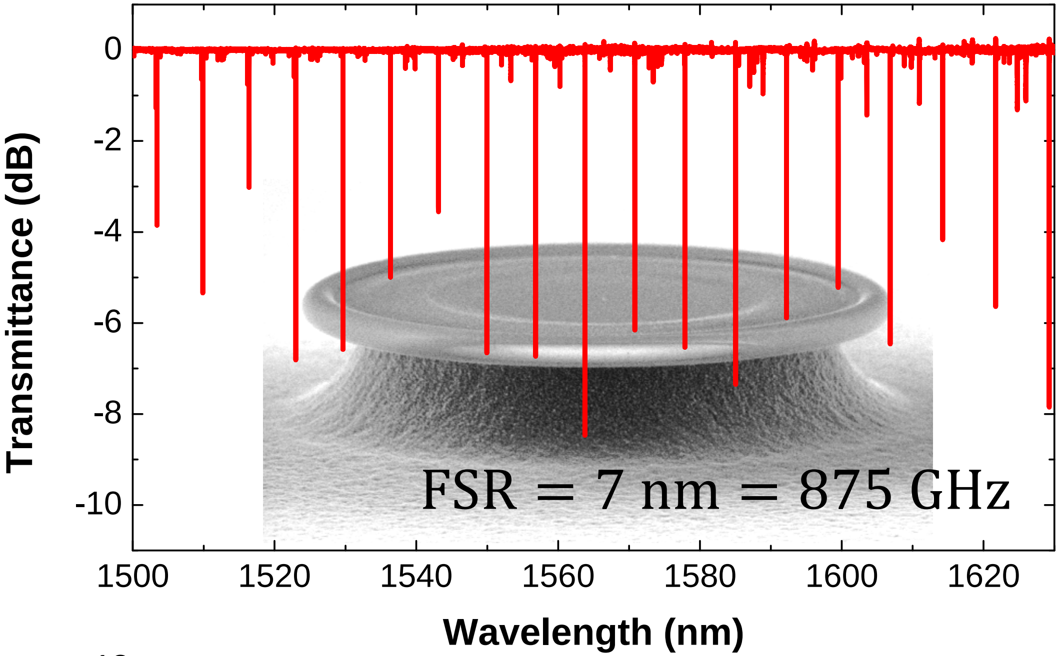
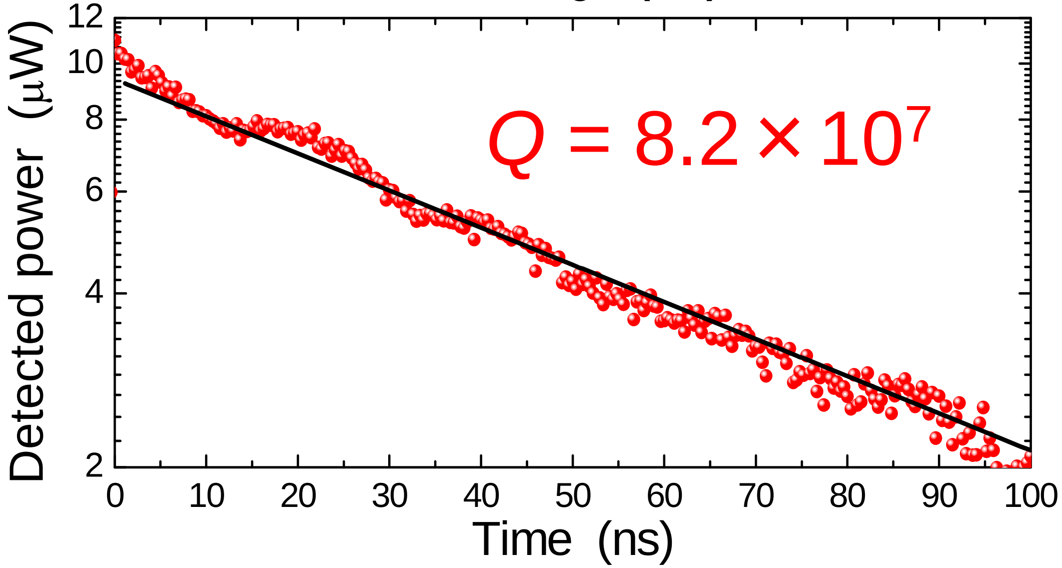
October 21, 2014, 17:15~17:30

Ultra-high *Q* microcavity

▶Ultrahigh-Q microcavity





▶Quality factor and mode volume

◆Q-factor

$$Q = \omega \times \frac{\text{stored energy}}{\text{power in/out}}$$

◆Photon density

$$\propto Q/V$$

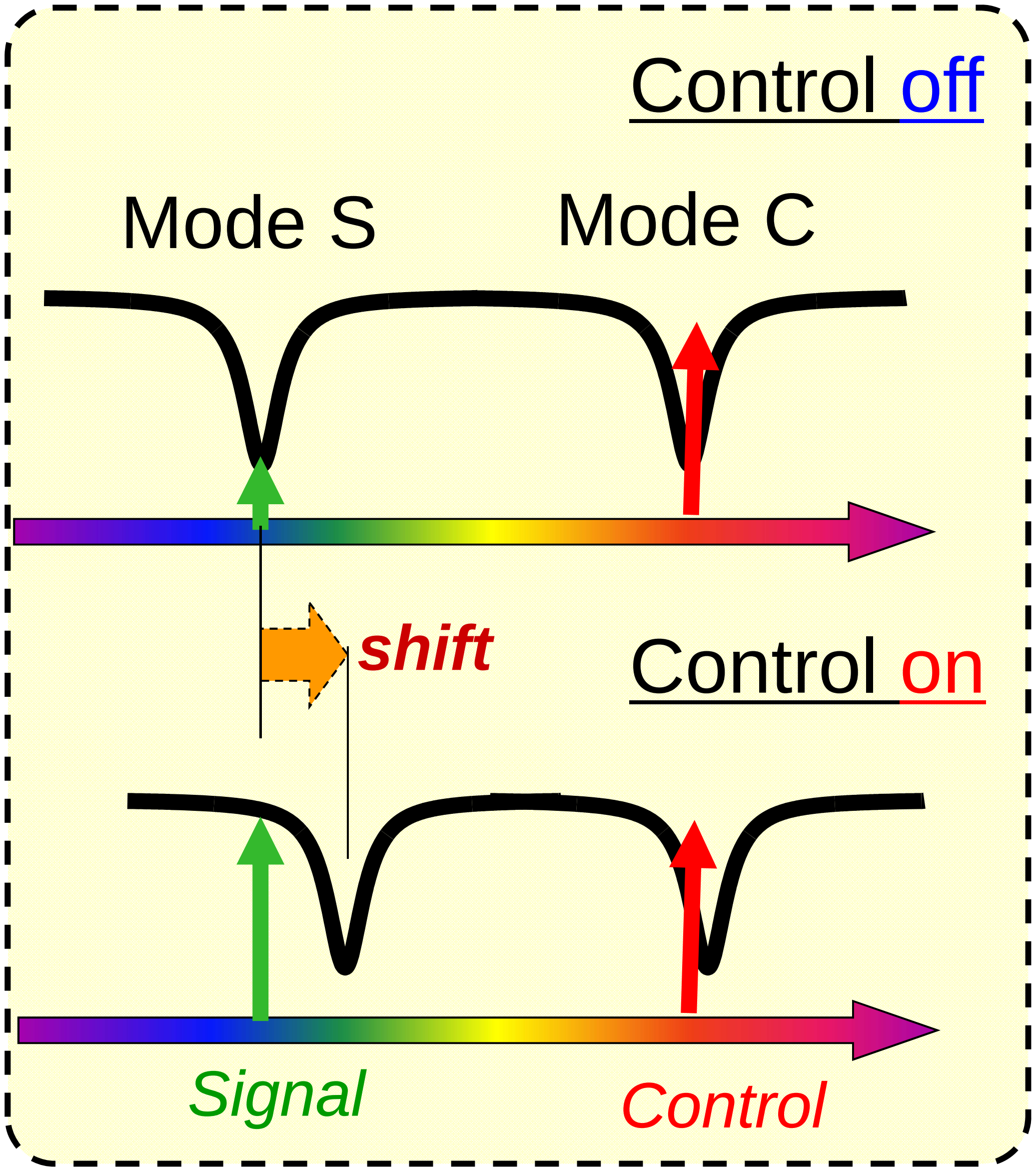
▶Applications

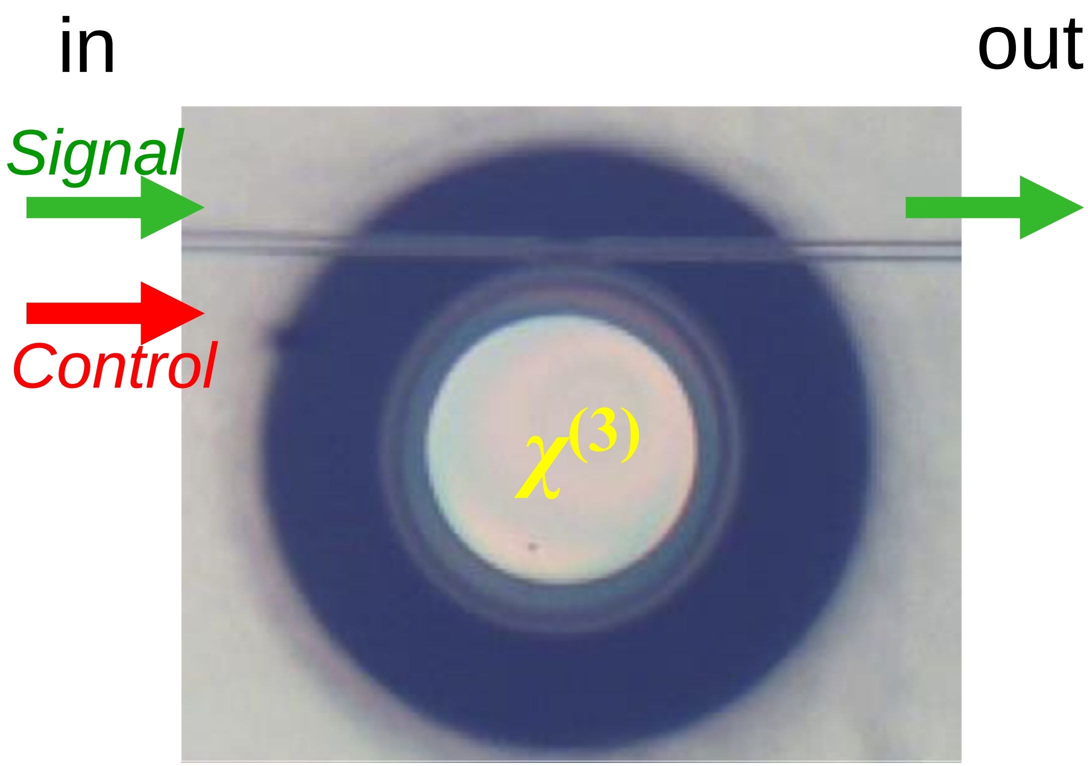
- ▸All-optical switching
- ▸Cavity QED devices
- ▸Low-threshold lasers
- ▸Optical sensors
- ▸Optical frequency combs

Optical switch in a microcavity: speed or power?

W. Yoshiki and T. Tanabe, Opt. Express **22,** 24332 (2014).

▶Switching principle



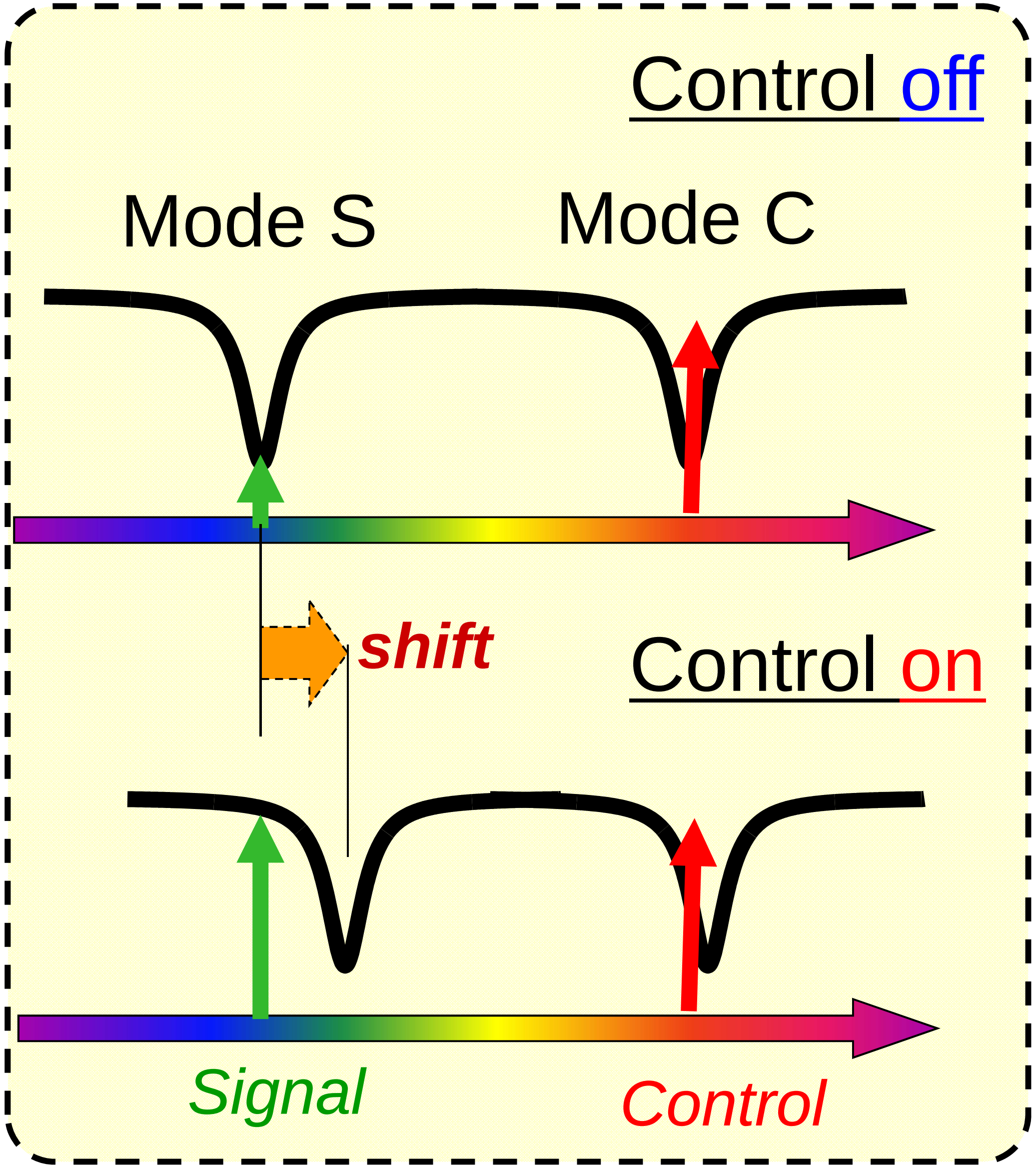


Silica toroidal microcavity

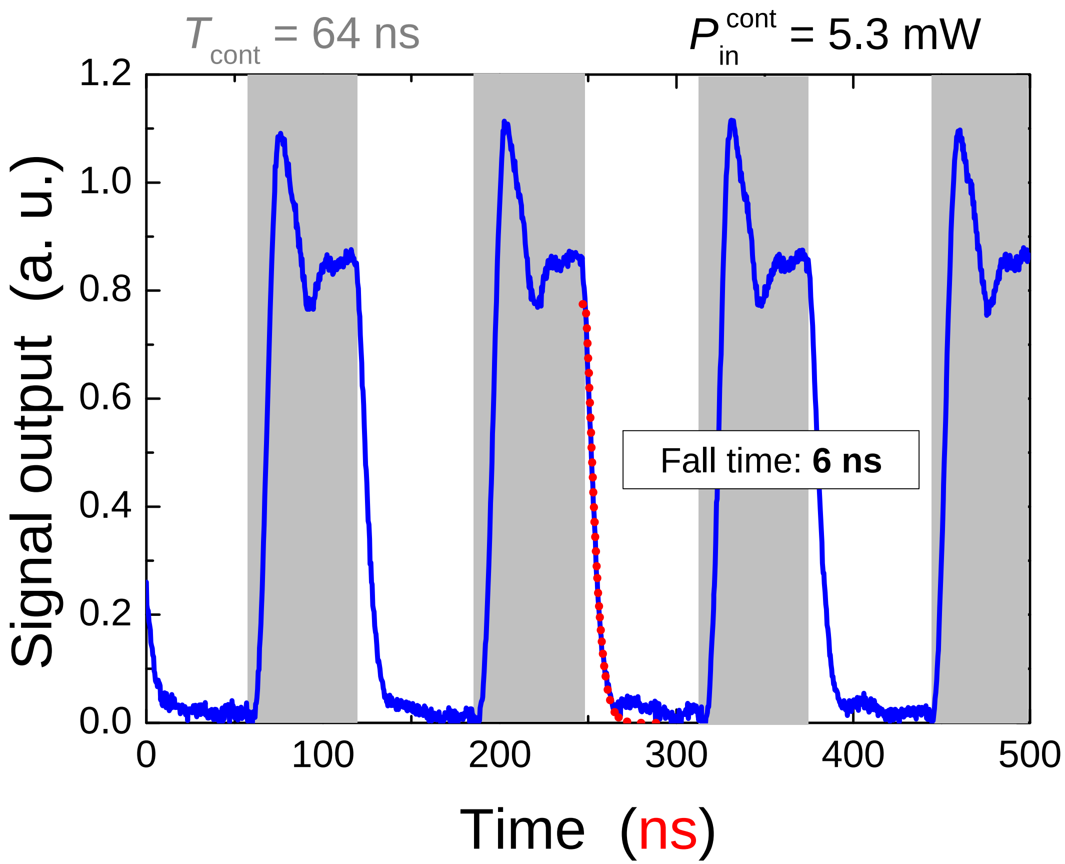
Optical switch in a microcavity: speed or power?

W. Yoshiki and T. Tanabe, Opt. Express **22,** 24332 (2014).

▶Switching principle



▶Low power Kerr switch



Modulation observed at 36 μW

Trade-off between *Q* and speed

Motivation

Problems

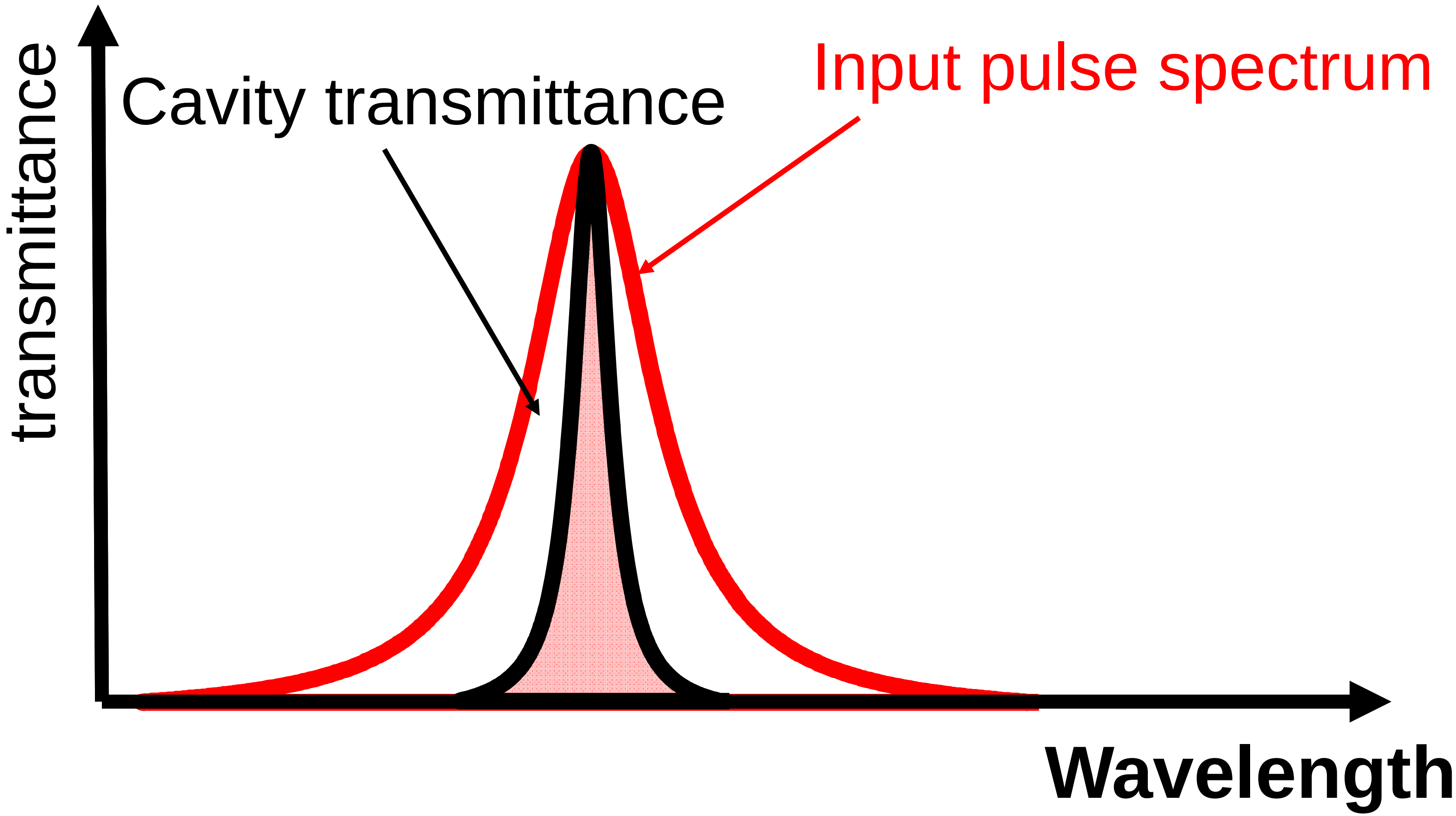
- ☐ Trade-off between power and speed (high Q or low Q?)

Purpose of this study

- ☐ Transmit broad bandwidth pulse through high-Q nanocavity with simple scheme

Basic idea – using self modulation of cavity

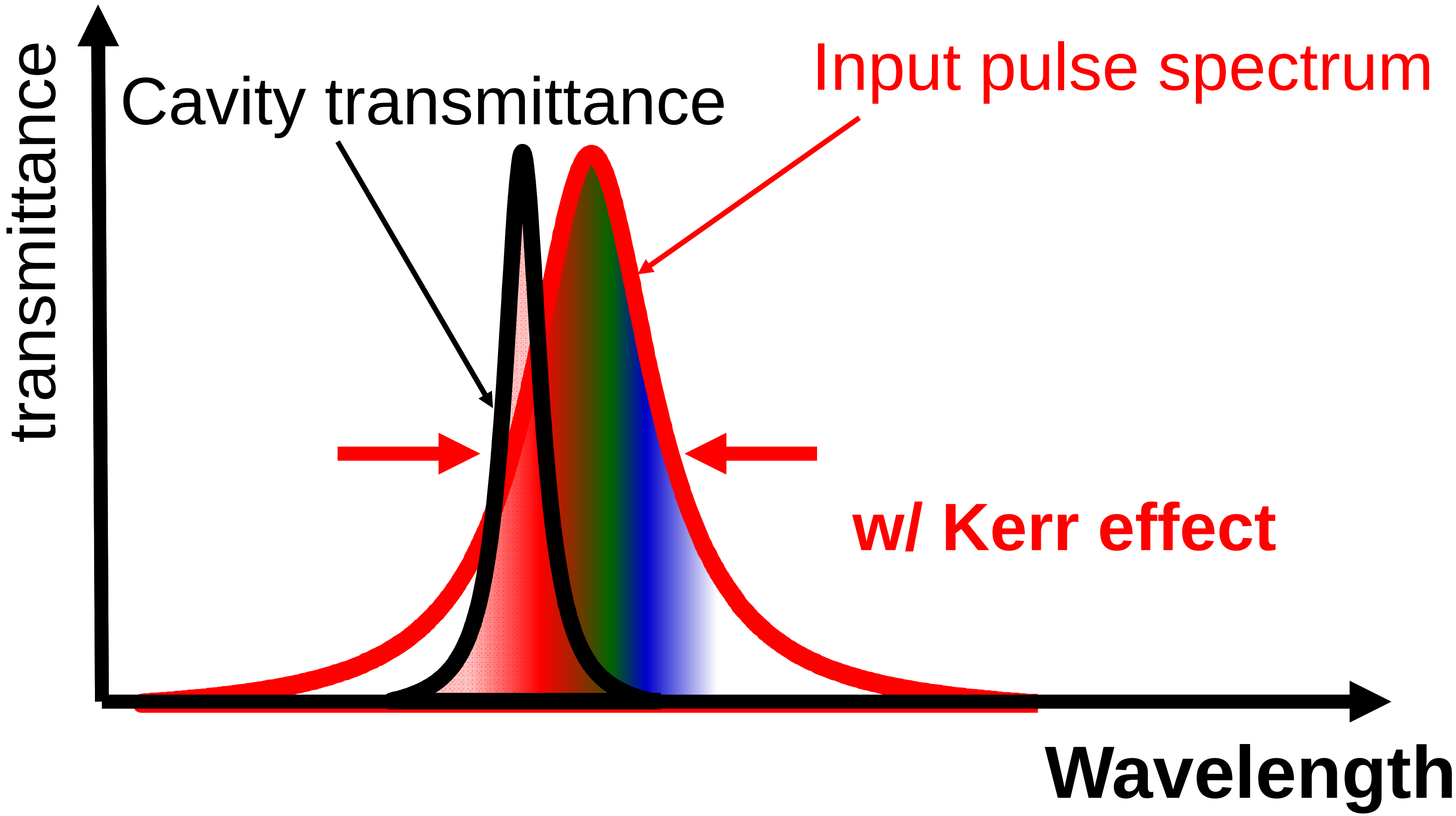
w/o optical nonlinear effect



Only a portion of the pulse spectrum can transmit
(i.e. narrow bandwidth)

Basic idea – using self modulation of cavity

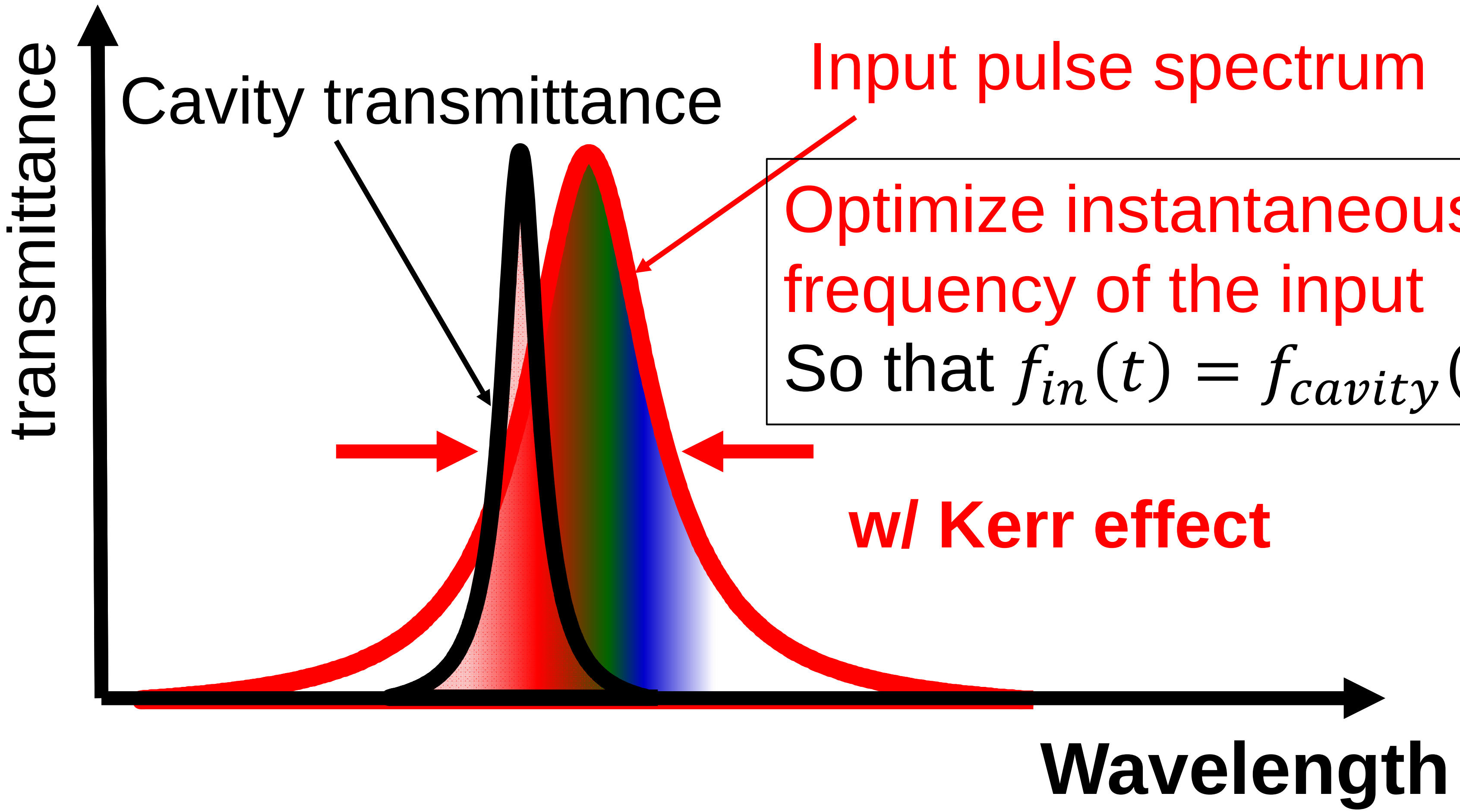
w/ optical nonlinear effect



Broad bandwidth pulse can transmit ultrahigh Q cavity

Basic idea – using self modulation of cavity

w/ optical nonlinear effect



Optimize instantaneous frequency of the input
So that $f_{in}(t) = f_{cavity}(t)$

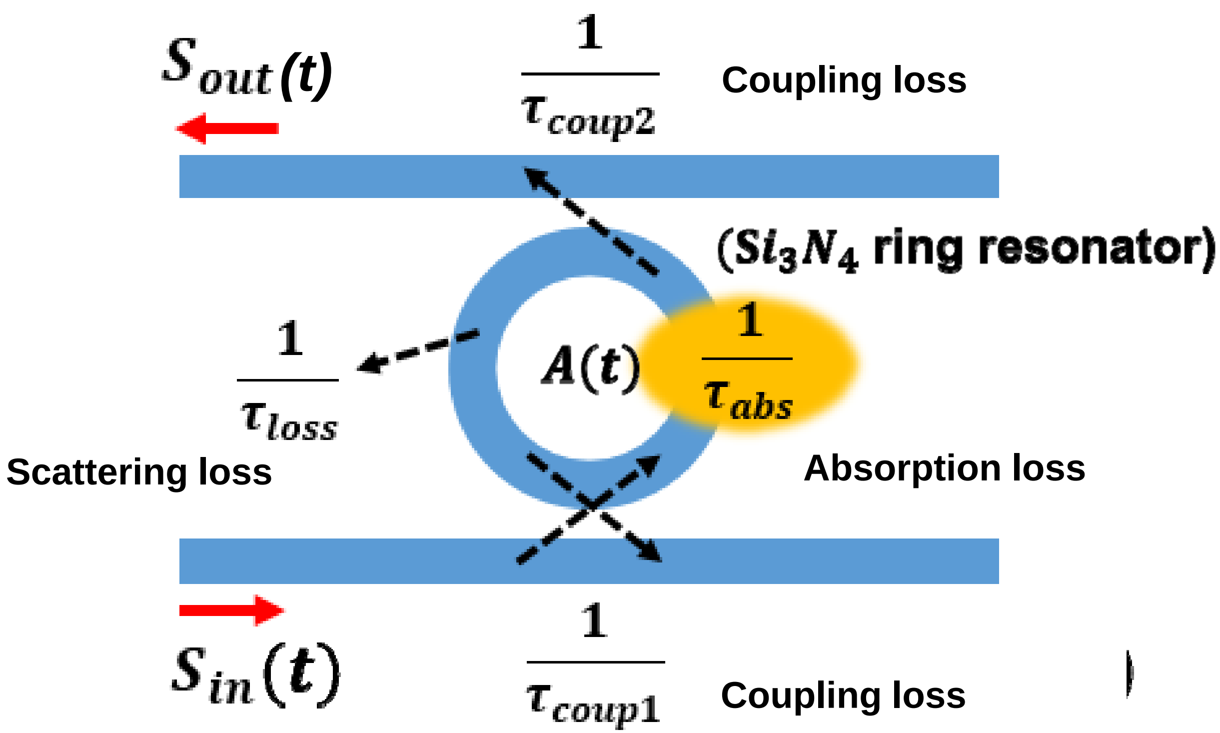
Broad bandwidth pulse can transmit ultrahigh Q cavity

Model – Add-drop system & CMT

Coupled mode theory (CMT)

$$\frac{dA(t)}{dt} = \left[j2\pi c \left(\frac{1}{\lambda_r + \delta\lambda(t)} - \frac{1}{\lambda_{in}} \right) - \frac{1}{2} \left(\frac{1}{\tau_{loss}} + \frac{1}{\tau_{abs}} + \frac{1}{\tau_{coup1}} + \frac{1}{\tau_{coup2}} \right) \right] A(t) + \sqrt{\frac{1}{\tau_{coup1}}} \exp(j\theta)\, S_{in}(t)$$

☐ Add-drop system



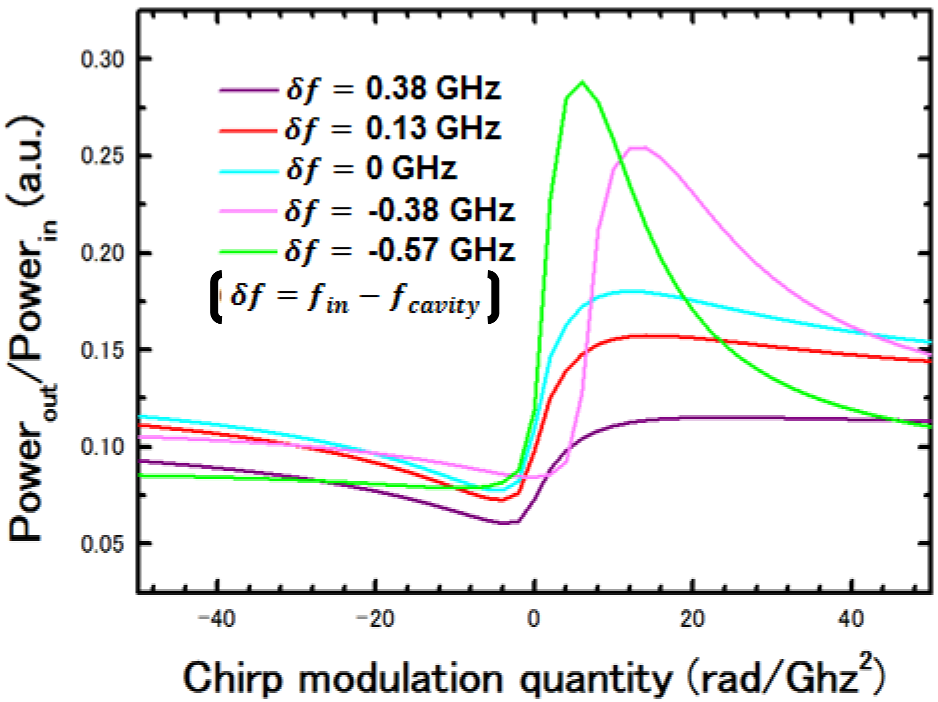
$A(t)$: Cavity mode amplitude
λ_0: Resonant wavelength (cold cavity)
$\delta\lambda(t)$: Resonance wavelength shift
λ_{in}: Input wavelength
θ: Phase difference

Analyze $S_{out}(t)$ in Add-drop system by CMT

Optimized spectrum phase & detuning

Input energy: 28.4 pJ
FTL pulse width: 0.45 ns (1.2 GHz)

Q = 7.5x10^5
(T ~ 11% w/ TL input)



28% of input energy can be transported through cavity
(2.4 times greater than that of FTL pulse)

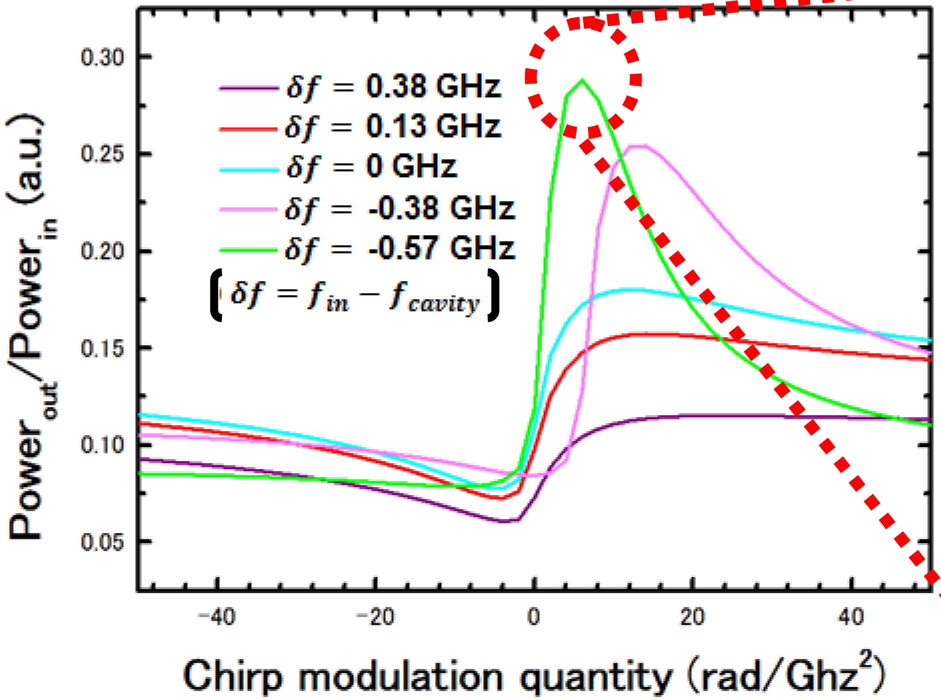
Optimized spectrum phase & detuning

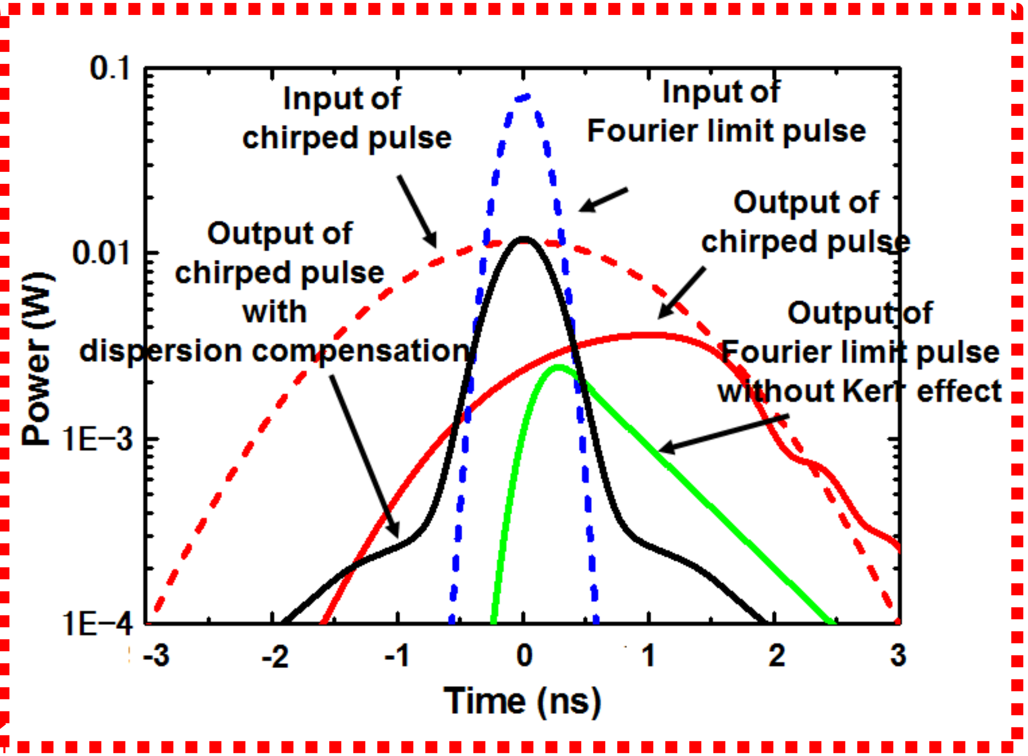
Input energy: 28.4 pJ

FTL pulse width: 0.45 ns (1.2 GHz)

$Q = 7.5 \times 10^5$

(T ~ 11% w/o Kerr)



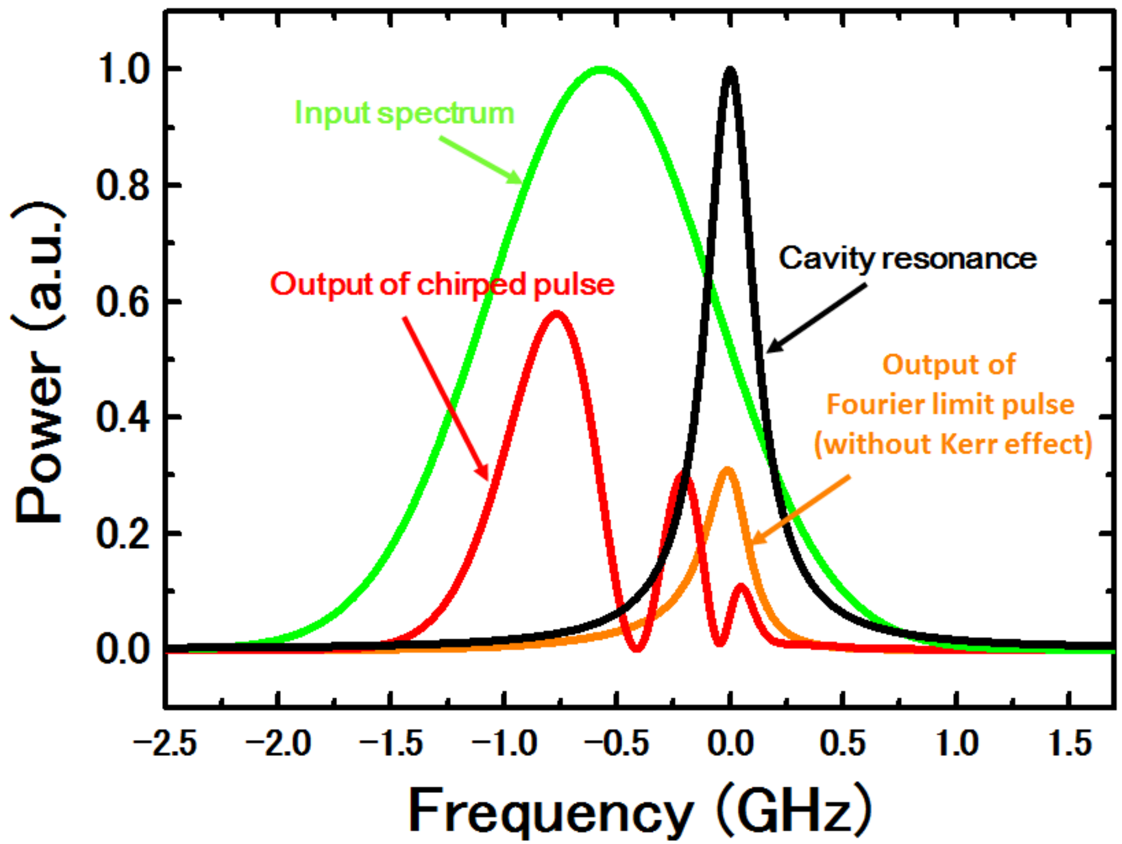


28% of input energy can be transported through cavity

(2.4 times greater than that of FTL pulse)

Discussion

(Quantity of second spectrum phase : 4.5 rad/GHz^2,
Resonance frequency (cool cavity) : 194 THz, $\delta f = -0.57$ GHz)



Discussion

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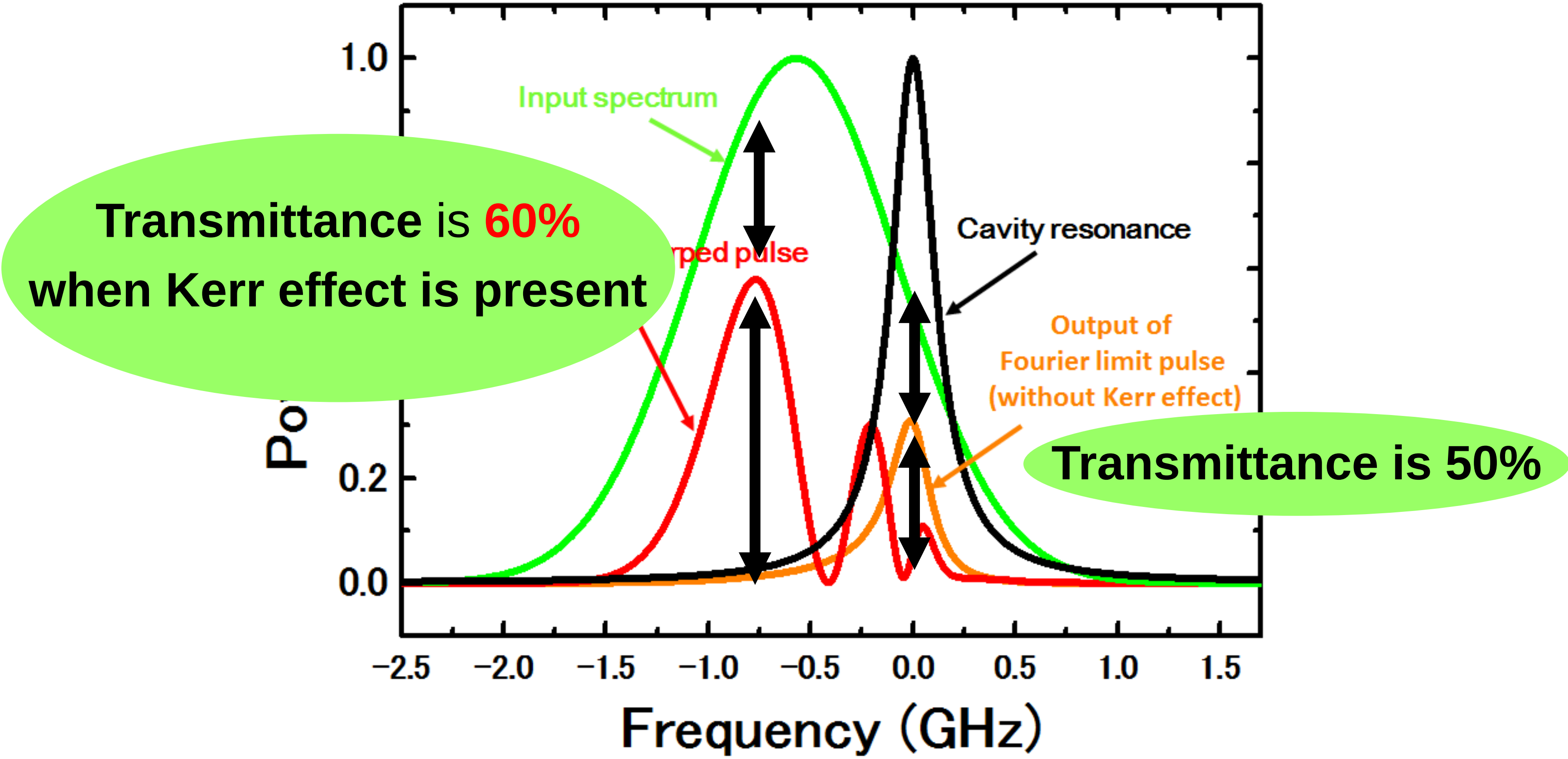


- Why high transmittance ?

Classic (adiabatic) wavelength tuning of light

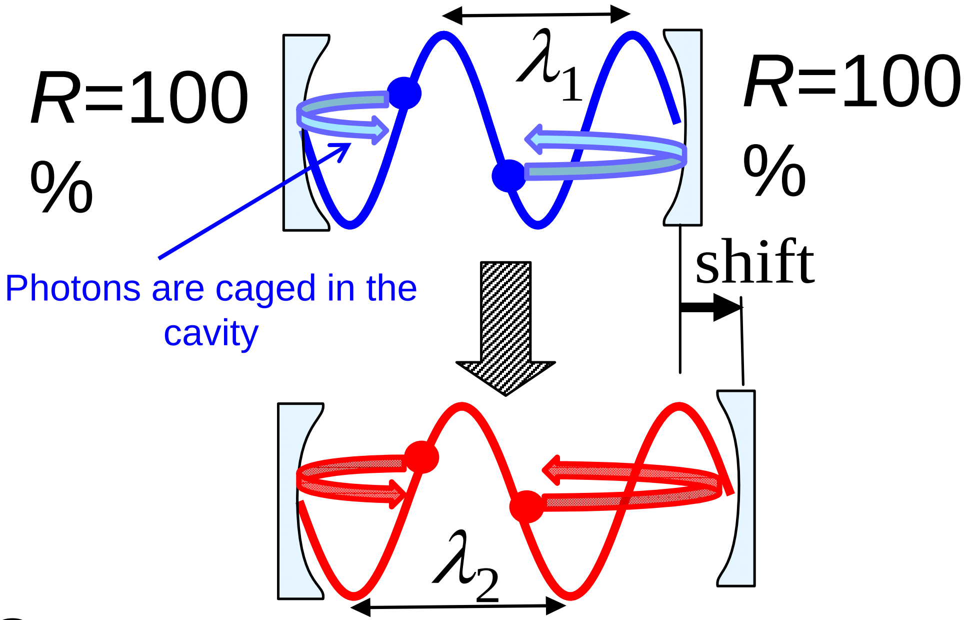
T. Tanabe, *et al.*, Phys. Rev. Lett. **102,** 043907 (2009)

Classical frequency tuning: Case of tone (ex: guitar string)

Q: How can we change the pitch when the string is already plucked?

A: By changing the tension of the string. But it must be done before the tone disappears.

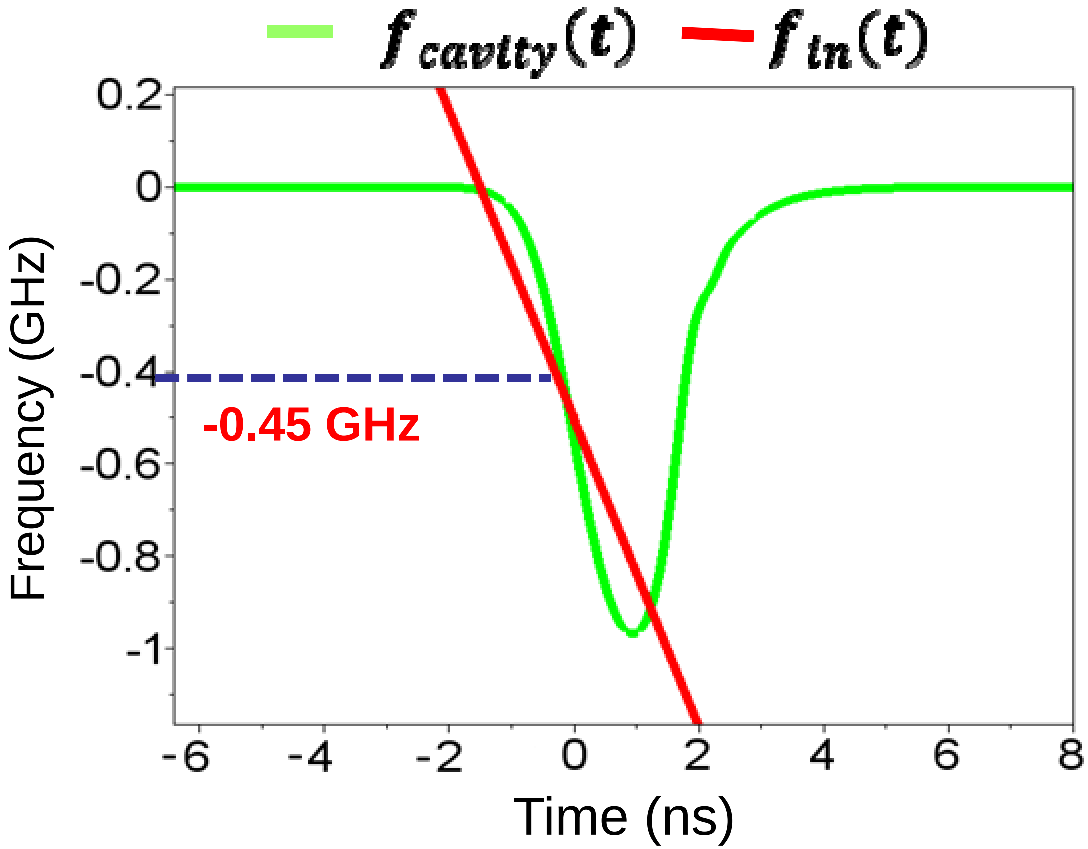
Classical frequency tuning: Case of light (ex: high-*Q* cavity)

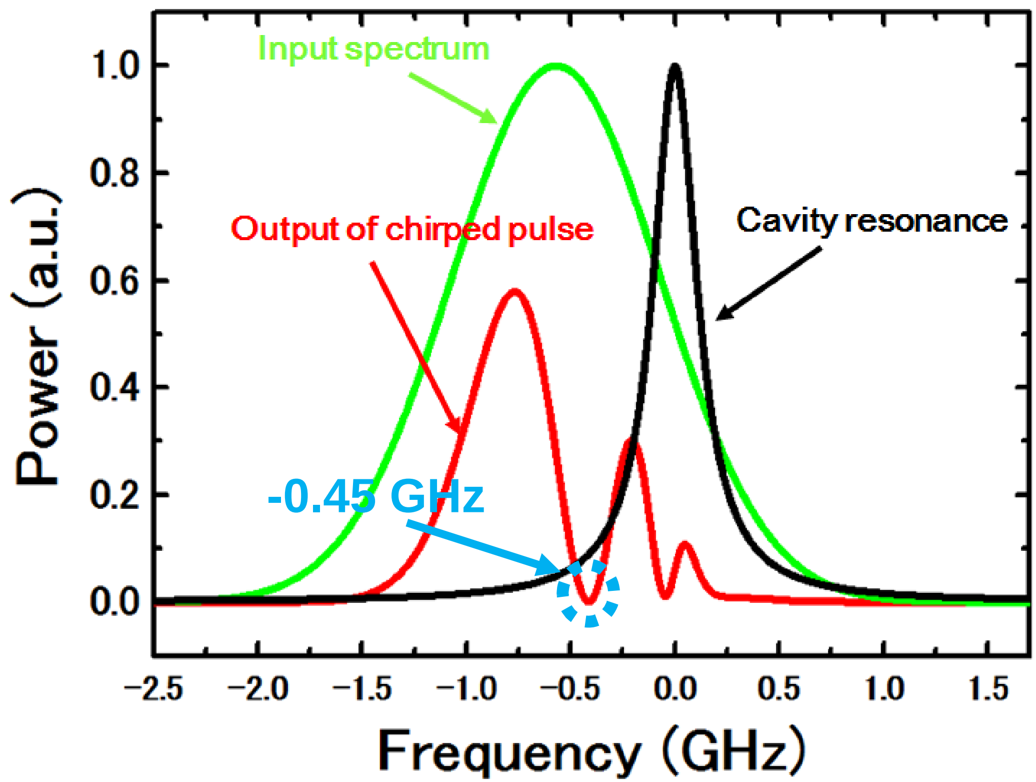


Q: What will happen when we change the cavity length, when the mirror is perfect and the light cannot escape?

A: The frequency of the light will follow the cavity resonance adiabatically!

Analysis of adiabatic wavelength conversion





Speed of the cavity resonance shift is the highest at -0.45 GHz

frequency component at -0.45 GHz changes their wavelength and then output as a low frequency light

Summary & Acknowledgment

- Obtained optimized linear chirp to permit broad-bandwidth transmittance
  - 28% of input energy can transmit
  - 2.4 times greater than inputting FTL pulse
- Showed adiabatic wavelength conversion plays an important role in this event

総務省
MIC Ministry of Internal Affairs and Communications

Strategic Information and Communications R&D Promotion Programme (SCOPE), from the Ministry of Internal Affairs and Communications

