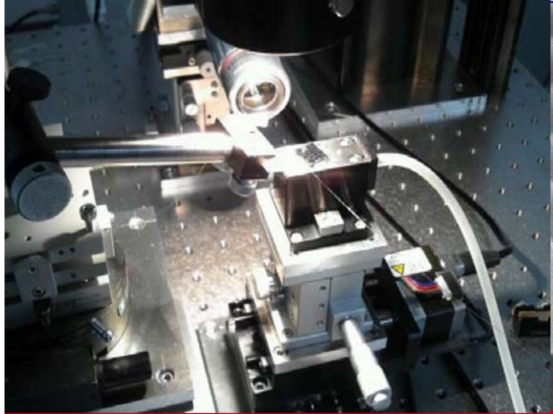
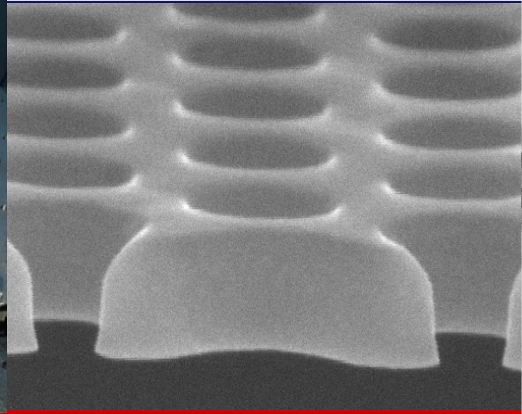
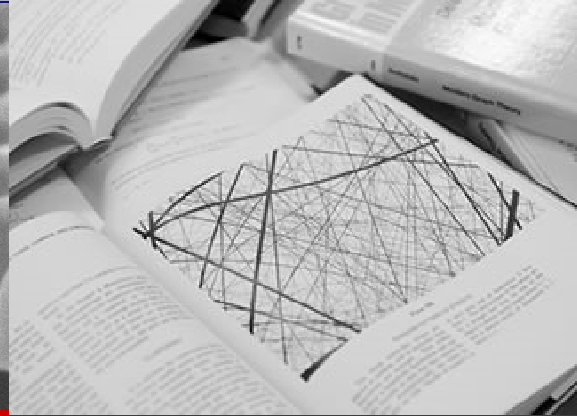

IEEE Photonics Conference 2014
MF 3.4 Cavity Optomechanics and Optical Forces in Microcavities

High-Q silica zipper cavity with strong opto-mechanical coupling for optical radiation pressure driven directional switching

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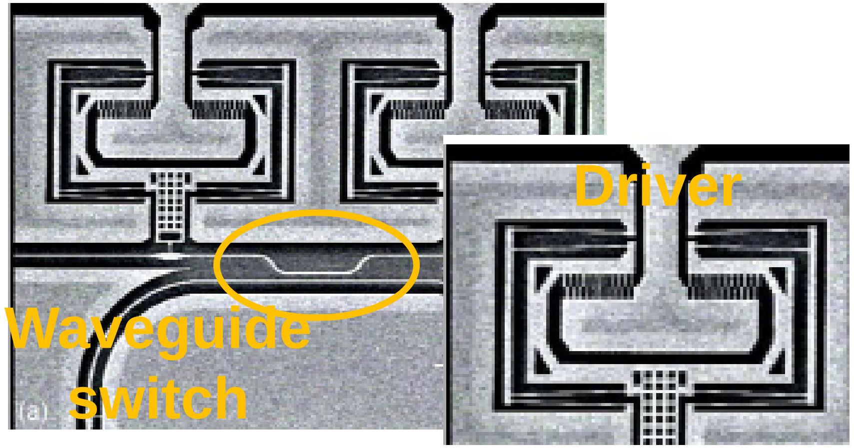
Tomohiro Tetsumoto and Takasumi Tanabe*

Background：Opto-mechanical switches

Micro-Opto Electro-Mechanical-Systems (MOEMS)



Drive force: electrostatic force

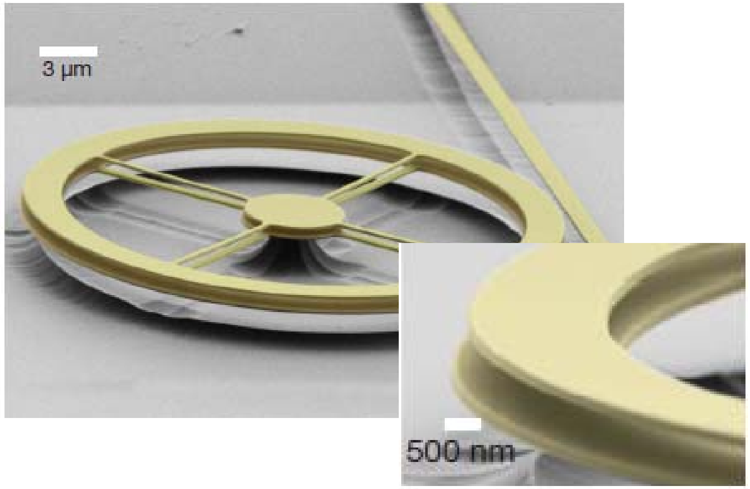
✓msec. ~ μsec.

✓High contrast

⇒Extra drivers needed

Y. Akihama, et al., Opt. Express **19**, 23658-663 (2011).

Micro-Opto-Mechanical-Systems (MOMS)



Drive force: optical radiation force

✓μsec. order

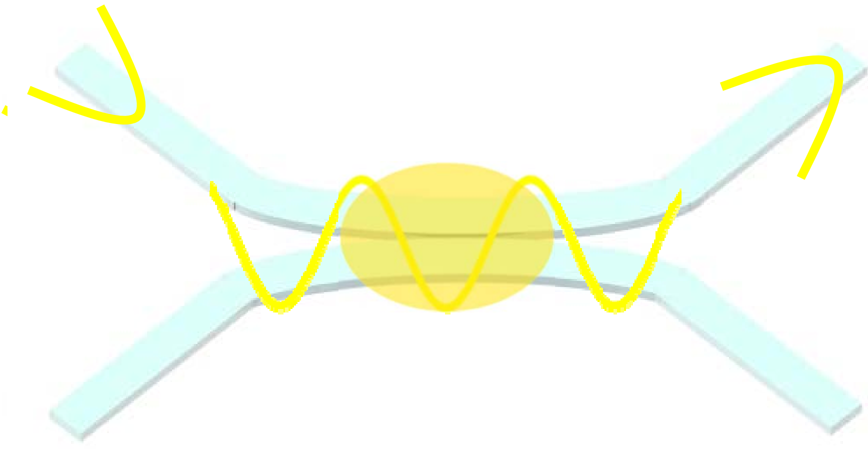
✓High contrast

✓Can be made small (Suitable for integration)

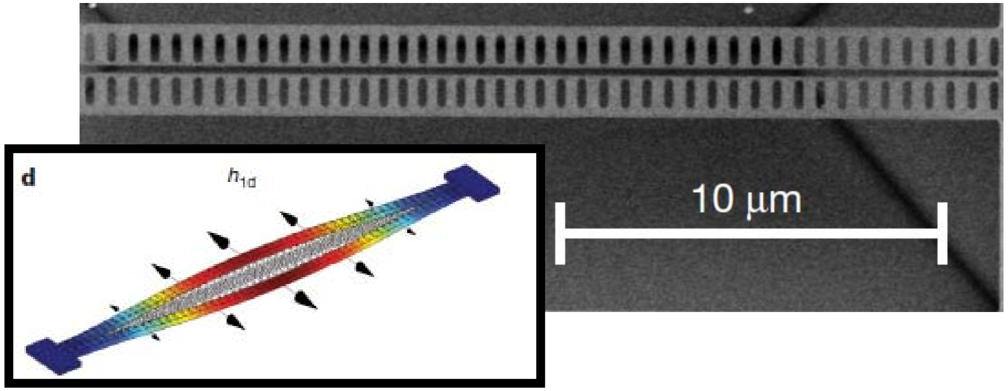
G. S. Wiederhecker, et al., Nature **462** , 633-6 (2009)

Opto-mechanical directional coupler switch

Directional coupler



Zipper cavity



M. Eichenfield, et al., Nature **459**, 550-555 (2009)

Silica

✓Easy to deform

✓Transparent in broadband range
(770-nm control light 1550-nm signal light)

✓ Ultra-low loss at telecom wavelength

Motivation and objectives

Motivation

- ✓ High contrast and compact.
- ✓ Demonstration of new type of optical switch

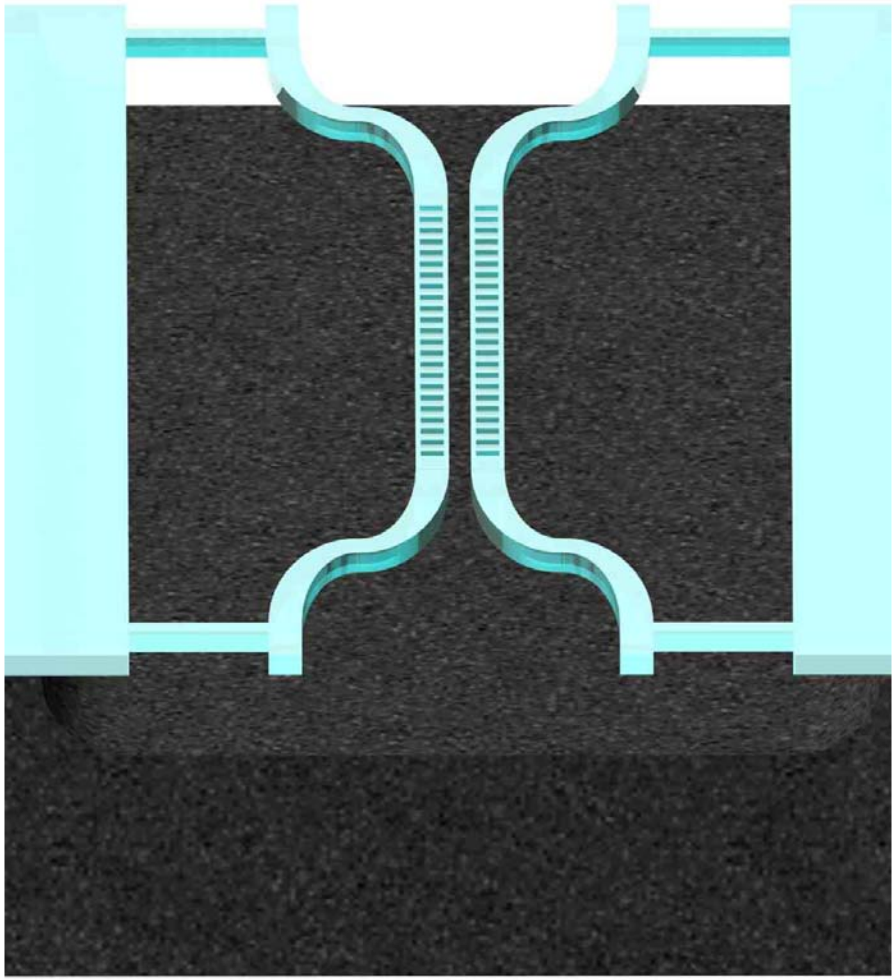
Objectives

- ✓ Design & analyze properties of silica zipper directional switch.
- ✓ Develop silica zipper cavity fabrication method

Outline of design strategy

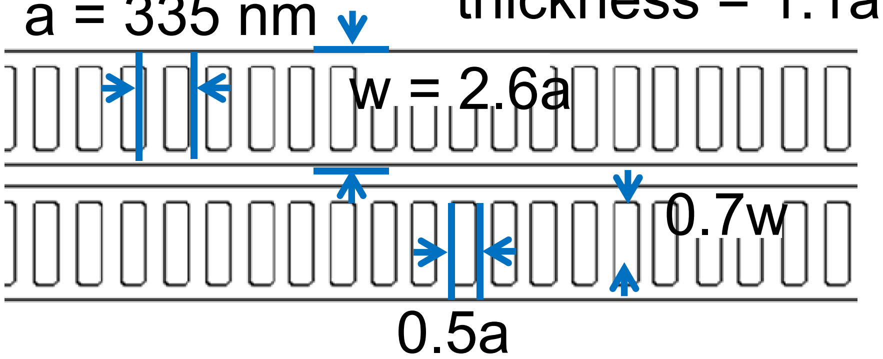
Essential propeties

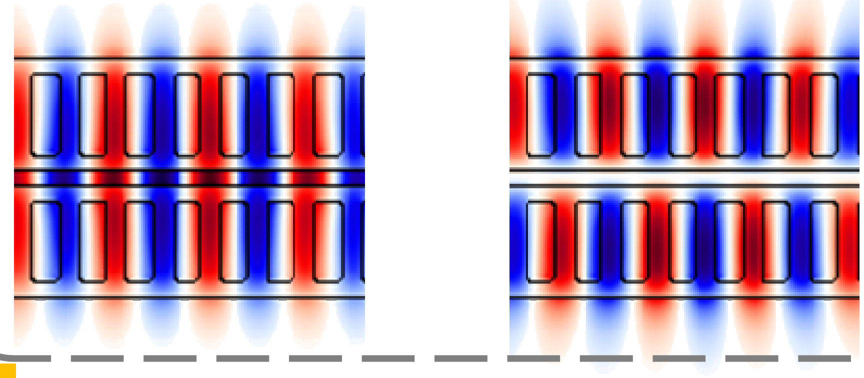
1. Optical resonant properties (Q, ω)
2. Mechanical resonant properties (Ω_{m}, τ_{m})
3. Light propagation properties (extinction ratio)
4. opto-mechanical properties (deformation, power)



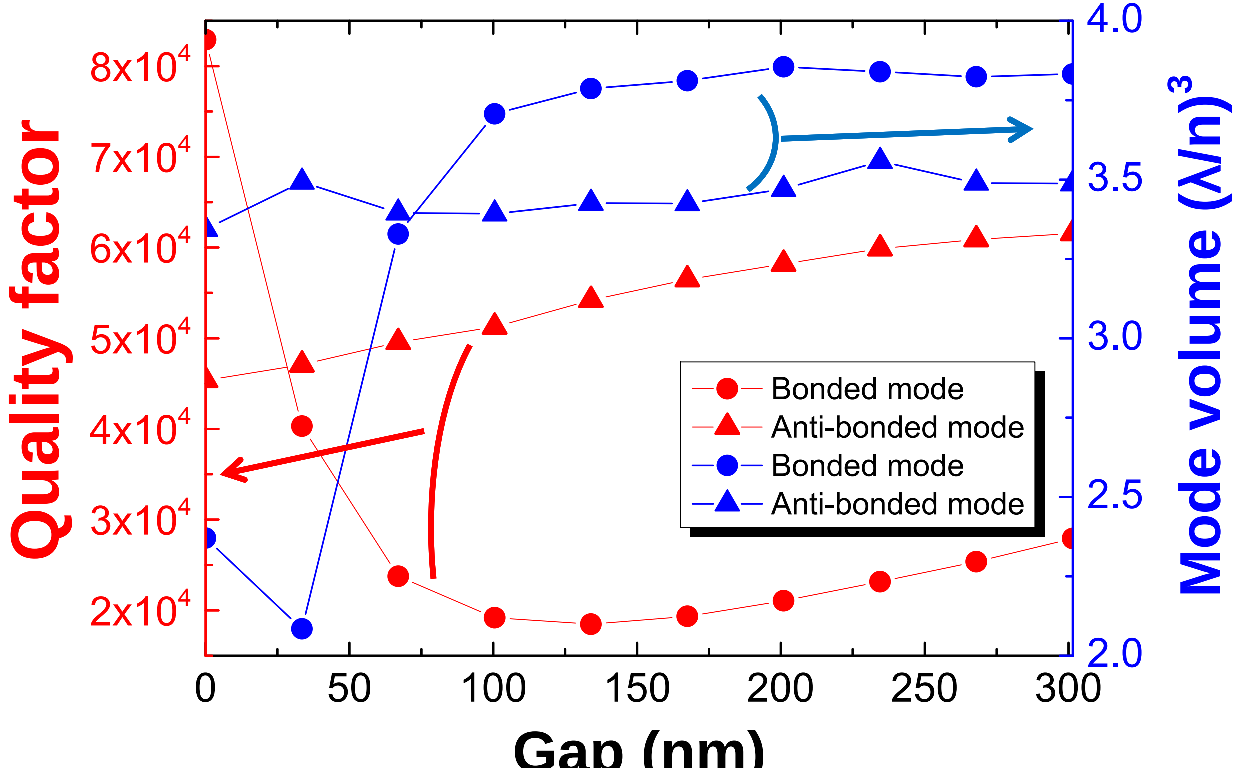
Optical design of silica zipper cavity

Design of optical cavity





Gap dependence versus *Q* & *V*



Highest Q/V

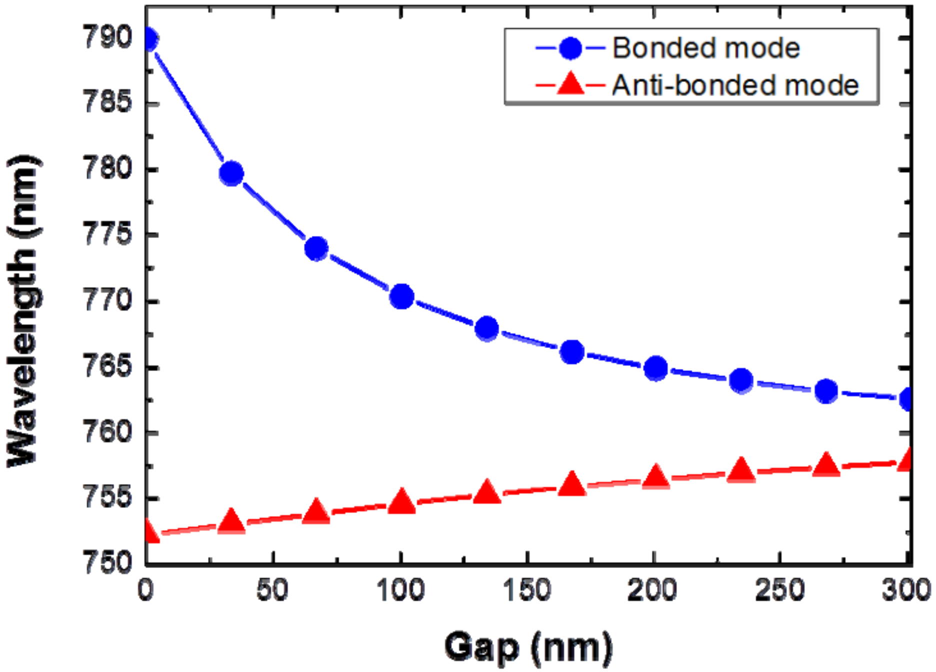
$$Q = 4.0 \times 10^4$$

$$V = 2.1(\lambda/n)^3$$

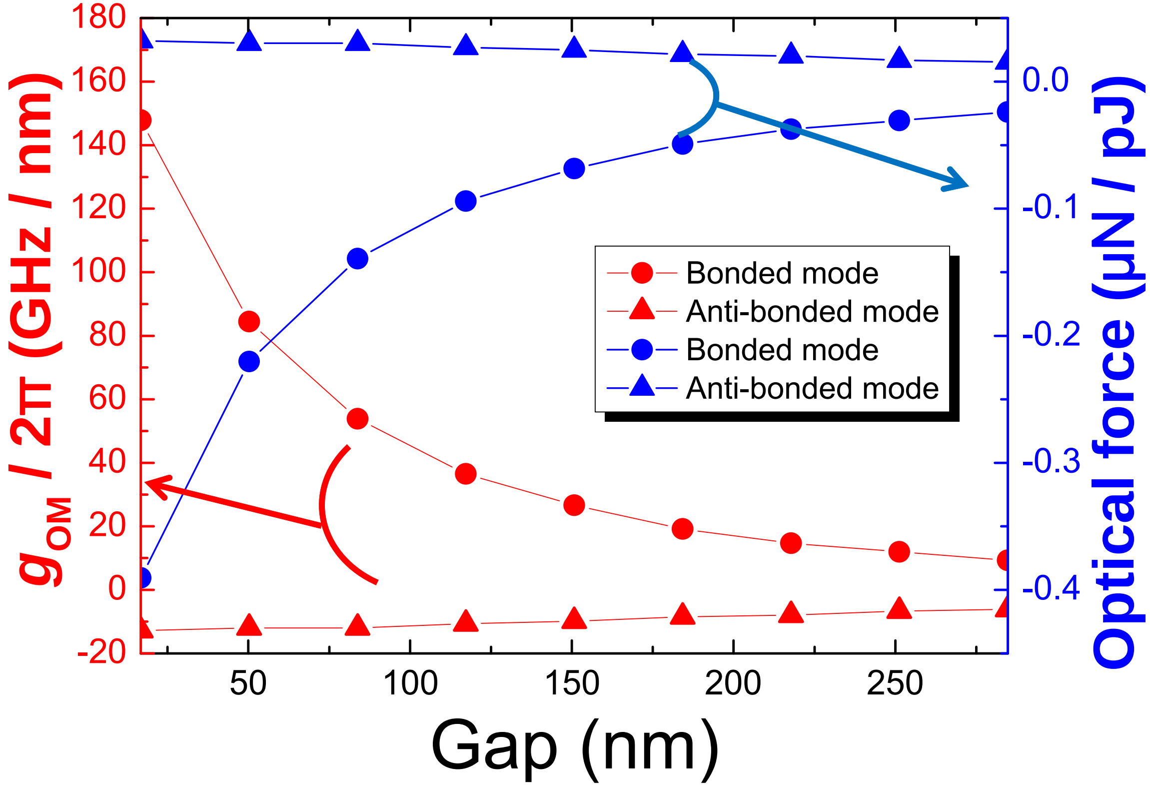
@gap = 34 nm
for bonded mode

Opto-mechanical coupling and induced optical force

Gap vs. resonant wavelength



Gap vs. g_{OM} & optical force



Opto-mechanical coupling

$$g_{OM}/2\pi = d\omega/ds$$

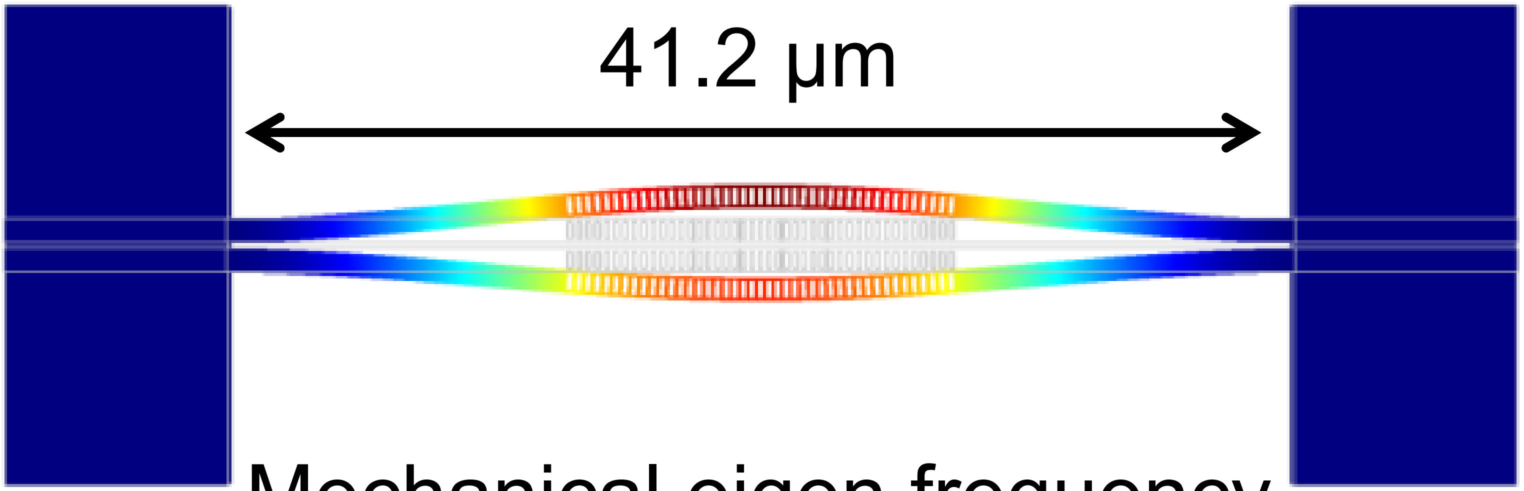
Optical force

$$F = -\frac{dU}{ds} = -\frac{\hbar d\omega}{ds}$$

$$g_{OM}/2\pi > 100\ \mathrm{GHz/nm}$$

@gap < 40 nm

Mechanical design of silica zipper cavity



Mechanical eigen frequency

$$\Omega_m/2\pi = 3.2\ \mathrm{MHz}$$

Operating speed of the device

Operating speed

≈

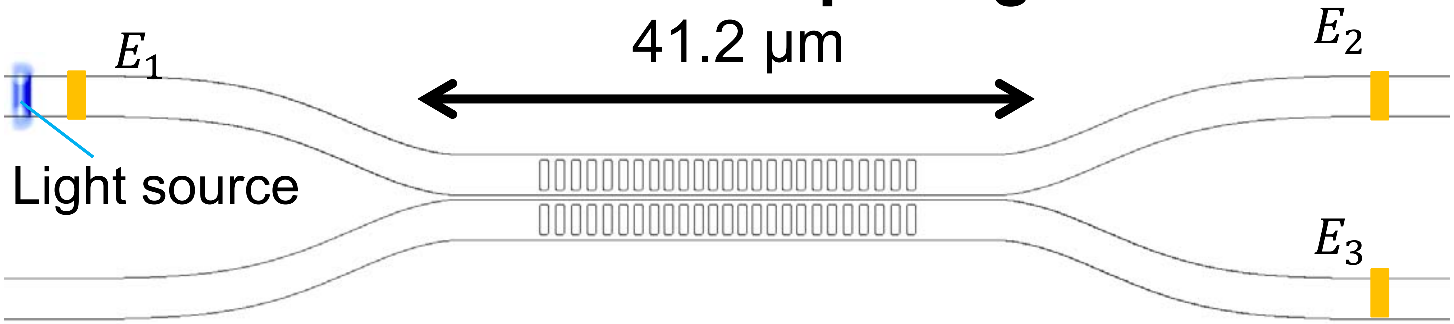
Lifetime of oscillation

$$\tau = Q_m/\Omega_\mathrm{m} = 3.1\ \mu\mathrm{s}$$

$(Q_m \approx 10$ (in Air))

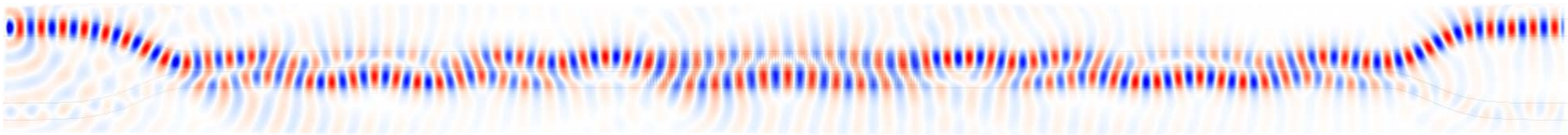
Light propagation in silica zipper cavity

Model for computing

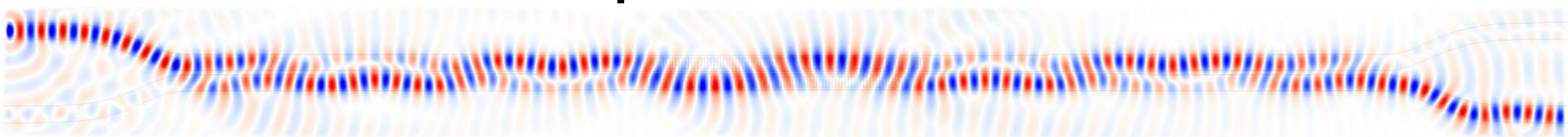


$$(\text{Extinction ratio}) = \left|10\log\left(\frac{E_1}{E_2}\right) - 10\log\left(\frac{E_1}{E_3}\right)\right| = \left|10\log\left(\frac{E_3}{E_2}\right)\right|$$

Initial state : Gap = 194 nm Extinction ratio: 17.8 dB



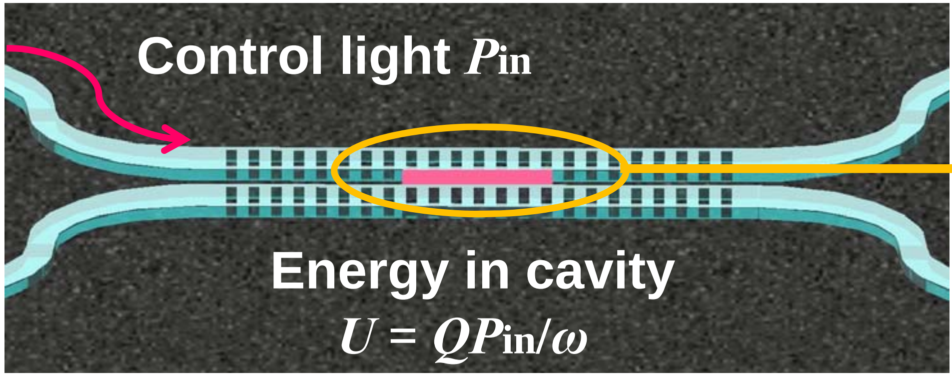
After deformation : Gap = 93 nm Extinction ratio: 18.2 dB

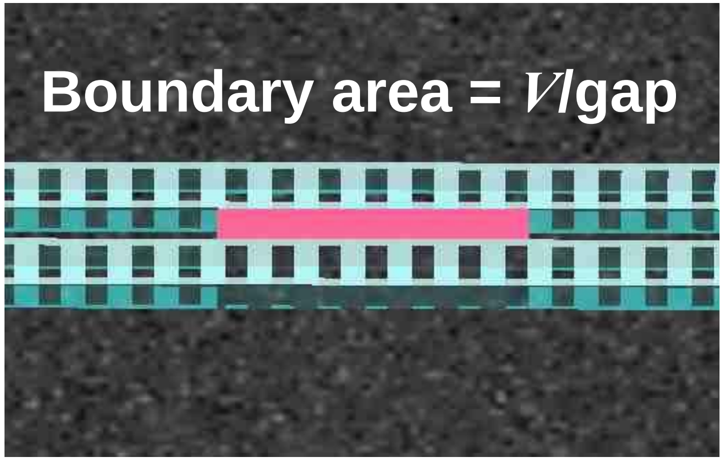


We can obtain a high switching contrast of ≥ 17.8 dB with about a 100-nm deformation of the structure.

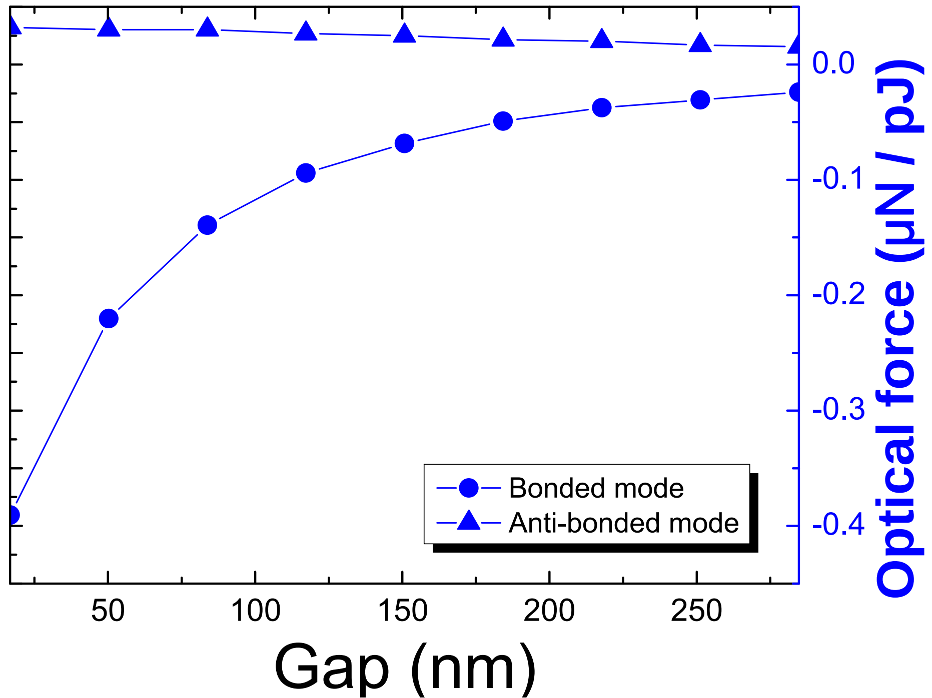
Computing of deformation

Model of computing





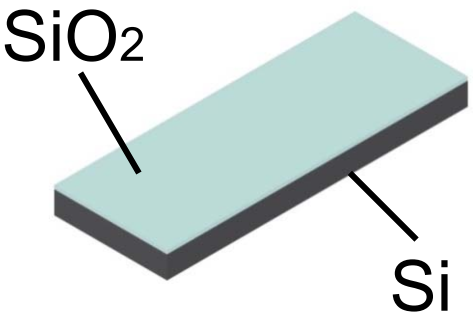
Gap dependence of the optical force per energy U

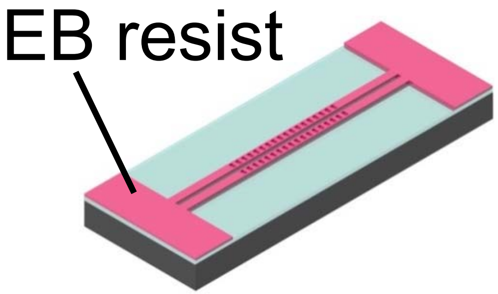


Input power of **190 mW** deform structure by 100 nm

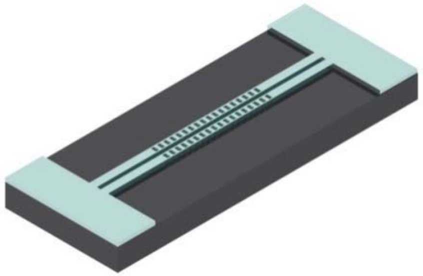
Fabrication of silica zipper cavity

1. EB lithography

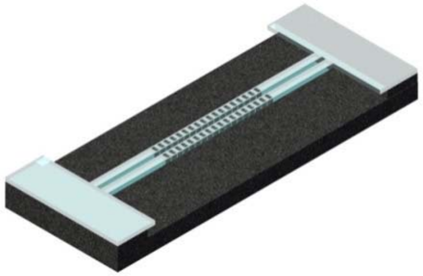


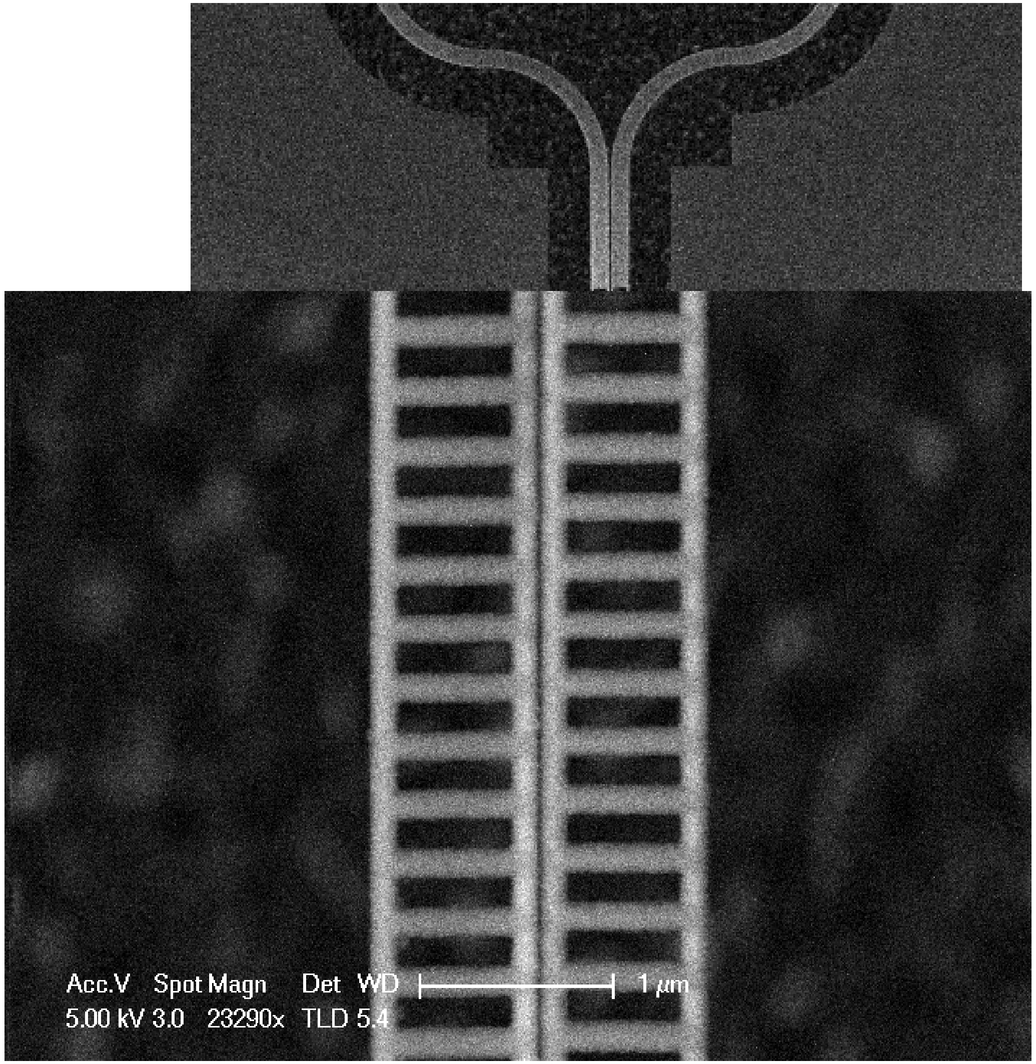


2. Dry etching of silica



3. Dry etching of sacrificial layer





Summary

- ✓ We demonstrated numerical study of new type of opto-mechanical directional switch
  - ➢ Designed cavity which has high Q (4×10^4)
  - ➢ Obtained extinction ratio of 17.8 dB with control power of 190 mW
- ✓ We fabricated sharp silica zipper structure with simple process

Acknowledgement

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JSPS KAKENHI Grant Number 25600118

For more information,
T. Tetsumoto and T. Tanabe, AIP Advances, Vol. 4, 077137 (2014).