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

Department of Electronics and Electrical Engineering, Faculty of Science and Technology, Keio University, 3-14-1 Hiyoshi Kohoku, Yokohama 223-8522, Japan
*email: takasumi@elec.keio.ac.jp

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


Micro-Opto-Mechanical-Systems (MOMS)

Drive force: optical radiation force
✓ μsec. order
✓ High contrast
✓ Can be made small
(Suitable for integration)

Opto-mechanical directional coupler switch

Directional coupler

Zipper cavity


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 properties

1. Optical resonant properties 
   \((Q, \omega)\)
2. Mechanical resonant properties 
   \((\Omega_m, \tau_m)\)
3. Light propagation properties 
   (extinction ratio)
4. opto-mechanical properties 
   (deformation, power)
Optical design of silica zipper cavity

Design of optical cavity

\( a = 335 \text{ nm} \)

\( \text{thickness} = 1.1a \)

\( w = 2.6a \)

\( 0.7w \)

\( 0.5a \)

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

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

Optical force

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

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

@gap < 40 nm
Mechanical design of silica zipper cavity

Mechanical eigen frequency

\[ \frac{\Omega_m}{2\pi} = 3.2 \text{ MHz} \]

Operating speed of the device

Operating speed

\[ \tau = \frac{Q_m}{\Omega_m} = 3.1 \mu\text{s} \]

(Lifetime of oscillation

\( Q_m \approx 10 \) (in Air))
Light propagation in silica zipper cavity

Model for computing

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

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 \(\geq 17.8\) dB with about a 100-nm deformation of the structure.
Computing of deformation

Model of computing

Control light $P_{\text{in}}$

Energy in cavity

$U = QP_{\text{in}}/\omega$

Boundary area = $V$/gap

Gap dependence of the optical force per energy $U$

Input power of 190 mW deform structure by 100 nm

Optical force ($\mu$N / pJ) vs Gap (nm)

- Bonded mode
- Anti-bonded mode
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 $Q$ ($4 \times 10^4$)
  - Obtained extinction ratio of 17.8 dB with control power of 190 mW
- We fabricated sharp silica zipper structure with simple process

Acknowledgement

This work was supported by JSPS KAKENHI Grant Number 25600118