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FTu4A.5 Silicon-based Nano-photonic Structures

Polygonal silica toroidal microcavity for easy and stable coupling with waveguides

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Outline

1. Background
   - ✓Silica toroidal microcavity
   - ✓Barriers for practical application
2. Fabrication process for polygonal silica toroid
   - ✓Anisotropic etching for silicon
3. Mode analysis using 2D-FDTD simulation
   - ✓WG-like modes of a polygonal cavity
4. Experimental result
5. Summary

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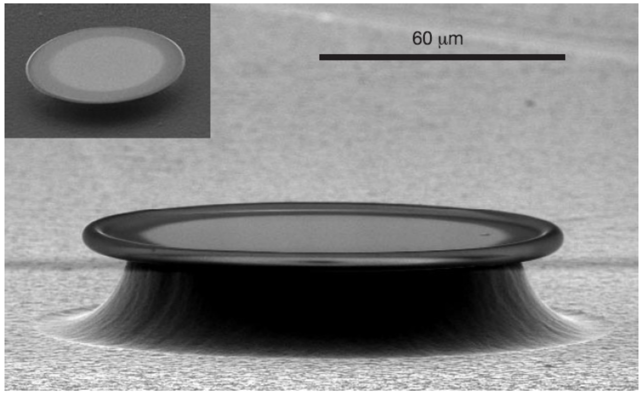
Silica toroid microcavity



D. K. Armani *et al.*,
Nature **421,** 925 (2003).

Application
- ✓ Optical frequency comb source
- ✓ Single molecule detection
- ✓ Third nonlinear effect

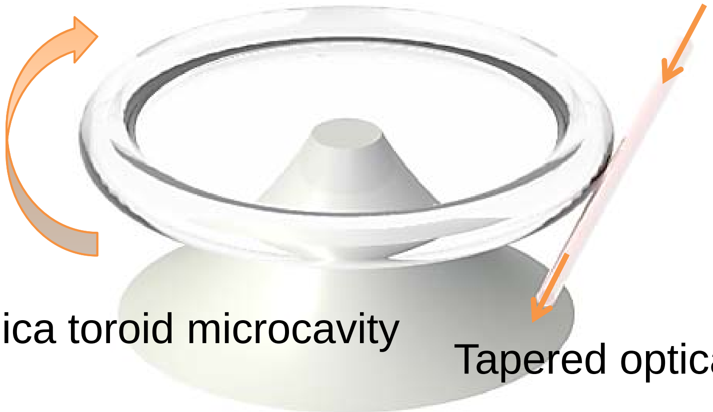
High Q and small V is required

Advantage
- ✓ Ultra high-Q $Q \approx 1.0 \times 10^8$
- ✓ Small mode volume V
- ✓ Silica and fiber couple well
- ✓ Silicon wafer is low cost

Disadvantage
- ✓ Must use tapered fiber

Vulnerable to vibrations

Coupling light to WGM cavity

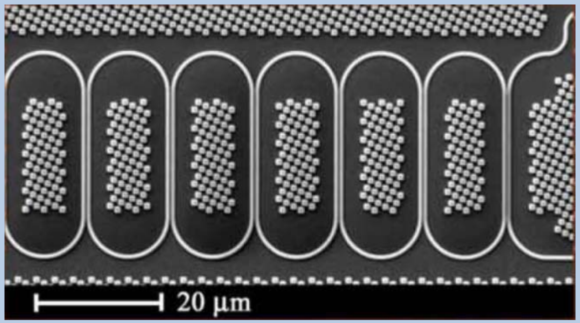


Main coupling difficulties

- ✓ Sensitive control of air gap
- ✓ Fragile tapered fiber

Obstacles for practical applications

Microcavity design for robust coupling : Non-circular structure



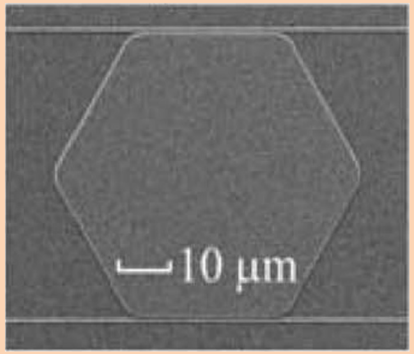
M. L. Cooper *et al.*,
Opt. Lett. **35,** 3030 (2010).

Racetrack type

- ✓ Long coupling length

Polygon type

- ✓ Multiple flat sidewalls for coupling



C. Li *et al.*, IEEE J. Sel. Top. Quantum Electron. **12,** (2006).

Motivation

Need for an ultrahigh-Q cavity that is robust as regards mechanical vibrations for practical applications

In silicon microrings

Structure must be tolerant to fabrication error → demonstrated → Change cavity design
- Racetrack
- Hexagon

Not difficult because we can use CMOS process

Silica toroid microcavities

Coupling w/ tapered fiber must be robust & optimized even in contact → our idea → Fabricate polygonal silica toroid microcavity

But how?

Developing a fabrication method for changing the shape of silica toroid microcavity

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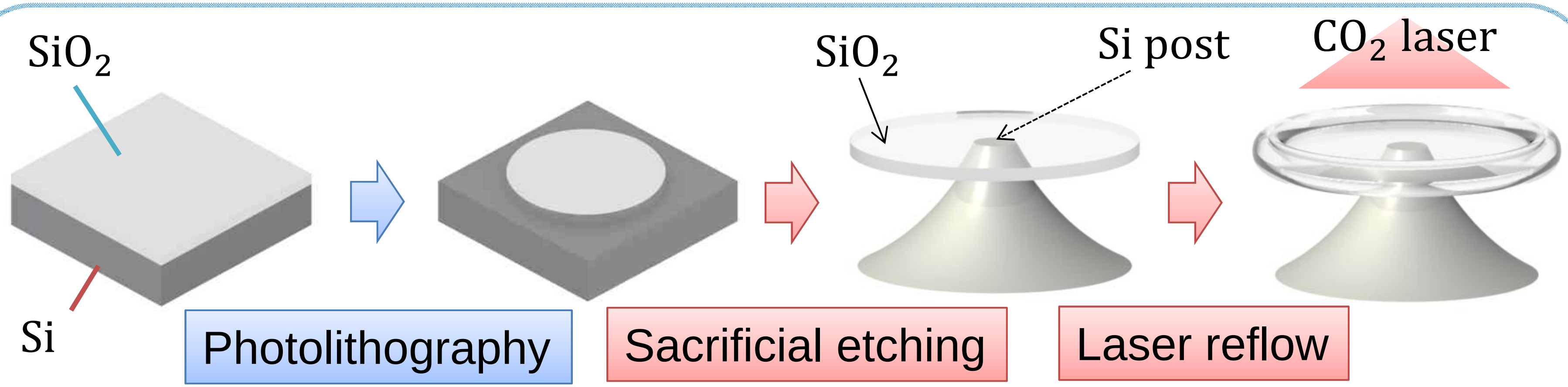
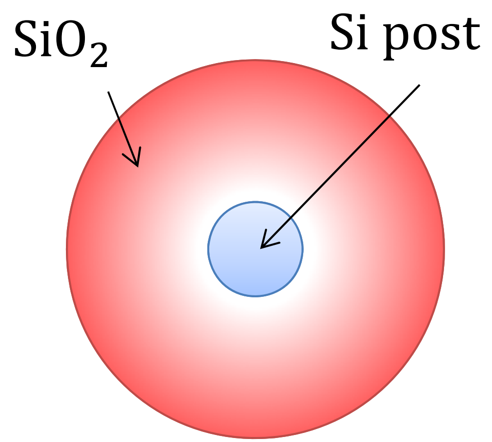
Silica toroid fabrication process



Point

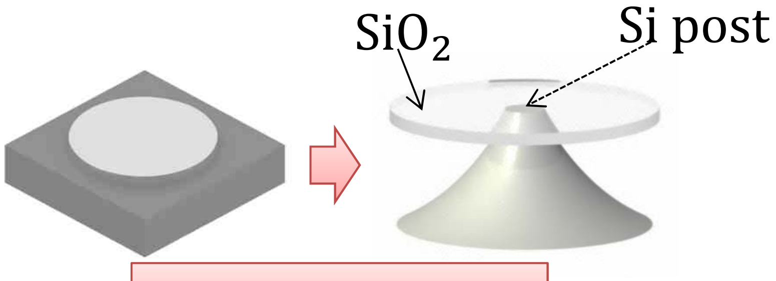
The shape of the SiO_2 toroid depends on the shape of the Si post because the post works as heatsink during the laser reflow

Thermal conductivity(300 K) $[W \cdot m^{-1} \cdot K^{-1}]$ $\begin{cases} Si & : 150 \\ SiO_2 & : 1.74 \end{cases}$



Heat profile at laser reflow

Fabricating polygonal silica toroid



Sacrificial etching

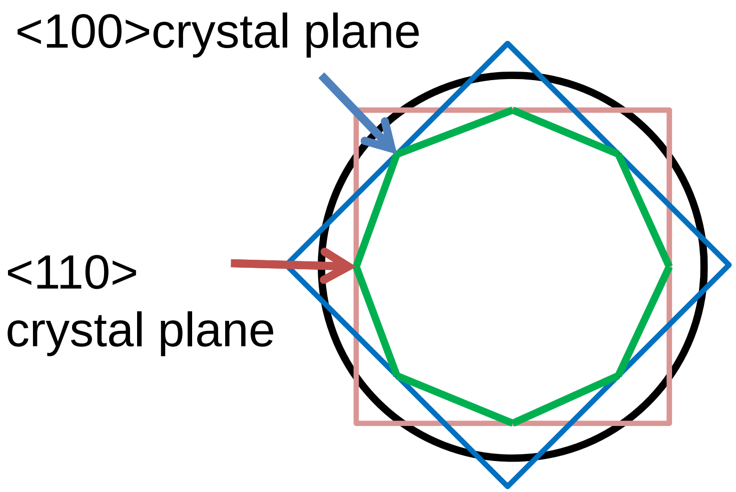
Conventional method

- ✓ XeF_2 gas dry etching : isotropic etchant

Proposed method

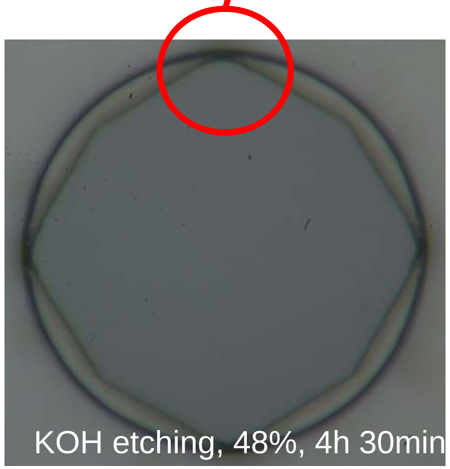
- ✓ KOH wet etching : anisotropic etchant

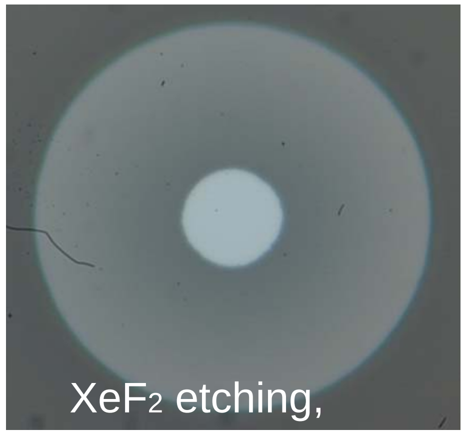
Anisotropic etching for silicon



Problem: Undercut is too small

Using only KOH is not enough...

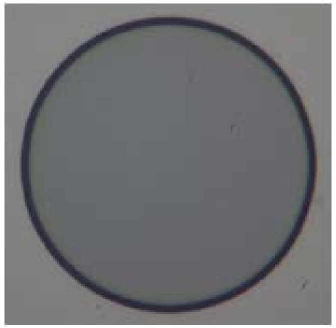




Fabricating polygonal silica toroid

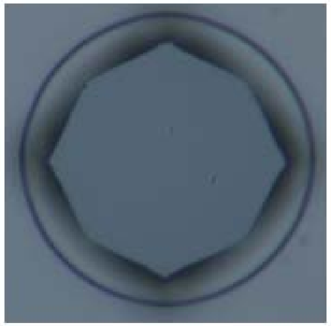
To obtain sufficient undercut to fabricate a polygonal silica toroid, we used a combination of isotropic and anisotropic etching for sacrificial etching

- Fabrication flow
  1. Prepare a substrate after photolithography
  2. Use HNA wet etching (isotropic) for 30 seconds
     - HF(48%): Nitric(69%): Acetic(99%) acids = 3 :5 :3
  3. Use KOH wet etching (anisotropic) for 3 hours
     - KOH(48%), Thermal control
  4. Use CO_2 laser for reflow process
     - 14 W, 100 ms, focal length 38.1 mm

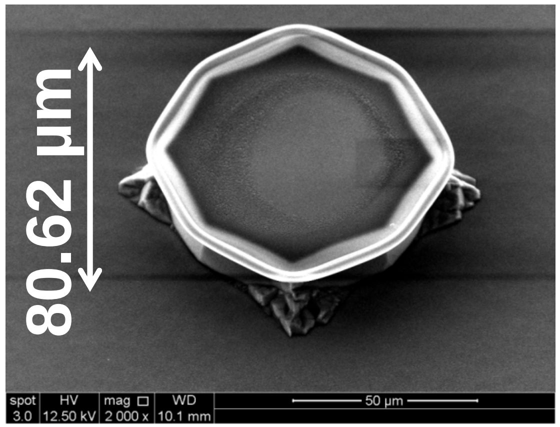


SiO_2 patterning after photolithography

3:5:3 HNA etching 30 seconds



KOH 48% etching 3 hours



SEM image of silica toroid after laser reflow

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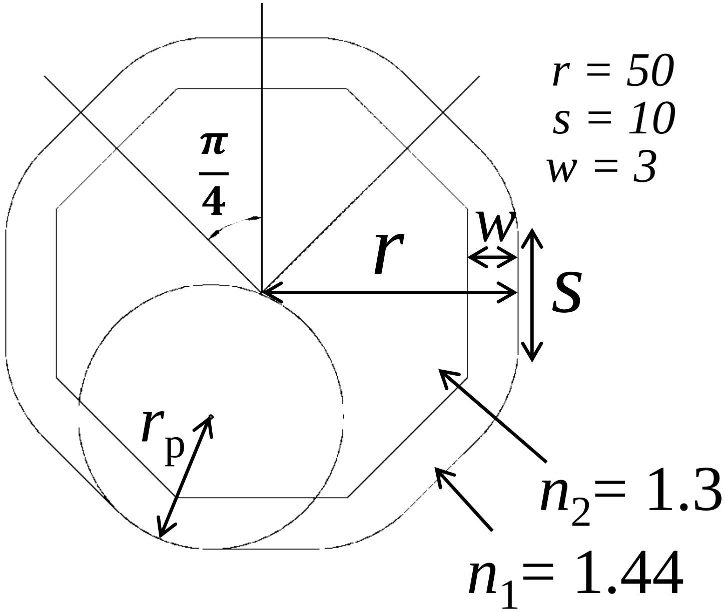
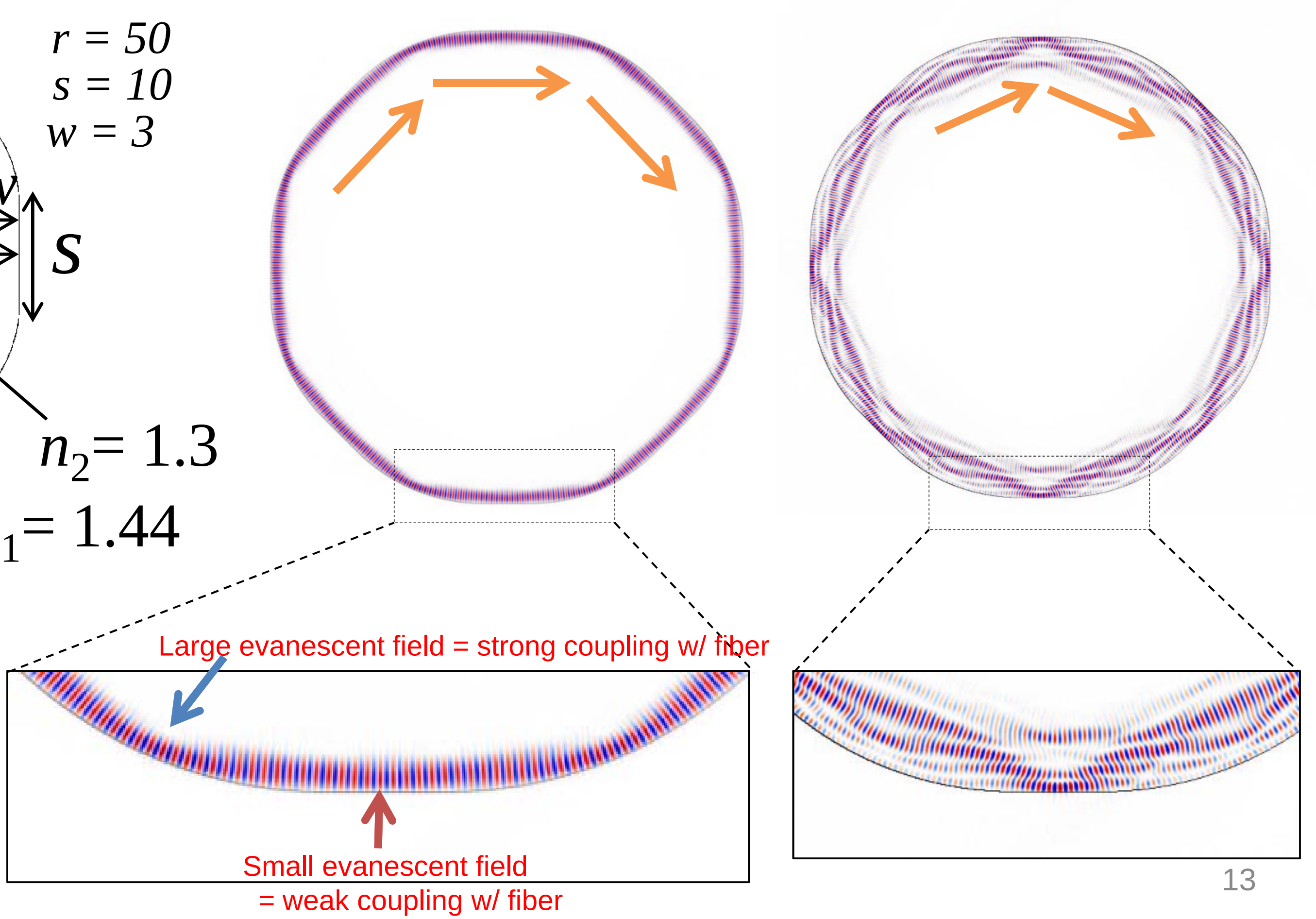
Mode analysis of polygonal silica toroid

Simulation model



Perturbed WG mode Quasi-WG mode



Perturbed WG mode
$Q = 8.8 \times 10^6$

Quasi-WG mode
$Q = 4.5 \times 10^4$

Coupling coefficient of each part

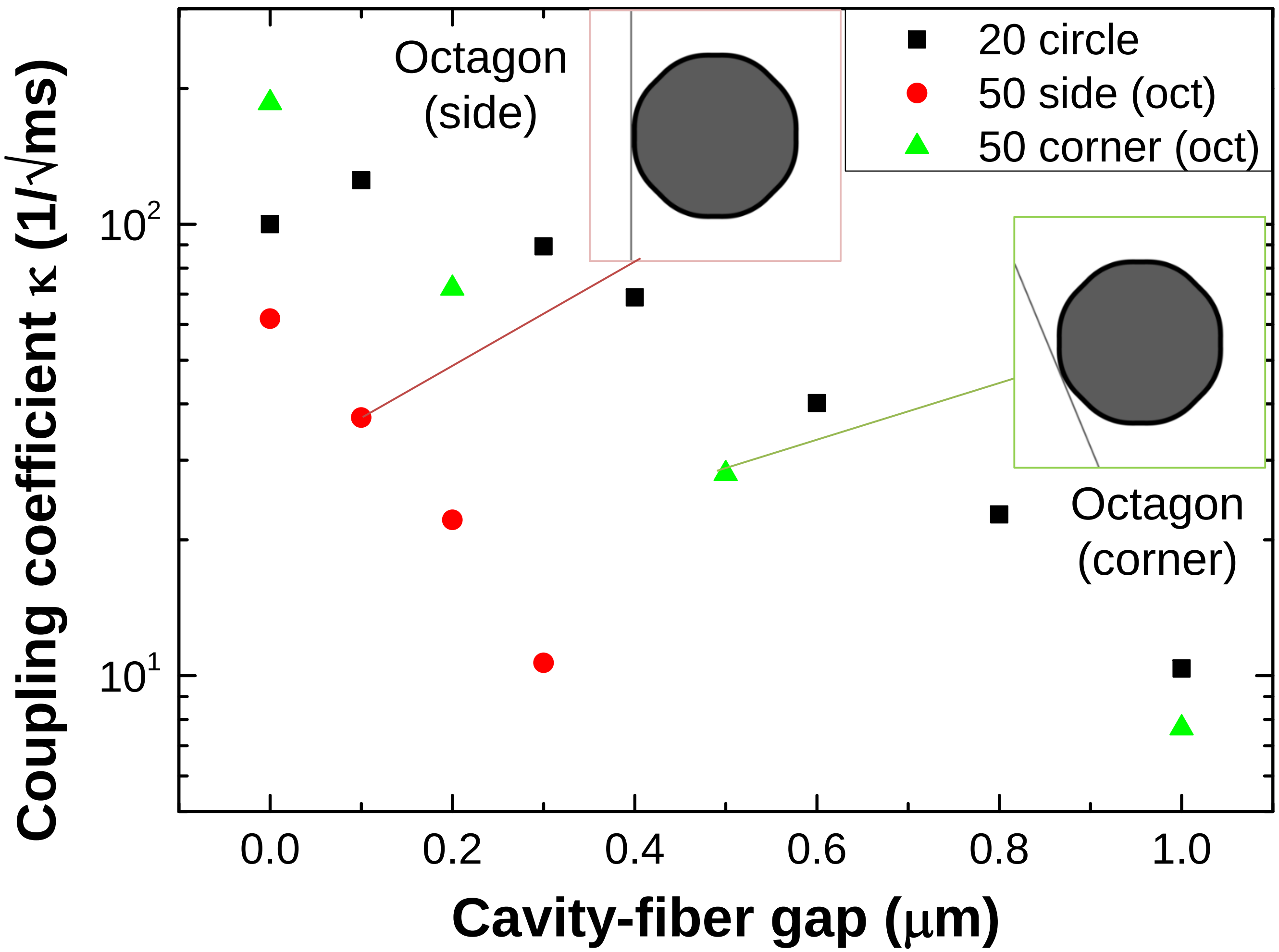
Polygonal cavity has two ways of coupling

If we use corner part

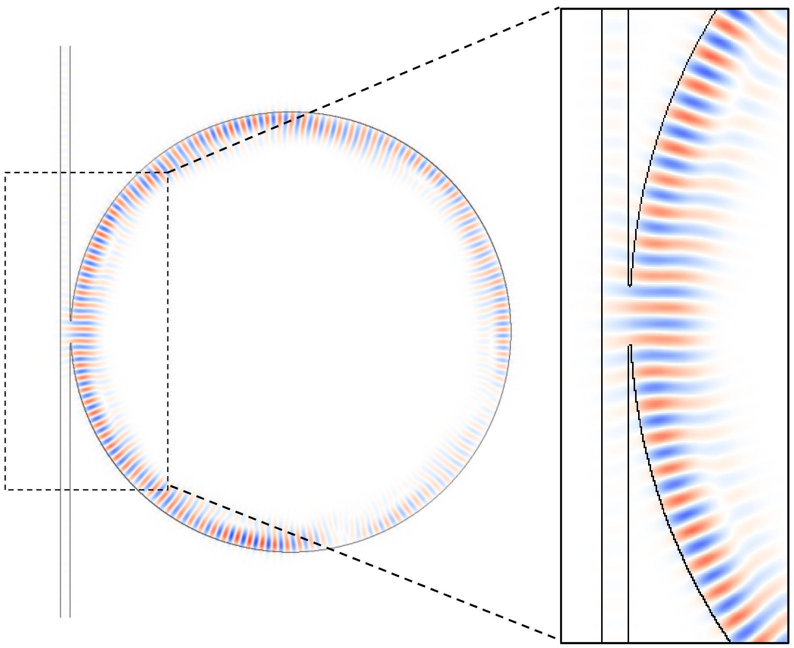
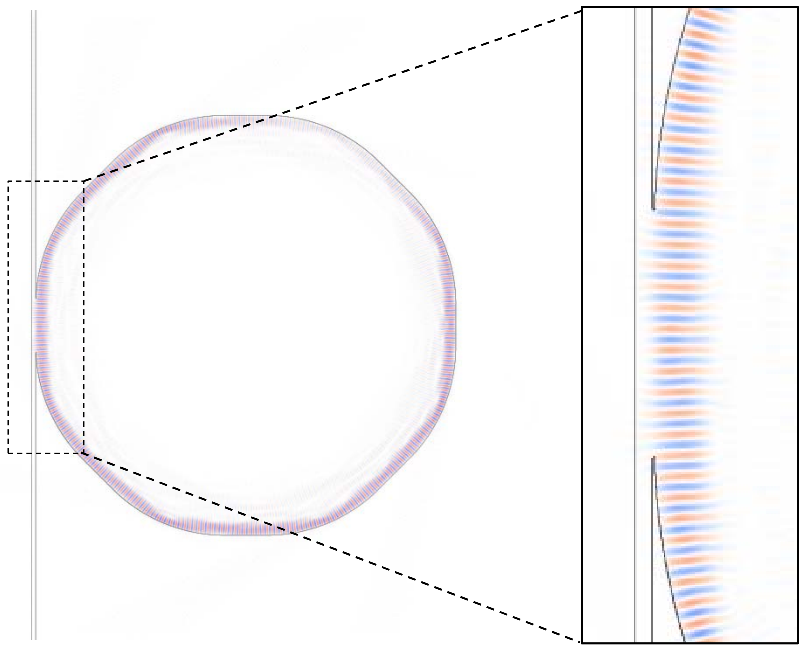
Coupling rate is high

If we use **side** part

Coupling is suppressed (avoid over-coupling)



Contacting tapered fiber for mechanical stable coupling

Circular type	Polygonal type
	
Vulnerable to surface condition	**Robust** against surface condition
$Q_{\mathrm{load}} = 1.2 \times 10^5$	$Q_{\mathrm{load}} = 3.0 \times 10^5$

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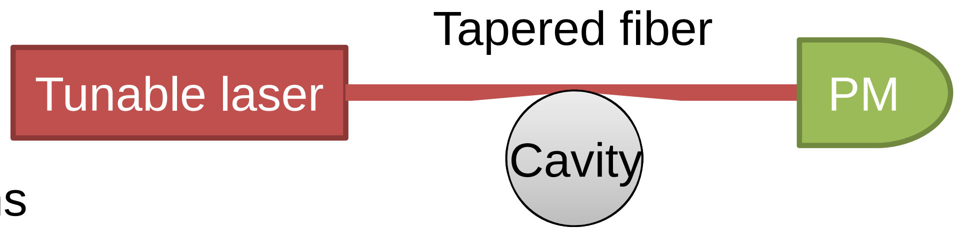
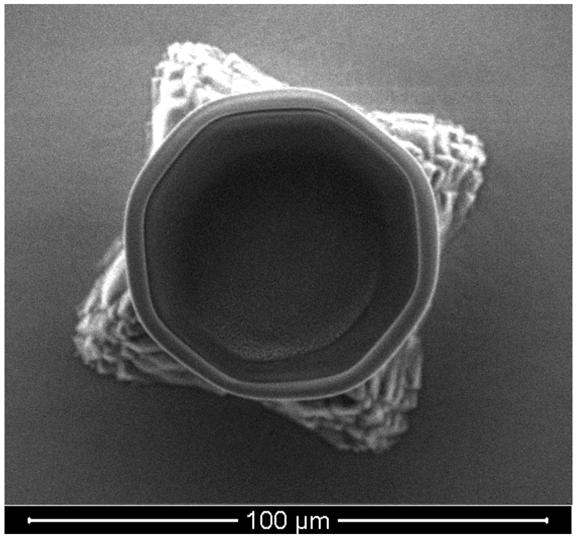
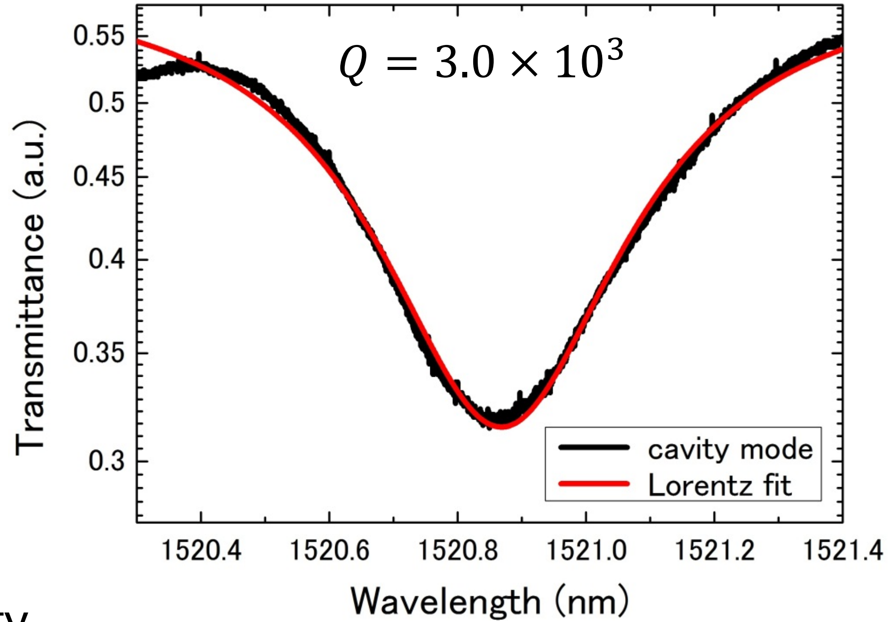
Optical measurement

Device fabrication condition
- XeF_2 etching 108 seconds
- KOH etching 1 hour
- CO_2 laser reflow process 12 W, 100 ms





SEM image of fabricated octagonal cavity



Summary

- We fabricated a polygonal silica toroid using a combination of isotropic and anisotropic etching for sacrificial etching
- We designed a polygonal shape, which enabled to control the coupling by moving the fiber to the corner or side wall
- We suppressed of over-coupling even when we brought the fiber into contact with the surface.
- Q = 3000 is demonstrated

Thank you very much

□ Reference
T. Kato, W. Yoshiki, R. Suzuki and T. Tanabe,
“Octagonal silica toroidal microcavity for controlled optical coupling,”
Appl. Phys. Lett. **101,** 121101 (2012)