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Octagonal toroid microcavity for mechanically robust coupling with optical fiber

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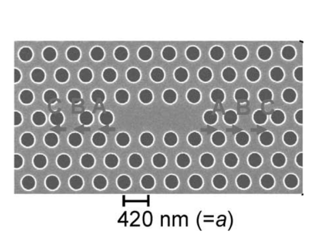
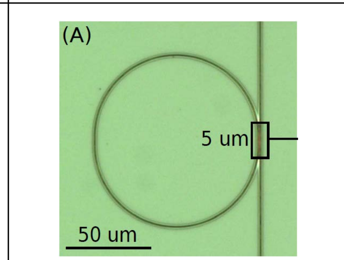
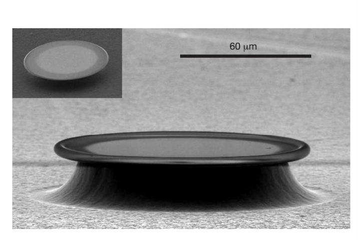
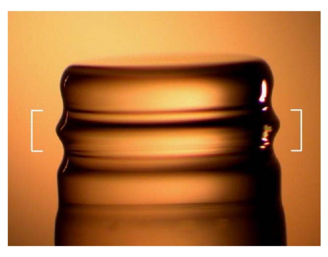
Abstract

Critical coupling and mechanically robust coupling between a whispering-gallery mode and a tapered fiber is simultaneously demonstrated by using an octagonal toroid microcavity with a theoretical Q of 8.8×10^6 and an experimental value of 4.3×10^4.

Background: High-Q optical cavity

	Photonic Crystal	Silicon Microring	Silica Toroid	Crystalline
				
Q-factor	~ 10^6	~ 10^5	> 10^8	> 10^{10}
Mode volume	~ 10^{-1} μm^3	~ 10 μm^3	~ 10^3 μm^3	~ 10^5 μm^3
Integration	○	◎	○	△

T. Asano *et al.*, *IEEE j. sel. top. quantum electron.* **12**, 1123 (2006). A. Griffith *et al.*, *Opt. Express* **20**, 21342 (2012). D. Armani *et al.*, *Nature* **421**, 925 (2003). I. Grudinin *et al.*, *Phys. Rev. A* **74**, 063806 (2006).

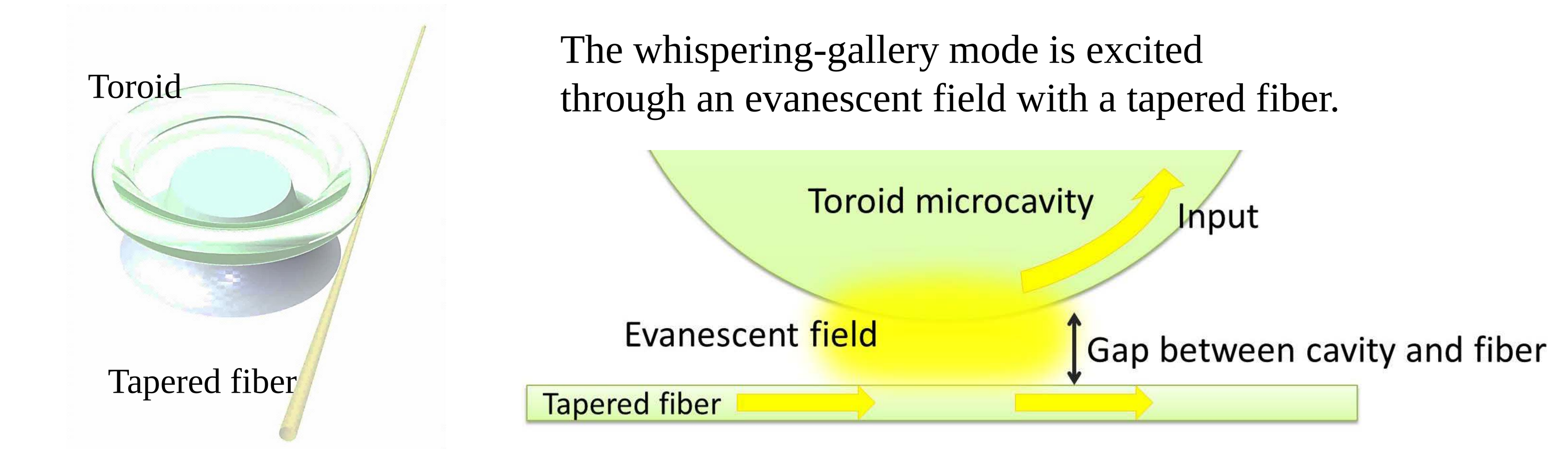
High Q-factor optical cavities are used for sensing, frequency comb generation, opto-mechanics, etc.

$$Q = \omega \frac{E_{\mathrm{cav}}}{P_{\mathrm{diss}}} = \omega\tau$$

E_{cav} : energy stored in the cavity
P_{diss} : dissipated power
τ : photon life time

Background: Optical coupling

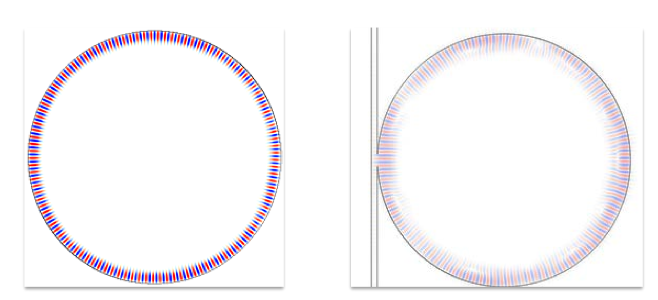
The whispering-gallery mode is excited through an evanescent field with a tapered fiber.



Difficulty

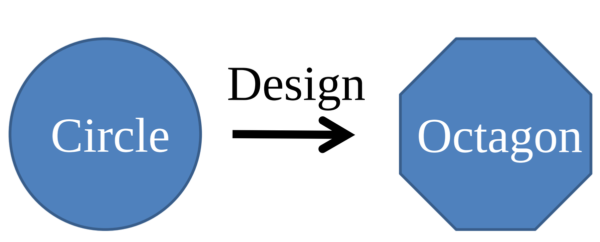
To obtain maximum coupling efficiency (critical coupling), we need sub-μm gap control between the cavity and the fiber.

	Large gap	Fiber in contact
mode perturbation	small (good)	large
mechanical robustness	low	high (good)

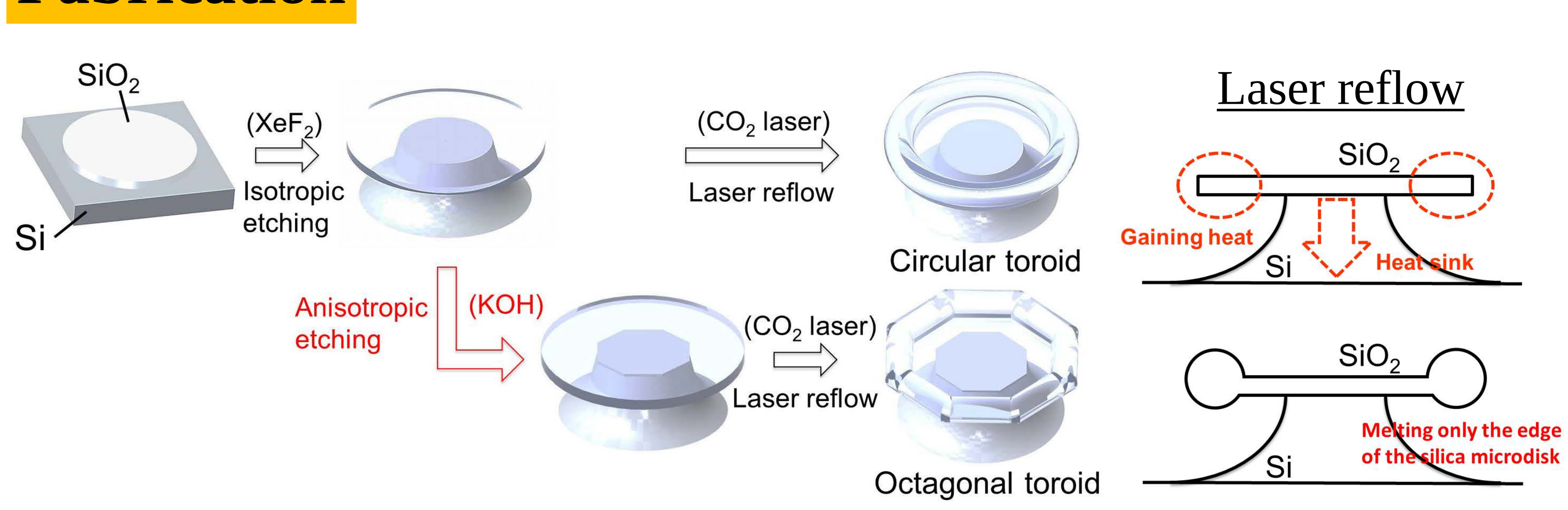

w/o waveguide w/ waveguide

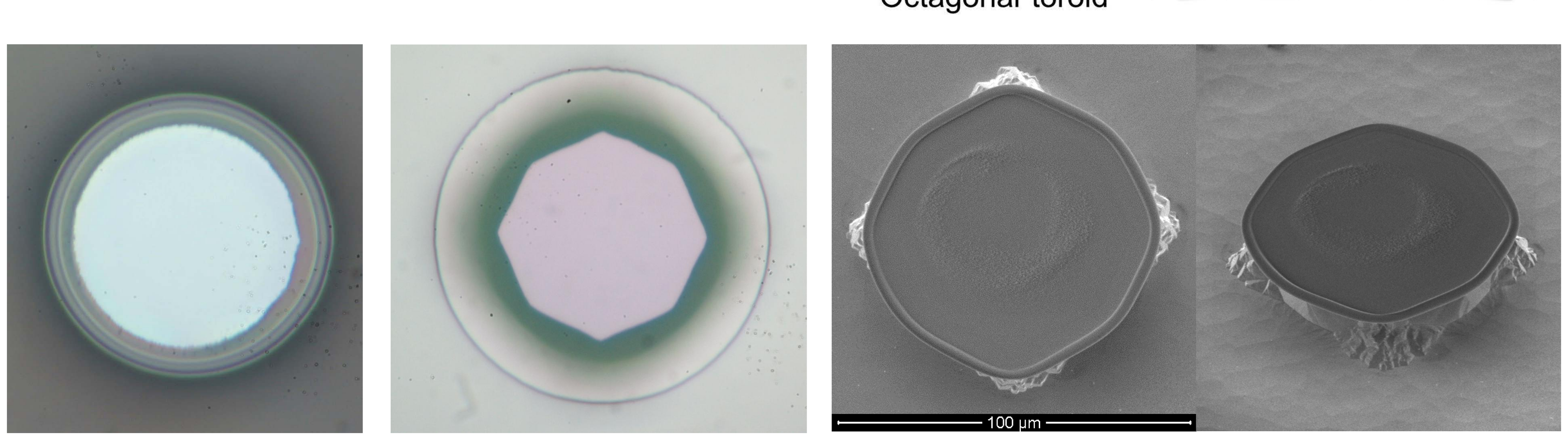
Motivation

Design the cavity shape
⇨ { to achieve critical coupling
to achieve mechanical robustness



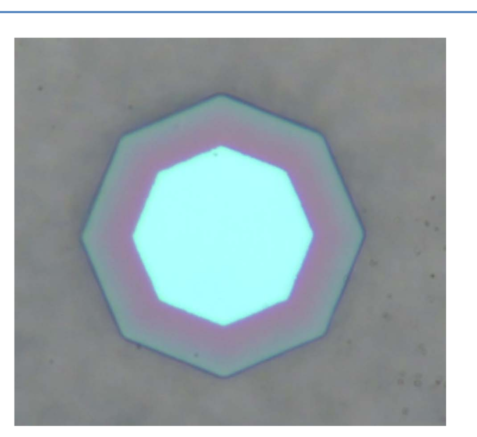
Fabrication

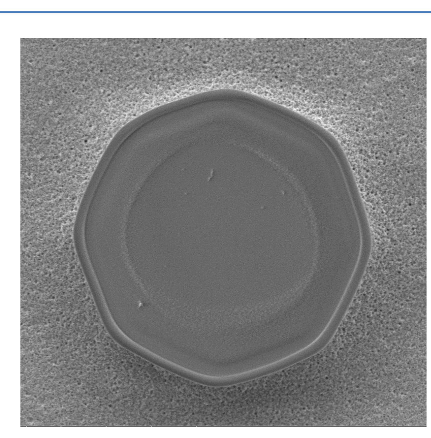



Circular toroid After anisotropic etching Octagonal toroid

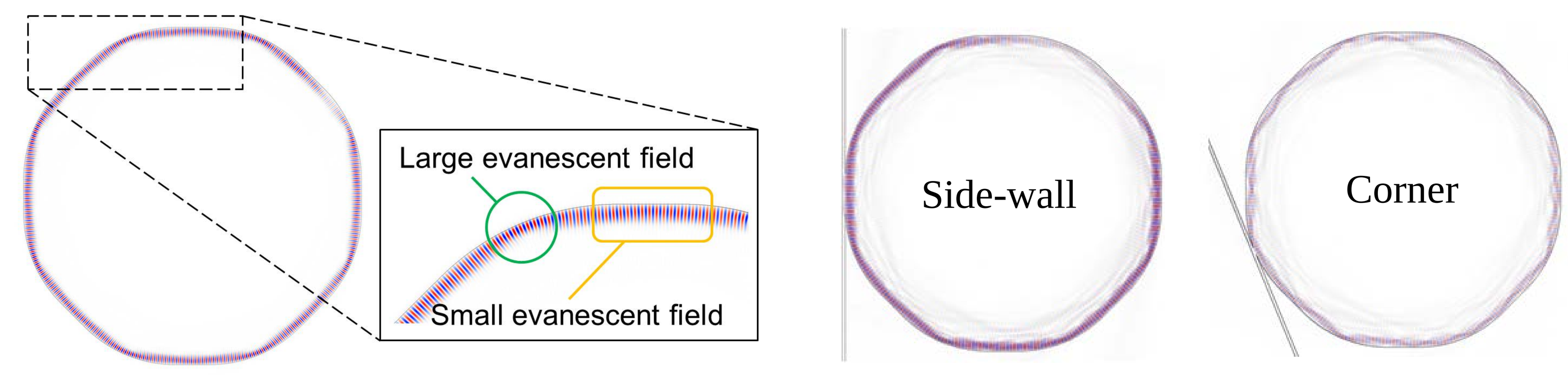
Other fabrication method

Using an octagonal silica disk, we do not need anisotropic etching.


After isotropic etching


Octagonal toroid

FDTD simulation (Mode calculation)



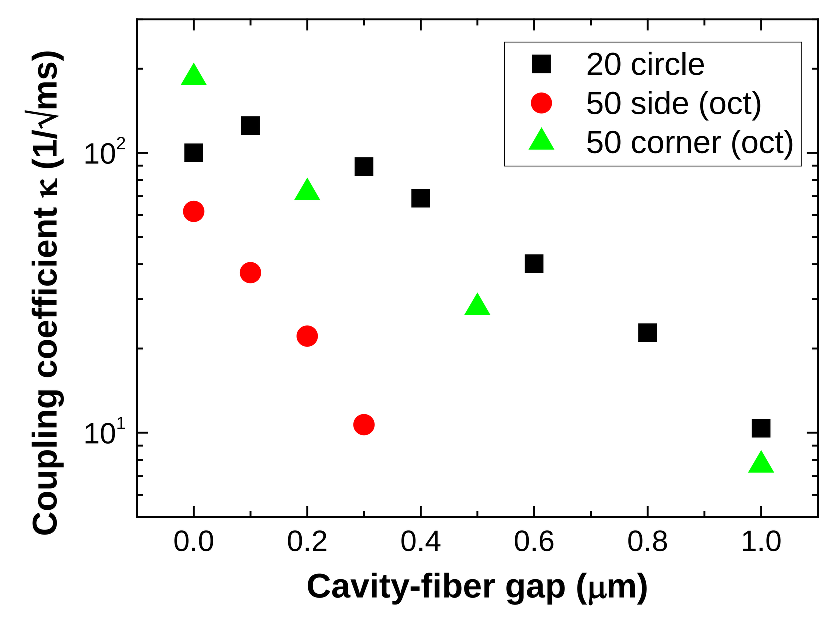
w/o waveguide ($Q = 8.8\times10^6$) w/ waveguide differently touched to the surface

Large evanescence: Strong coupling (κ: high)
Small evanescence: Small coupling (κ: low)

$$Q_{\mathrm{load}}^{-1} = Q_{\mathrm{unload}}^{-1} + Q_{\mathrm{coup}}^{-1}$$

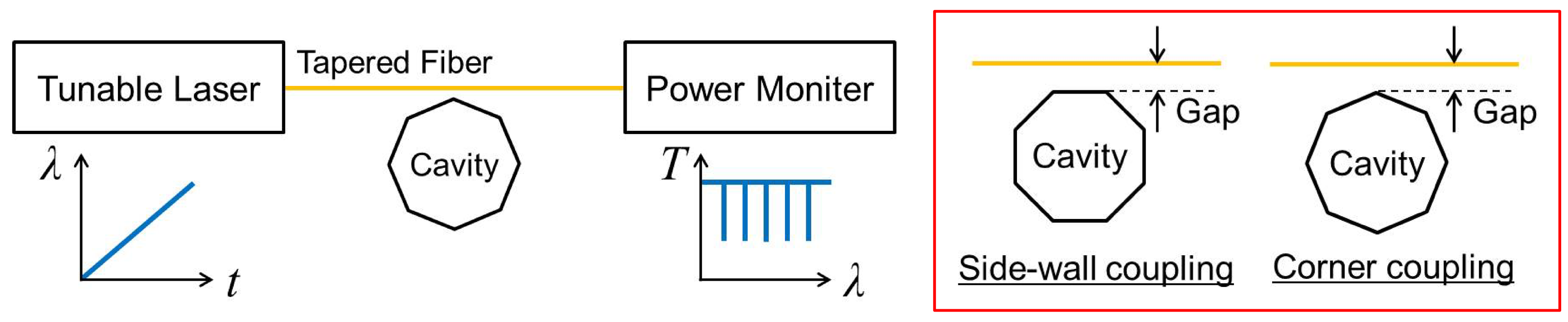
Q_{load} : Loaded Q (w/ waveguide)
Q_{unload} : Intrinsic Q (w/o waveguide)
Q_{coup} : Coupling Q (= ω / κ^2)

⇒ Different coupling can be obtained by changing the contact point.



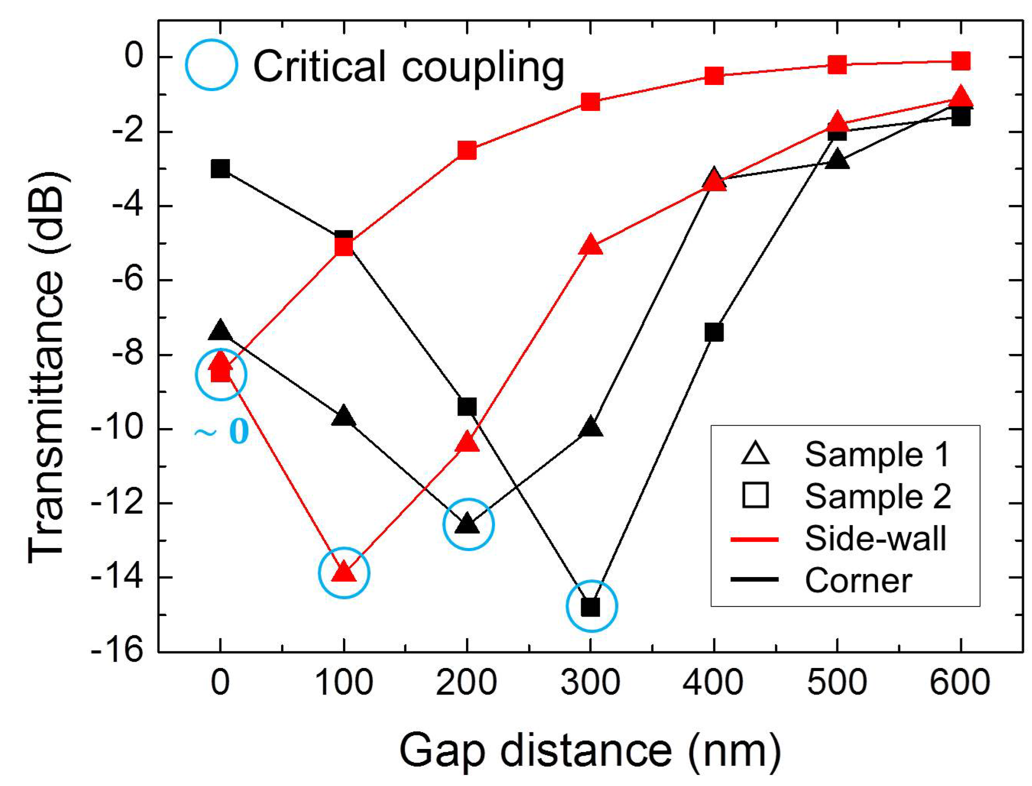
T. Kato *et al.*, *Appl. Phys. Lett.* **101**, 121101 (2012).

Spectrum measurement method



Experiment: Measurement results

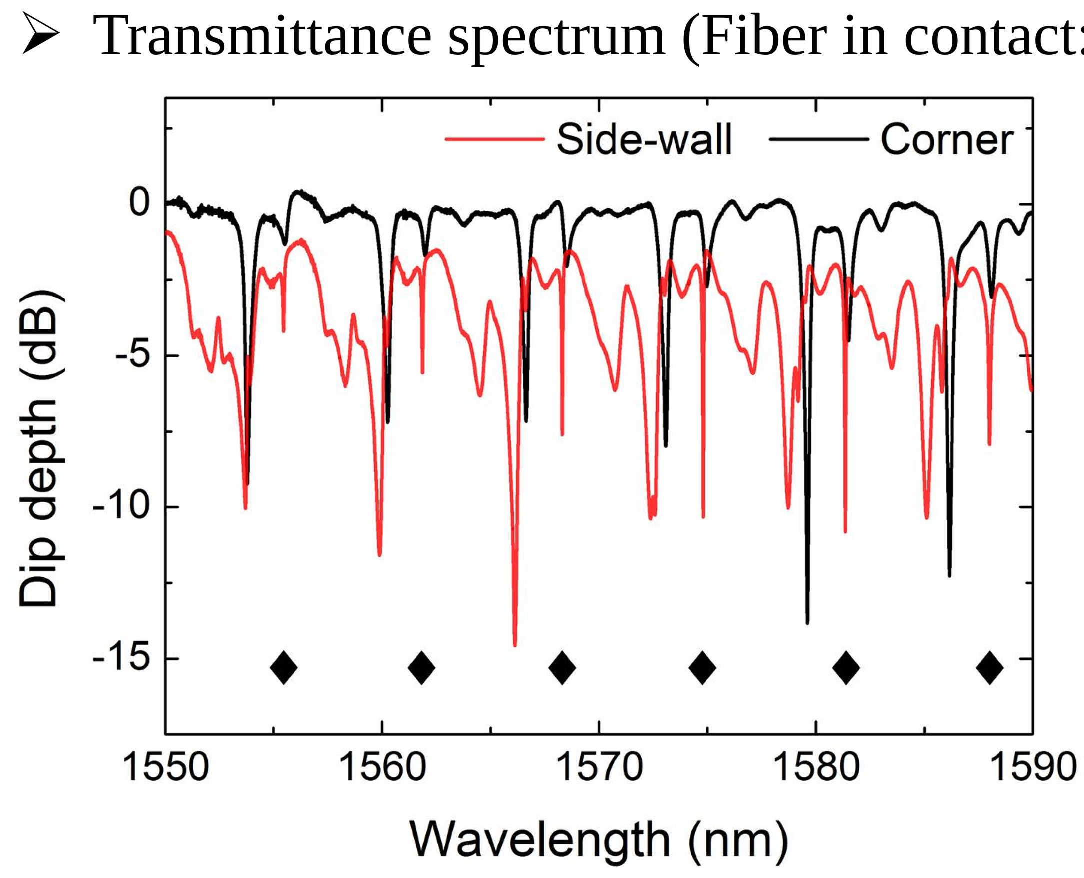
➢ Gap distance vs. Transmittance



Comparing with gap distances @ critical coupling

Side-wall coupling
lower κ
Corner coupling
higher κ

➢ Transmittance spectrum (Fiber in contact: gap = 0 nm)



Comparing with Q-factors (resonance wavelength ◆)

Side-wall coupling
$Q_{load} = 2.2\times10^4$
Corner coupling
$Q_{load} = 6.3\times10^3$

Conclusion

We designed the coupling κ by making WGM cavities octagonal. Higher κ is obtained for corner coupling and lower κ is obtained for side-wall coupling. The coupling is closer to the critical coupling even when we touch the fiber to the surface of the cavity.

Acknowledgement

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