Investigation of an optimal coupling condition with a nanobeam cavity made of low refractive index material

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Abstract

In this study, we investigated an optimum coupling condition in a side-coupled cavity system consisting of a silica nanobeam cavity and a tapered nanofiber. For achieving high coupling efficiency, intrinsic Q must be sufficiently higher than coupling Q although it is expected that intrinsic Q will drop due to an effective index modulation caused by a side coupled waveguide when the gap is small. We experimentally showed that avoiding the drop of intrinsic Q is possible by employing a thin nanofiber and achieved a coupling efficiency of >95% with a high Q of over 10^3.

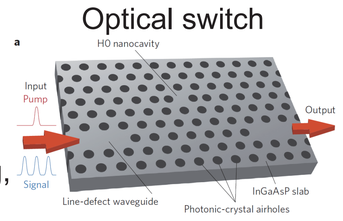
Background

PhC nanocavities

- High Q, extremely small V
- Integrated structure

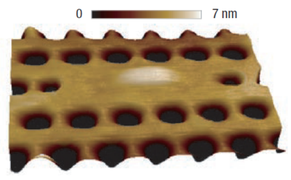
Applications: Optical signal processing, cavity QED, sensing etc.

Optical switch



K. Nozaki, et al., Nat. Photon. **4**, 477-83 (2010)

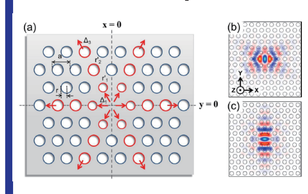
Purcell enhancement



S. Noda, et al., Nat. Photon. **1**, 449-58 (2007)

Coupling methods

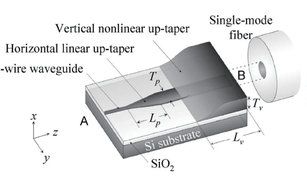
Free space



H. Takagi et al., Opt. Express **20**, 28292-300 (2012)

CE: 60%

Spot size conveter



K. Shiraishi, et al., Appl. Phys. Lett. **91**, 141120 (2007)

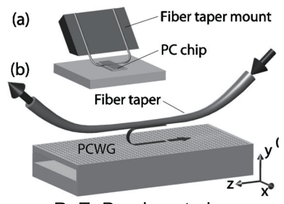
CE: 89%*

Grating coupler

Y. Ding, et al., Opt. Lett. **39**, 5348-50 (2014)

CE: 87%*

Nanofiber



P. E. Barclay et al., Opt. Lett. **29**, 697-9 (2004)

CE: 94%

* Coupling loss between a rectangular waveguide and a photonic crystal waveguide is usually more than 5 dB

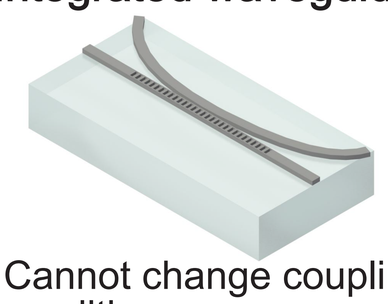
Nanofiber method has the highest coupling efficiency (CE)

Motivation

Investigate an optimum coupling condition in a side coupling configuration between a nanofiber and a silica nanobeam cavity

- Condition of $Q_{int} > Q_{coup}$ is necessary for high coupling efficiency
- Decrease of Q_{int} is expected when the gap became small

Integrated waveguide



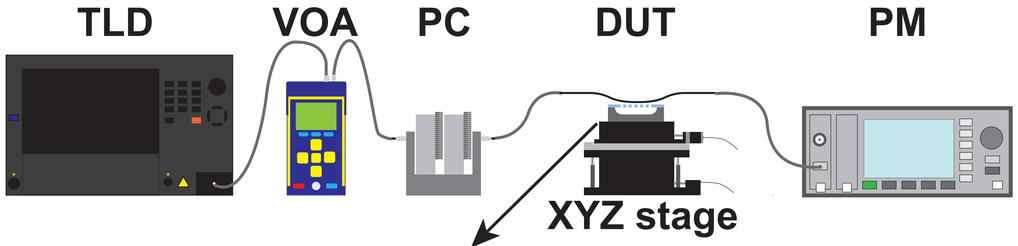
- Cannot change coupling condition

Nanofiber coupling

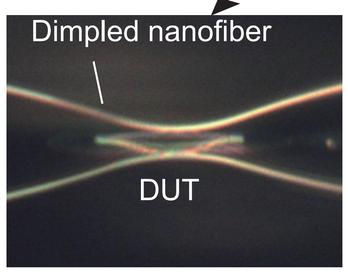
- Can control coupling Q by changing gap diatance

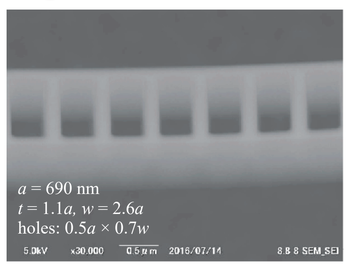
Optical measurement of fabricated cavity

Experimental setup

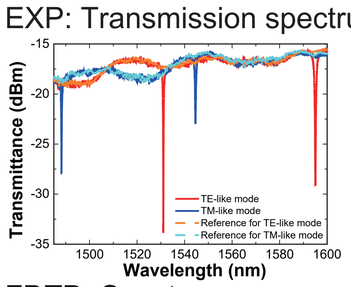


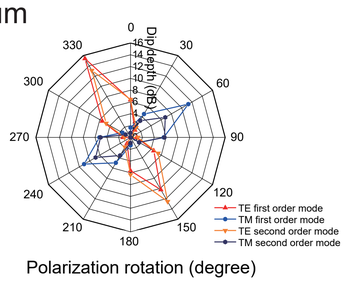
TLD: Tunable laser diode (Santec)
VOA: Variable optical (Oz optics)
PC: Polarization controller (Alnair lab.)
DUT: Device under test
PM: Power monitor (Keysight)





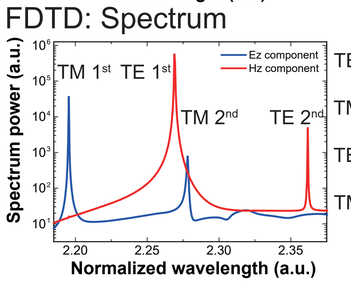
EXP: Transmission spectrum

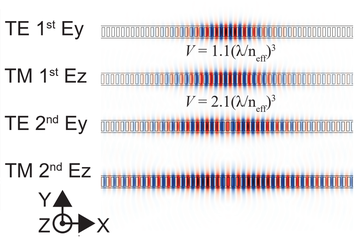




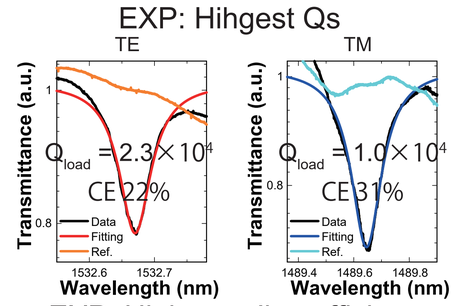
Polarization rotation (degree)

FDTD: Spectrum

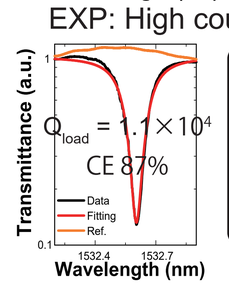




EXP: Hihgest Qs



EXP: High coupling efficiency



Definition

$$Q_{load}^{-1} = Q_{int}^{-1} + Q_{coup}^{-1}$$

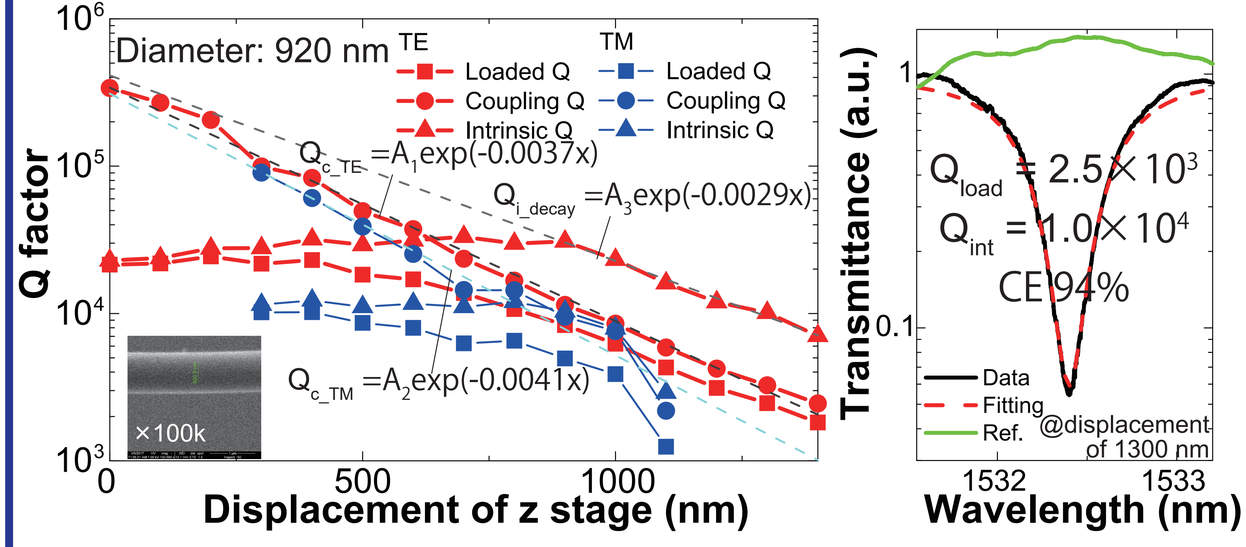
$$Tr = \left(\frac{1}{1 + Q_{int}/Q_{coup}}\right)^2$$

$$CE = 1 - Tr$$

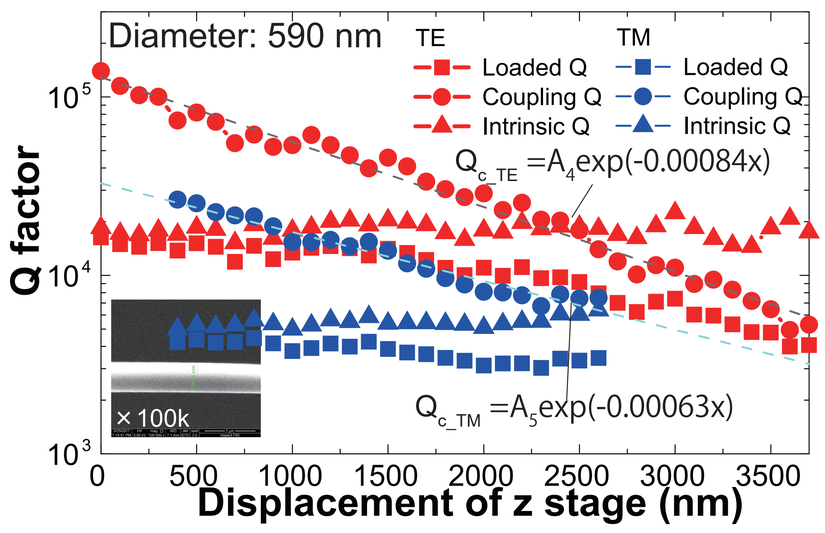
Tr: Transmittance
CE: Coupling efficiency

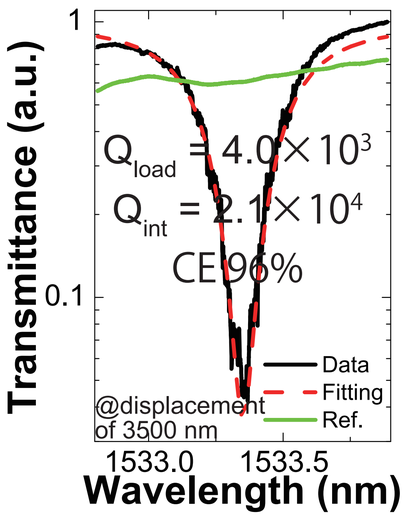
We obtained the high Q of $>10^4$ for both TE and TM modes

Q vs. gap distance



Intrinsic Q dropped due to the effective index modulation caused by a nanofiber





By employing a sufficiently thin nanofiber, we successfully maintained high intrinsic Q

Summary

- Demonstrated a high Q silica nanobeam cavity with TE & TM modes
- Investigated coupling efficiency dependence on gap distance change between a nanofiber and a silica nanobeam cavity
- Achieved a high coupling efficiency of 87% with loaded Q of over 10^4
- Observed degradation of intrinsic Q caused by a presence of a nanofiber
- Showed thin nanofibers are effective to maintain high intrinsic Q

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- Strategic Information and Communicatinos R&D Promotion Programme (SCOPE) from the Ministry of Internal Affairs and Communications (MIC)(#152103015).
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