Observation of isolated mode and formation of coupled cavity in fiber coupled PhC cavity platform

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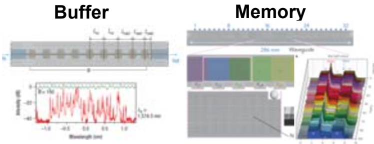
Abstract: Slow light and optical memory are important functions with which to realize optical signal processing. A coupled cavity on a photonic crystal (PhC) platform is an effective way to realize these functions because of its large bandwidth, low group velocity and compact size. Recently, we demonstrated high *Q* cavity formation employing a fiber coupled PhC cavity (FCPC). We also demonstrated multi-cavity and coupled-cavity formation using an FCPC platform. In this study, we observed the presence of an isolated mode, which couples nanofiber very weakly in an FCPC platform. In addition, we demonstrated coupled-cavity formation with 1.8 GHz mode splitting using an isolated mode.

Background & Motivation

Optical signal processing w/ PhC

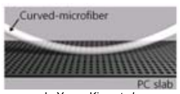


M. Notomi, *et al.*, *Nat. Photon.* **2**, 741-7 (2010).

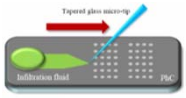
E. Kuramochi, *et al.*, *Nat. Photon.* **8**, 474-81 (2014).

- Small footprint
- Not good coupling w/ an optical fiber

Reconfigurable PhC cavity



Ju-Young Kim, *et al.*, *Opt. Express* **17**, 13009-16 (2009).



C. L. C. Smith, *et al.*, *Opt. Express* **16**, 15887-96 (2008).

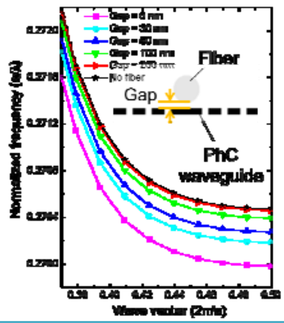
- Can control the position of the cavity on demand
- Not high *Q* (10^4)

Motivation

Proposing **reconfigurable** PhC platform for optical signal processing with **high coupling efficiency (CE)** between an optical fiber

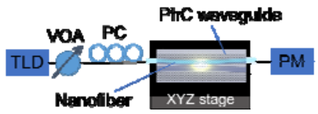
Principal & Method

Band diagram



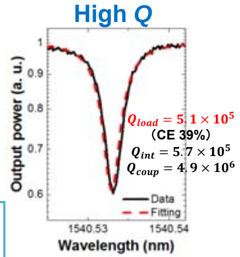
Modegap cavity is formed by effective refractive index modulation caused by a nanofiber

Experimental method

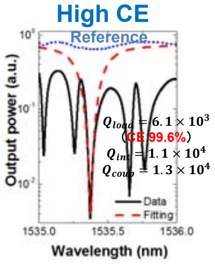


TLD: Tunable laser diode VOA: Variable optical attenuator
PC: Polarization cotroller PM: Power monitor
PhC: W0.98 PhC waveguide
Fabricated w/ photolithography (KrF 248 nm). Silica clad was removed w/ HF.

High *Q*



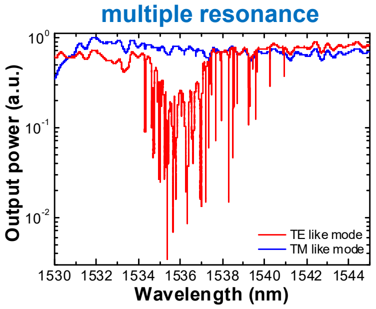
High CE



T. Tetsumoto, *et al.*, *Opt. Express* **23**, 16256-63 (2015).

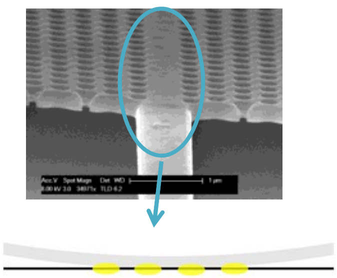
Multiple resonant peaks

Polarization dependence & multiple resonance



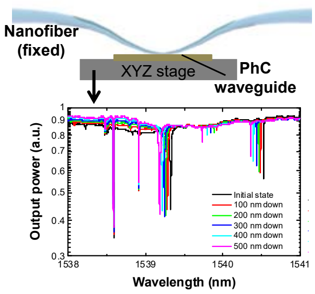
Multiple resonances were observed

Surface of the sample



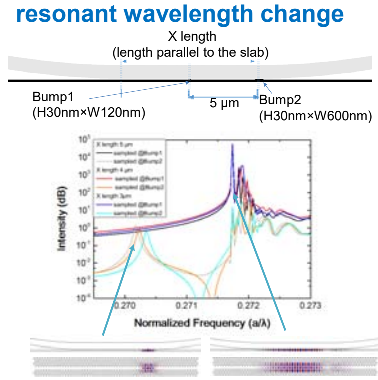
The bumps may be the cause of coupled cavity

Resonant wavelength tuning



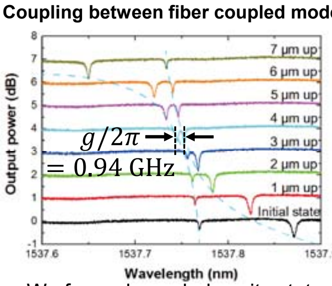
The amount of shift is different between modes

Position dependence of bump vs. resonant wavelength change

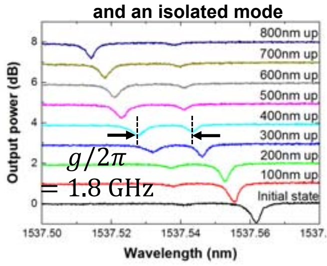


Coupled cavity formation in FCPC platform

Experimental demonstration of the formation of coupled cavity



We formed coupled cavity state with mode splitting of 0.94 GHz

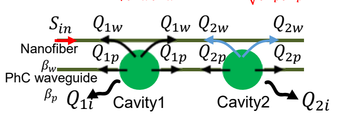


We demonstrated coupling w/ an isolated mode with mode splitting of 1.8 GHz

Numerical analysis with coupled mode equations

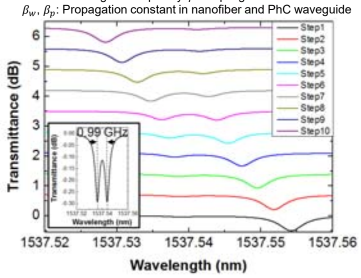
$$\frac{da_1}{dt} = i\omega_1 a_1 - \frac{\gamma_{1i} + 2\gamma_{1w} + \gamma_{1p}}{2} a_1 + \sqrt{\gamma_{1w}} s_{in} + e^{i\beta d}\sqrt{\gamma_{2w}\gamma_{1w}} a_2 + e^{i\beta_p d}\sqrt{\gamma_{2p}\gamma_{1p}} a_2$$

$$\frac{da_2}{dt} = i\omega_2 a_2 - \frac{\gamma_{2i} + 2\gamma_{2w} + \gamma_{2p}}{2} a_2 + \sqrt{\gamma_{2w}} e^{i\beta d} s + e^{i\beta d}\sqrt{\gamma_{1w}\gamma_{2w}} a_1 + e^{i\beta_p d}\sqrt{\gamma_{1p}\gamma_{2p}} a_1$$



$Q_{1i} = 3.7 \times 10^5$, $Q_{2i} = 3.9 \times 10^5$, $Q_{1w} = 1.2 \times 10^7$, $Q_{2w} = 1.0 \times 10^{10}$, $Q_{1p} = Q_{2p} = 4.0 \times 10^5$, $\beta_w d = \beta_p d = 1$

S_{in}: input power Q_w:coupling Q with nanofiber
Q_p:coupling Q with PhC waveguide Q_i:intrinsic Q of cavity
ω: resonant angular frequency γ: coupling rate
β_w, β_p: Propagation constant in nanofiber and PhC waveguide



We observed coupling w/ **isolated mode** by tuning the resonant wavelength

Summary

- **We demonstrated fiber-coupled PhC cavity formation using Si PhC waveguide**
  - ✓ Achieved a high *Q* of 5.1×10^5 with a coupling efficiency of 39%
  - ✓ Achieved a high coupling efficiency of **99.6%** with a loaded *Q* of 6.1×10^3
- **We demonstrated coupled cavity formation in FCPC platform**
  - ✓ Obtained a coupling strength of 0.94 GHz
  - ✓ Observed an isolated mode and achieved coupling w/ the mode w/ mode splitting of 1.8 GHz. This mode will be available as optical memory mode.

Acknowledgement

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