Recent progress on high-Q photonic crystal nanocavities: Photolithographic fabrication and reconfigurable system

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1. Background & Motivation

2. Ultrahigh Q nanocavity w/ photolithographic Si PhC

3. Controlling the randomness: EO modulator

4. 8-ch in-plane DWDM DEMUX

5. Reconfigurable high-Q PhC nanocavity

6. Summary
Motivation: Si-photonics vs. PhC

Si-photonics

1. Photolithography
2. SiO$_2$-cladding

Photonic crystals

EB-lithography
Air-bridge

1. Background & Motivation
Photonic Structure Group, Keio University

Fusion of Si-photonics & Photonics crystals

T. Yin, et al., Optics Exp. 15, 13965 (2007)

2. Ultrahigh Q nanocavity w/ photolithographic silicon PhC

Photonic Structure Group, Keio University

Design & Simulation

Width-modulated line defect cavity  

Photolithographic fabrication? & Dielectric cladding?

FDTD – w/ SiO₂ cladding  

Principle of confinement

Optimized structure

\[ Q = 7.1 \times 10^6 \quad V = 2.4 \left( \frac{\lambda}{n} \right)^3 \]

Fabricated parameter

\[ Q = 8.1 \times 10^5 \quad V = 1.7 \left( \frac{\lambda}{n} \right)^3 \]
Photolithographic fabrication & proximity effect

SEM images (effect of fabrication error)

Width-modulated line defect cavity
Max amount of shift: 9 nm

L3 cavity
Max amount of shift: 63 nm

Width-modulated line defect cavity is robust against the proximity effect

Experiment: High-Q demonstration

Transmission spectrum

Top view

The highest $Q$ w/ photolithography

$Q = 2.2 \times 10^5$

Managing the randomness

Design of our device

Waveguide width
- W1.05 → wide
- W0.98 → narrow

Cutoff frequency (mode gap)

Position of light localization occurs randomly in W0.98
Managing the randomness

Design of our device


Waveguide width

```
W1.05  wide
W0.98  narrow
```

Cutoff frequency (mode gap)

```
freq. ω
W1.05  W0.98  W1.05
```

Position of light localization
occurs only in **W0.98**

The effect of randomness occurs in a limited area (controlled way)
3. Controlling the randomness: EO modulator

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Theory & experimental result


\[ Q = 2.4 \times 10^5 \]

Localization observed at desired position

Calculation

Experiment

Performed 18 times calculation

2 nm deviation to the diameter and position of PhC holes

18 devices measured

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Yield rate of obtaining localization


Calculation

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<thead>
<tr>
<th>Length (period)</th>
<th>Q</th>
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<tr>
<td>22</td>
<td>10^4</td>
</tr>
<tr>
<td>28</td>
<td>10^4</td>
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<td>34</td>
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</tr>
<tr>
<td>40</td>
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Experiment

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> 80% yield obtained
Using random PhC for controlled experiment


EO modulation achieved w/ pin structure integrated at W0.98 regime

EO modulation achieved w/ pin structure integrated at W0.98 regime
In-plane 8ch DWDM demonstration

(a) Image showing the in-plane 8-channel DWDM system.

(b) Graph showing the voltage characteristics across different wavelengths.

(c) Diagram highlighting the input, heater, and output along with the eight-channel DeMUX.
In-plane 8ch DWDM demonstration

Setup

Eye pattern

1 GHz

2.5 GHz

(c)
Outline

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6. Summary
Principle of cavity formation

Frequency

Real space

Modegap

Effective refractive index change results in formation of modegap cavity


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Measurement of $Q$ and CE of FCPC


Highest Q

$Q_{load} = 6.7 \times 10^5$

$Q_{int} = 6.8 \times 10^5$

$Q_{coup} = 3.9 \times 10^7$

Highest coupling

$Q_{load} = 6.1 \times 10^3$

$Q_{int} = 1.1 \times 10^4$

$Q_{coup} = 1.3 \times 10^4$
Resonant wavelength tuning


Nanofiber

PhC waveguide

Change the position at 100-nm step

Tuning sensitivity

\[
\frac{\text{Wavelength shift}}{\text{Stage shift}} = 0.27 \text{ pm/nm}
\]
Summary

1. Very high-Q is achieved w/ SiO₂ clad photolithographic Si PhC (Q = 2.4×10⁵)

2. Practical EO modulation is demonstrated w/ controlled random PhC device

3. 8-ch in-plane DWDM demonstrated

4. Reconfigurable (position & wavelength) high-Q PhC nanocavity (Q = 6.7×10⁵) w/ high-transmittance (T > 99%) demonstrated using nanotapered optical fiber
Acknowledgement

The team

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Ms. Nurul Ashikin Binti Daud (PhD candidate)
Mr. Yuta Ooka (M2)
Mr. Naotaka Kamioka (B4)

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