Ultrasmall in-plane photonic crystal demultiplexer fabricated with photolithography

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Outline

1. Background

2. Design & Fabrication
   • DeMUX design
   • Photolithographic fabrication

3. Optical measurement
   • Spectral property & wavelength tunability
   • Signal transmittance experiment & crosstalk

4. Discussion
   • Crosstalk preventable by optimizing position of output PhC waveguide

5. Summary
1. Background

Requirements for DeMUXs:
Small footprint, photolithographic process, silica-clad and in-plane operation

- **Wavelength Division Multiplexing (WDM)**
- **Previous work to realize DeMUX**
  1. **Glass Arrayed Waveguide Grating (AWG)**
    *Footprint: 60 mm²/ch*
  2. **Silicon AWG**
    *Footprint: 0.07 mm²/ch*

3. **Silicon Photonic Crystal (PhC)**
   *Footprint: 0.0001 mm²/ch*

- **Good points already achieved**
  i. Ultrasmall
- **Bad points need to improve**
  ii. EB lithography
  iii. Air-bridge
  iv. Out-of-plane radiation

This is our motivation.
2. Design & Fabrication: Designing DeMUX

Width-modulated line defect nanocavity based DeMUX

- Top view

Elements
- PhC
- Installation of output WG
- Width-modulated nanocavity

Achievements
- i. Ultrasmall
- ii. In-plane
- iii. Photolithographic
- iv. Silica-clad

Our latest research

Input

110 μm²/ch
2. Theory – Width-modulated nanocavity

High Q achieved with photolithographic & silica-clad WM nanocavity


- Structure

- Transmission spectrum

- IR image

Q > $10^4$ required for dense WDM
2. Theory – Principle of our DeMUX

Linear frequency tuning achieved by changing lattice constant

- Top view

- FDTD calculation
3. Results – Basic properties - 1

Photolithographic DeMUX is fabricated properly.

- **Fabrication**
  - CMOS process foundry (IME in Singapore)
  - 248-nm lithography (with phase-shifting mask)

- **Setup**

- **Loss**
  - Total loss : 26 dB
  - Spot size converters : 5 dB
  - Si wire – PhCWG : 13 dB
  - Cavity – PhCWG : 8 dB

- **Transmission spectra**
  - $\Delta f = 267$ GHz
  - $\sigma = 45$ GHz
  - $Q = 4 \times 10^4$
3. Results – Basic properties - 2

Photolithographic DeMUX is fabricated properly.

- **Cross-section**
  
  ![Cross-section diagram](image)

- **Microscope image**
  
  ![Microscope image](image)

- **Heater tuning**
  
  ![Heater tuning graph](image)
3. Results – Achievements of this work

First demonstration of photolithographically fabricated photonic crystal DeMUX

<table>
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<tr>
<th>Stability &amp; Structure</th>
<th>Fabrication method</th>
<th># of channels</th>
<th>Channel spacing</th>
<th>Configuration</th>
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<td>Photo-lithography</td>
<td>8</td>
<td>267 GHz</td>
<td>In-plane</td>
<td>110 μm²</td>
<td>WM cavity</td>
<td>This work</td>
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<td>Low &amp; PhC air-bridge</td>
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<td>3.7 THz</td>
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<td>OE 14, 12394 (2006)</td>
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<td>Low &amp; PhC air-bridge</td>
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<td>High &amp; Si-AWG</td>
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<td>8</td>
<td>250 GHz</td>
<td>In-plane</td>
<td>17000 μm²</td>
<td>-</td>
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3. Results – Property to process signals – 1

2.5 GHz transmittance demonstrated

• Setup

![Diagram of experimental setup]

• Eye diagram

![Eye diagram image]

Extinction ratio : 13.3 dB
Signal-noise ratio : 8.9 dB
3. Results – Property to process signals – 2

DeMUX operation achieved

• Input vs output chart

Return to zero 1 GHz square pulse
4. Discussion – Cause of crosstalk

Crosstalk occurs because transmittance decreases as channel number increases.

- Crosstalk chart magnification
4. Discussion – How to prevent crosstalk

With optimized design, coupling between cavity and output PhC waveguide does not decrease as lattice constant decreases

- **Original output PhC waveguide**
- **Optimized output PhC waveguide**

Three columns shift
4. Discussion – How to prevent crosstalk

We can achieve high and flat transmittance by optimizing the position of the output PhC waveguides.

- **Original output PhC waveguide**
- **Optimized output PhC waveguide**

![Diagram showing the original and optimized output PhC waveguides with a three columns shift.]

FDTD calculation
5. Summary

An ultrasmall, photolithographic, silica-clad and in-plane PhC DeMUX has been demonstrated.

- 110 μm²/channel
- 8 channels
- 267 GHz spacing
- Tunability
- 2.5 GHz signal processing
- Crosstalk (can be suppressed by optimization)

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