A CMOS compatible in-plane compact wavelength demultiplexer based on photonic crystal nanocavities

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**Background**

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

- **Wavelength Division Multiplexing (WDM)**
  - **Signal flow**
  
  - **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
- ii. EB lithography
- iii. Air-bridge
- iv. Out-of-plane radiation

**Bad points need to improve**

This is our motivation.
Design & Fabrication: Designing DeMUX

Width-modulated line defect nanocavity based DeMUX

Our latest research


• Top view

Elements

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

Features

i. Ultrasmall
ii. In-plane
iii. Photolithographic
iv. Silica-clad
Design & Fabrication: 
Width-modulated nanocavity

High Q achieved with photolithographic & silica-clad WM nanocavity


- Design

- IR image

- Transmission spectrum

Q > 10^4 required for dense WDM
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: $2.5 \times 2 = 5$ dB
  - Si wire – PhCWG: $6.5 \times 2 = 13$ dB
  - Cavity – PhCWG: $4 \times 2 = 8$ dB
Results – Basic properties - 2

Photolithographic DeMUX is fabricated properly.

- Cross-section
  - TiN
  - Si
  - SiO₂
  - 210 nm
  - 269 nm
  - 190 nm
  - 2000 nm

- Transmission spectra & Heater tuning
  - $\Delta f = 267$ GHz
  - $\sigma = 45$ GHz
  - $Q = 4 \times 10^4$
  - 1555 nm
  - 1560 nm
  - 1565 nm
  - 1570 nm

- Microscope image
  - Input
  - Heater
  - AL wires
  - Output
  - Eight-channel DeMUX
Results – Property to process signals – 1

2.5 GHz transmittance demonstrated

- Setup

- Eye diagram

Extinction ratio: 13.3 dB
Signal-noise ratio: 8.9 dB
DeMUX operation achieved

• Input vs. output chart

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

Crosstalk occurs because transmittance decreases as channel number increases.

- Crosstalk chart magnification
Discussion – How to prevent crosstalk

Calculation for optimizing structure demonstrated

- **Strategy for optimization**

- **Mapping of transmittance**
Discussion – How to prevent crosstalk

With optimized design, overlap between cavity mode and the waveguide increases.

- Original output PhC waveguide
- Optimized output PhC waveguide

FDTD calculation

\[ |E_y|^2 \] for 420 nm
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

FDTD calculation
Discussion – Possible number of channels

We can achieve DeMUX with 64 channels with small crosstalk

FDTD calculation

- Transmittance of 32 channels DeMUX
  
  Ch. 32  Ch. 1

- Transmittance of 64 channels DeMUX
  
  Ch. 64  Ch. 1
Results – Improvement of transmittance

We improved the flatness of transmittance experimentally by employing optimized design.

- Original design

- Optimized design (Three columns shift)
Summary

First demonstration of photolithographically fabricated photonic crystal DeMUX


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<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>High &amp; PhC SiO₂ clad</td>
<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>EB lithography</td>
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<td>3.7 THz</td>
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<td>L3 cavity</td>
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<td>Low &amp; PhC air-bridge</td>
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<td>250 GHz</td>
<td>In-plane</td>
<td>17000 μm²</td>
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References