Photonic Crystal Nanocavity Photodetector Integrated with p-i-n Junction Fabricated by Photolithography Process

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Outline

1. Background

2. Design & Fabrication
   • Photolithographic fabrication

3. Photodetector properties
   • Electrical properties
   • Transmission and current spectrum at different input power
   • Responsivity

4. Discussion
   • Increase quantum efficiency

5. Summary
All-Si Photodetector

- **All Si photodetector**

  Optical input signal
  
  Electrical output signal

  Ideal photodetector characteristics:
  - Low dark current
  - High quantum efficiency
  - High responsivity
  - Small footprint

- **Previous research in photodetector**
  1. Ge integration on Si
     - High dark current
  2. Ion-implantation
     - High dark current
  3. p-i-n integrated Si waveguide
     - High optical input
PhC Nanocavity

PhC nanocavity
✓ High Q factor
✓ Small mode volume, $V$

Energy-efficient optical signal processing

Achievements
i. Low dark current
ii. High quantum efficiency on chip
iii. Low input power

Improvements
i. EB lithography
ii. Air-bridge structure

This is our motivation

Si PhC nanocavity with $p-i-n$

PhC Device

Achieved high $Q$ factor with photolithography & silica clad


- Device structure
- IR image

- Transmission spectrum

✓ High $Q$ factor
✓ Stable and robust
Electrical properties (Leak current at RT)

Bias voltage
-7V to 0 V

A : Ammeter

Leak current

Current

Ammeter

Photocurrent (A)

1.6E-11
1.4E-11
1.2E-11
1.0E-11
8.0E-12
-7 -6 -5 -4 -3 -2 -1 0

Bias voltage (V)
In comparison,

- InGaAs\(^1\) 1.3 nA at -3V
- Ge on Si\(^2\) 1\(\mu\)A at 4V

Results

• Setup

➢ Transmission spectrum and current are measured at the same time

TLD: Tunable laser diode
VOA: Variable optical attenuator
PM: Power meter
A: Ammeter
Results

Photodetector properties - 1

- Transmission spectrum and photocurrent at different input powers

✓ Resonance of cavity enhance the photocurrent
Photodetector properties - 1

- Transmission spectrum and current spectrum at different input powers

✓ The power output power increase together with the increase of input power
Photodetector properties - 1

- Transmission spectrum and current spectrum at different input powers

- The power output power increase together with the increase of input power

- Thermo-bistability effect where carriers are generated by the two-photon absorption (TPA)
Results

Photodetector properties - 2

- Responsivity

![Graph showing photocurrent vs. input power]

- 13.4 mA/W

- 0.89 % at 0.3mW input power
# Achievements of current work

<table>
<thead>
<tr>
<th></th>
<th><strong>Ge on Si</strong>(^1)</th>
<th><strong>Si PhC nanocavity integrated p-i-n</strong>(^2)</th>
<th><strong>Our device</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Footprint</strong></td>
<td>10µm x 10µm</td>
<td>2.5µm x 4.4µm</td>
<td>2.9µm x 1.68µm</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td>Deposition Ge on Si</td>
<td>EB lithography Air-bridge</td>
<td>Photolithography SiO(_2) cladding</td>
</tr>
<tr>
<td><strong>Bias voltage</strong></td>
<td>-4V</td>
<td>-3V</td>
<td>-3V</td>
</tr>
<tr>
<td><strong>Responsivity</strong></td>
<td>3.2(A/W)</td>
<td>0.016(A/W)</td>
<td>0.013(A/W)</td>
</tr>
<tr>
<td><strong>Quantum efficiency</strong></td>
<td>&gt;300%</td>
<td>9.7%</td>
<td>0.89%</td>
</tr>
<tr>
<td><strong>Leak current</strong></td>
<td>1 µA</td>
<td>15pA</td>
<td>12pA</td>
</tr>
<tr>
<td><strong>Coupled w/ fiber</strong></td>
<td>No</td>
<td>-12 dB</td>
<td>-1.6 dB</td>
</tr>
</tbody>
</table>

Summary

1. PhC nanocavity integrated with p-i-n junction fabricated by photolithography and silica clad has been demonstrated as a photodetector operation

2. We achieved,

✓ Leak current : 12 pA at -3 V
✓ Responsivity : 13 mA/W
✓ Quantum efficiency : 0.89 %
Thank you

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