Cascaded Silicon Micro-Ring Modulators for WDM Optical Interconnection

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Introduction

- **Optical interconnection**
  - To solve bottleneck for next generation computing system

- **WDM**
  - To increase data rate
  - Full utilization of BW

- **Design goal**
  - Compact, Low power consumption
  - High BW, Low latency
  - With full CMOS-compatibility
  - Independent among WDM channels
  - High data rate

- **Cascaded Si Micro-ring modulator for WDM optical interconnection system**
  - Small size
  - Less RF power
  - Enable WDM channel to modulate independently
    - Only resonant \( \lambda \) is modulated
    - Other \( \lambda \) pass through
Design of Ring-Modulator

- Adopted from previous work
  “Micrometer-scale electro-optic modulator,”

- PIN structure: using plasma dispersion effect
  - Free carrier injection and extraction
  - Change of refractive index and resonant $\lambda$

- Limitation: speed of the modulator is 400Mbps (NRZ)
  - PIN junction is formed on only part of ring
    Can not be efficiently extracted $\rightarrow$ longer fall time
  - Only single channel
Proposed Design

- **Experimental structure**

- **To improve speed of modulator**
  1. n+ doped region is added to form nearly PIN junction
  2. Reduce the distance between doped region and ring

- **To achieve WDM system**
  1. Tx: 4 cascaded ring resonators
     - radii: 4.98, 5.00, 5.02, 5.04 μm
     - channel spacing: 3.6 nm
  2. Rx: demux using similar ring with drop ports

- Increase extraction speed with same reverse bias
- Generate WDM channels independently
✓ **Ununiformed channel spacing**
  - Imperfection of resonator
  - Would be compensated by heating

✓ **Depth of dip : extinction ratio**
  - Critical-coupling : CH.1 & CH.2
  - Under-coupling : CH.3 & CH.4

✓ **Double-dip**
  - Coupling between clockwise and counter-clockwise traveling modes
  - By roughness induced back-reflection
Eye-diagram

Data rate of each channel: 4Gbps
- CH.1: 1558.1nm
- CH.2: 1556.8nm
- CH.3: 1552.9nm
- CH.4: 1549.5nm

Data rate of channel: 6Gbps
- Black: measured
- Red: simulated
- Blue: temporal change of resonant λ

Rise and fall times:
- 40ps and 60ps
- Possible modulation speed: 10Gbps

Overshoot at rising edge:
- Most: Inherent property of ring modulator
- Small portion: response of optical detector
On-resonance:
- Small output: destructive interference between input and trapped light

Off-resonance:
- Resonant \( \lambda \) change: no destructive interference any more
- Slightly \( \lambda \) shift in ring
- Overshoot frequency: proportional to \( \lambda \) shift
- Damping ratio: determined by photon life time
Channel Crosstalk

Ring 1 is modulated at 4Gbps

Crosstalk is analyzed between CH.1 and 2

- Black: output at resonant $\lambda$ of ring 1
- Blue: output at resonant $\lambda$ of ring 2
- Green: output at edge of resonant $\lambda$ of ring 2
- Red: output at outside of ring 2 - resonant $\lambda$

- No significant modulation is observed
- No crosstalk between channels 1.3nm apart
- Theoretically, spacing can be reduced below 0.6nm
Conclusion

- Cascaded Si micro-ring resonator based WDM optical interconnection was proposed and experimented
  - To solve bottleneck + To utilize wide BW

- New design was proposed
  - To improve speed of modulator
    - 10Gbps data rate possibly achieve

- Channel crosstalk was analyzed
  - No crosstalk at spacing 1.3nm
    - theoretically, 50 channels support (with ring diameter 3μm)

- 10Gbps × 50 channels data BW can be expected in such system
Thank you for listening
- Question and Answer

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