**Ring Resonator Optical Switches for Interconnection on Si Chips**

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**Si LSI with Optical Interconnects**

Si based light emitting devices are difficult to be realized.

Integrate many ring resonator switches instead of LDs

Monolithic Integration except for light emitting devices

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**Advantage of Ring Resonator Switches**

- **Mach-Zehnder interferometer type**
  - Waveguide length for switching
  - Assuming $\Delta n = 5 \times 10^{-4}$,
  - $L = \lambda / (2 \Delta n) = 850 \mu m$ ($\lambda > 0.85 \mu m$)

- **Ring resonator type**
  - Ring diameter
  - $2R = 10 - 50 \mu m$

Suitable for integration due to their compactness

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**Device Parameters**

- Waveguide
  - $W = 2, 3 \mu m$
  - $g = 0.05, 0.10, 0.15 \mu m$
  - $R = 10 \mu m$
  - $L = 12.56 \mu m$

- $W = 0.9 \mu m$
  - $SiO_2 n = 1.447$
  - $Si n = 1.80$
  - $Si$ substrate

- Ring resonator
  - $W$, $g$, $R$, $L$: Fixed for free spectral range > 10 nm

- Through
  - $W = 5 \mu m$

- Fabrication Process
  - Plasma enhanced chemical vapor deposition
    - CF$_4$:N$_2$ = 10:1
    - Pressure: 4.0 Pa
    - Bias: $-410$ V
  - Electron beam lithography
    - Dose: $14 \mu C/cm^2$
  - Reactive ion etching
    - SAL601 SR7

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**Single-Mode Condition**

- Wavelength 1.3 $\mu m$

- TE mode

- First-order mode

- Multimode

- Single-Mode

- Second-order mode

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**Fabricated ring resonator**
Resonance Characteristics

Valleys of through port correspond well to Peaks of drop port.

Agreement with theoretical values

W = 2 µm, g = 0.10 µm

Subpeaks are observed.

W = 3 µm, g = 0.10 µm

Multimode ring resonator behaves similarly to single-mode one.

Valleys of through port correspond well to Peaks of drop port.

Through

Drop

Gap Dependence of FWHM

Wide gap gives narrow FWHM

Simulation of Bending Loss

Multimode: Suitable for realizing compact devices

Principle and Application for Optical Switches

Cross Section of the Ring Resonator Switches

Bias V for applying electric field $E$

$V = D_{core} \cdot E + 2D_{cladding} \cdot \frac{\varepsilon_{core}}{\varepsilon_{cladding}} \cdot E$

$\varepsilon$: dielectric constant

Cladding: SiO2, KH2PO4(KDP)

Low $n$, High $\varepsilon$

Candidates of electro-optic materials

- LN LiNbO3 Widely used for EO materials
- BST (Ba,Sr)TiO3 Introduced in silicon process already
- KTN K(Ta,Nb)O3 Very large EO coefficient

$\lambda = \frac{2\pi R}{m}$

$\lambda_{eq} = \frac{1}{2} \lambda'$

$\lambda'$: Resonance wavelength

$\lambda_{eq}$: Equivalent index

$r$: Ring radius

$m$: Integer

$P_{core}, P_{cladding}$: Power in core, cladding

$D_{core}, D_{cladding}$: Diameter of core, cladding
**Operation Voltage**

<table>
<thead>
<tr>
<th>Material</th>
<th>Operation Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>BST/(\text{SiO}_2)</td>
<td>56.9V (D_{\text{core}}=6.0 \mu\text{m})</td>
</tr>
<tr>
<td>LN/(\text{SiO}_2)</td>
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<tr>
<td>LN/KDP</td>
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<tr>
<td>KTN/(\text{SiO}_2)</td>
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LN and BST have high operation voltage. KTN is promising if available in Si process.

**Time Dependence of Resonance Characteristics**

- \(R = 12 \mu\text{m}, n_{eq} = 2.0\)
- No bending loss

**Time Dependence of Peak Power and FWHM**

- \(R = 12 \mu\text{m}, n_{eq} = 2.0\)
- Coupling 0.2

**Operation Speed**

- Operation speed is limited by resonance time.
- Operation frequency > 66 GHz

**Conclusions**

- We have fabricated multimode ring resonators. The resonance characteristics behaved similarly to those of single-mode ring resonators.
- The multimode ring resonators are useful for interconnection on Si chips.
- We proposed ring resonator optical switches using EO materials, which are promising devices for application to interconnection on Si chips.