Numerical Analysis and Optimization of a Multi-Mode Interference Polarization Beam Splitter


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Outline

• Introduction to Silicon Photonics
  • Polarization sensitivity
  • Modes in a Si waveguide

• Theory and Concept
  • Polarization splitters
  • Effect of variations in photonics nanofabrication
  • Multi-Mode Interference (MMI)

• Simulation Set-up
  • Modules and constraints
  • Multi-mode waveguides
  • Device geometry

• Results
  • TM optimization
  • TE optimization
  • Spectral response

• Future Work

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Silicon Photonics

- Integrated solution to photonic systems and circuits
- Intra-datacenter signal processing - routing, switching, modulation
- CMOS compatible, non-toxic
- Robust
- Compact devices due to high index ratio

“Silicon photonic chip” © 2014 Lukas Chrostowski, reproduced with permission
Modes: Refractive Index

- Si/SiO2 – core/cladding
  - High core/cladding index ratio
- Mode confinement -> TE, TM

![Mode Confinement Diagram]

- TE
  - $E_{TE0}$
- TM
  - $E_{TM0}$

Properties:

- BOX: $n = 3.4$
- Si Substrate: $n = 1.44$
Modes: Polarization Sensitivity

- Dispersion relation
- Orthogonal polarizations no longer degenerate
- High refractive index contrast + birefringence = strong polarization sensitivity
- Devices cater to TE or TM

Polarization Splitters (e.g.)


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Optimization of an MMI-based PBS
Fabrication Variations

• E-beam lithography, imperfect fabrication technique
• Variances can cause a huge change in some PBS devices
• Sidewall roughness
• MMI structures are tolerant to variation

Multi-Mode Interferometer (MMI)

\[ TE_0 + TE_1 + TE_2 + \ldots + TE_n = \]

\[ L_\pi \approx \frac{4n_r W_e^2}{3\lambda_0} \]

Self imaging length:
Modules & Constraints

- Wave Optics – Electromagnetic Waves, Beam Envelope (ewbe)
- Scattering boundary condition: Decaying field beyond sim domain
- Port excitation (input)
  - TE and TM separately
- Matched boundary condition (output)
  - Output issue – port causes reflections and no transmission
  - Smaller mesh needed with no port?
Multi-Mode Waveguide (3μm)
Geometry

- Angled input waveguide
- TM top port
- TE bottom port
- Tapers funnel light
Optimization for TM

Slice: E field norm at 110nm

Parametric Sweep:

\( W_{pl} \) VS \( x_{TM} \)

Table Surface: Power outflow, time average (W) TM @ TM 
\( x_{TM} \times 10^{-5} \)

Table Surface: Power outflow, time average (W) TE @ TM 
\( x_{TM} \times 10^{-5} \)
Optimization for TE

Slice: E field norm at 110nm

Parametric Sweep:

$l_{PBS}$ vs $\gamma_{TE}$

Table Surface: Power outflow, time average (W) TE @ TE

Table Surface: Power outflow, time average (W) TM @ TE
Spectral Performance Characteristics

<table>
<thead>
<tr>
<th>Mode @ Output Port</th>
<th>Insertion Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE @ TE</td>
<td>0.82</td>
</tr>
<tr>
<td>TE @ TM</td>
<td>18.75</td>
</tr>
<tr>
<td>TM @ TM</td>
<td>1.56</td>
</tr>
<tr>
<td>TM @ TE *</td>
<td>8.81</td>
</tr>
</tbody>
</table>

*Output waveguide bend to reduce TM @ TE

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Optimization of an MMI-based PBS
Future Work

• Fabrication
• Characterize temperature dependence in COMSOL
• Increase bandwidth
• Redesign for other central wavelengths
• Optimization module
• Boundary Element Method (?)
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Thank You

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For more information, visit our poster!
PolarizationSplitters(e.g.)


TM 1D optimization
TE 1D optimization

![Output Power](chart1)

![Output Power](chart2)