Design Rules for Polymer Waveguides and Measurement Techniques

Kai Wang, David R. Selviah, Hadi Baghsiahi and F. Anibal Fernández

Optical Devices & Systems, Department of Electronic & Electrical Engineering, UCL (University College London)

Ioannis Papakonstantinou

Sharp Laboratories of Europe Ltd (formerly at UCL)

Guoyu Yu

OpTIC Technium (Part of UCL)

Chairman: Henning Schröder, Co-Chairman: David R. Selviah

International IEEE Symposium on Photonic Packaging Electrical Optical Circuit Board and Optical Backplane

Sponsored by Fraunhofer IZM, VDI/VDE, IEEE-CPMT and IEEE-LEOS

Messe Munich, co-located with Electronica, Germany, 13th November 2008

Copyright © 2008 UCL
Outline

1. Motivation:
   - Optical versus Electronic interconnect
   - Demonstrator Structure
2. Waveguide fabrication techniques
3. Measurement technique
4. Crosstalk and loss measurement
   - Straight waveguides
   - Crossings
   - Bends
5. Optical system design
Outline

1. Motivation:
   - Optical versus Electronic interconnect
   - Demonstrator Structure
2. Waveguide fabrication techniques
3. Measurement technique
4. Crosstalk and loss measurement
   - Straight waveguides
   - Crossings
   - Bends
5. Optical system design
Optical versus Electronic Interconnect

- Copper tracks become inefficient as data rates rise above 10 Gb/s
  - Latency delay
  - Skin effects in the conductors
  - Cross-talk
  - Electromagnetic Interference (EMI)
  - Reflection
  - Signal loss and manufacturing cost increases.

- Optical interconnect has potential benefits
  - Less delay due to no RC components.
  - Low propagation loss 0.03 - 0.06 dB/cm at 850 nm wavelength in waveguide < 50 × 50 μm in cross-section.
  - Do not require impedance matching.
  - Wide bendwidth
  - Wavelength division multiplexing is achievable.
Demonstrator Schematic

Optical Connector

Optical and Electronic Interconnects

Backplane

Mezzanine Board (Daughter Board, Line Card)
1. Motivation:
   - Optical versus Electronic interconnect
   - Demonstrator Structure
2. Waveguide fabrication techniques
3. Measurement technique
4. Crosstalk and loss measurement
   - Straight waveguides
   - Crossings
   - Bends
5. Optical system design
Fabrication Techniques and Waveguides Samples

Straight waveguides – Optical InterLinks

90° Crossings – Dow Corning

90° Crossings – Heriot Watt University

50° Crossings – Exxelis

Copyright © 2008 UCL
Photolithographic Fabrication of Waveguides
End Facets of Waveguides

Through Nomarski Microscope with both front and back illumination
Outline

1. Motivation:
   - Optical versus Electronic interconnect
   - Demonstrator Structure
2. Waveguide fabrication techniques
3. Measurement technique
4. Crosstalk and loss measurement
   - Straight waveguides
   - Crossings
   - Bends
5. Optical system design
Optical Loss Measurement

850 nm VCSEL

50/125 μm step index fibre

150 μm pinhole

Index matching fluid

15.3 mm

50 ×75 μm

0 dBm

-1.63 dBm

nW Power Meter

Integrating sphere photodetector

Copyright © 2008 UCL
VCSEL Array for Crosstalk Measurement

Source: Microsemi Corporation

Source: ULM Photonics GmbH

Source: GRINTech GmbH

MT compatible interface
Outline

1. Motivation:
   - Optical versus Electronic interconnect
   - Demonstrator Structure
2. Waveguide fabrication techniques
3. Measurement technique
4. Crosstalk and loss measurement
   - Straight waveguides
   - Crossings
   - Bends
5. Optical system design
Design Rules for Inter-waveguide Cross Talk

- 70 µm x 70 µm waveguide cross sections and 10 cm long
- In the cladding power drops linearly at a rate of 0.011 dB/µm
- Crosstalk reduced to -30 dB for waveguides 1 mm apart
Schematic Diagram Of Waveguide Crossings at 90° and at an Arbitrary Angle, $\theta$
Loss per crossing (dB) vs Crossing angle (degree)

- Loss of 0.023 dB per 90° crossing consistent with other reports.
- The output power dropped by 0.5% at each 90° crossing.
- The loss per crossing ($L_c$) depends on crossing angle ($\theta$), $L_c=1.0779 \cdot \theta^{-0.8727}$. 

### Table: Recommended vs Used

<table>
<thead>
<tr>
<th>Crossing angle (degree)</th>
<th>Loss (dB)</th>
<th>Power Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>0.023</td>
<td>0.08 dB</td>
</tr>
</tbody>
</table>

Recommended

Recommended

Used
Loss of Waveguide Bends

<table>
<thead>
<tr>
<th>Width (μm)</th>
<th>Optimum Radius (mm)</th>
<th>Maximum Power (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>13.5</td>
<td>-0.74</td>
</tr>
<tr>
<td>75</td>
<td>15.3</td>
<td>-0.91</td>
</tr>
<tr>
<td>100</td>
<td>17.7</td>
<td>-1.18</td>
</tr>
</tbody>
</table>

Copyright © 2008 UCL
Outline

1. Motivation:
   - Optical versus Electronic interconnect
   - Demonstrator Structure
2. Waveguide fabrication techniques
3. Measurement technique
4. Crosstalk and loss measurement
   - Straight waveguides
   - Crossings
   - Bends
5. Optical system design
## Power Budget

<table>
<thead>
<tr>
<th>Input power (dBm/mW)</th>
<th>-2.07 / 0.62</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupling loss (dB)</td>
<td>4.4 at both input and output ends</td>
</tr>
<tr>
<td>Propagation loss (dB/cm)</td>
<td>0.08</td>
</tr>
<tr>
<td>Bend 90°</td>
<td></td>
</tr>
<tr>
<td>Radii (mm)</td>
<td>15.000</td>
</tr>
<tr>
<td>Loss per bend (dB)</td>
<td>0.94</td>
</tr>
<tr>
<td>Crossings</td>
<td></td>
</tr>
<tr>
<td>Crossing angles (°)</td>
<td>22.27</td>
</tr>
<tr>
<td>Loss per crossing (dB)</td>
<td>0.078</td>
</tr>
<tr>
<td>Min. detectable DC power (dBm/mW)</td>
<td>-15 / 0.03</td>
</tr>
<tr>
<td>Min. DC power no BER at $2^{31}$ (dBm/mW)</td>
<td>-12 / 0.06</td>
</tr>
</tbody>
</table>
## Calculated Waveguides Output

<table>
<thead>
<tr>
<th>No. Crossings</th>
<th>No. Bends</th>
<th>Straight (cm)</th>
<th>Calculated output without index matching (dBm)</th>
<th>Calculated output with index matching (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>4</td>
<td>2.17</td>
<td>9.71</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>4</td>
<td>2.17</td>
<td>9.71</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>4</td>
<td>2.14</td>
<td>9.72</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2.24</td>
<td>10.00</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>4</td>
<td>2.04</td>
<td>10.09</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>4</td>
<td>5.95</td>
<td>10.22</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>4</td>
<td>5.78</td>
<td>10.25</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>4</td>
<td>6.80</td>
<td>10.24</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>4</td>
<td>9.67</td>
<td>10.66</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>4</td>
<td>12.99</td>
<td>10.89</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>6</td>
<td>16.30</td>
<td>13.10</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>6</td>
<td>20.19</td>
<td>13.48</td>
</tr>
</tbody>
</table>
System Demonstrator

Fully connected waveguide laid out using design rules
Demonstrator Dummy Board

Waveguides were printed out using solder resist for visualization
Demonstrator with Optical Interconnects
The Shortest Waveguide Illuminated by Red Laser
Waveguide with 2 Crossings Connecting 1st to 3rd Linecard Interconnect
Output Facet of the Waveguide Interconnection
Conclusions

• Characterised photolithographically manufactured acrylate polymer multimode waveguide
• Design rules derived from the experiments

Acknowledgment

The authors thank

- EPSRC via IeMRC for funding
- Xyratex Technology Ltd
  - Dave Milward, for managing the project,
  - Ken Hopkins, and Richard Pitwon, for helpful discussions.
- Exxelis Ltd
  - Navin Suyal and Habib Rehman, for waveguide fabrication.
- Cadence
  - Gary Hinde, for technical support.
- Stevenage Circuits Ltd
  - Jonathan Calver, Jeremy Rygate and Dougal Stewart for fabricating waveguide dummy board.
- David R. Selviah for being technical lead
The End

Thanks for Your Attention

Any Questions?