Photolithographically Manufactured Acrylate Polymer Multimode Optical Waveguide Loss Design Rules

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Outline

1. Motivation:
   1. Optical versus Electronic interconnect
   2. Waveguide design rules
2. Photolithographic fabrication of acrylate polymer waveguides
3. Measurement technique
4. Loss measurement of waveguide components design rules
   1. Straight waveguides
   2. Crossings
   3. Bends
   4. Tapers
   5. Tapered bends
5. Optical system design
Optical versus Electronic Interconnect

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

- Optical interconnect has potential benefits
  - Less delay due to no RC components,
  - High speed travel in optical materials,
  - Low propagation loss $0.03 \sim 0.06$ dB/cm at 850 nm wavelength in waveguide $< 50 \times 50$ μm in cross-section,
  - Do not require impedance matching,
  - Wavelength division multiplexing is achievable.
The optical loss depends on several factors:

- Material,
- Fabrication
- Measurement Technique

- Photolithographically fabricated by Exxelis Ltd. using e-beam mask
- Truemode® acrylate polymer formulation
- Core refractive index 1.5560
- Cladding refractive index 1.5264
- NA = 0.302
- Cross sections typically 50 µm, 50 µm and 70 µm, 70 µm square
Electrical System with Optical Interconnect

- Optical Connector
- Optical and Electronic Interconnects
- Backplane
- Mezzanine Board (Daughter Board, Line Card)
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Photolithographic fabrication of waveguides, 50 µm × 50 µm Core
Waveguides Samples – Top View

- Straight waveguides
- Bends
- 90° Crossings
- 50° Crossings
Waveguide Output Facet Photographs

- VCSEL illuminated
- Under nomarski microscope

- Photolithographically fabricated by Exxelis, 50 μm × 50 μm waveguide
- Cut with a dicing saw, unpolished
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Optical Loss Measurement

850 nm VCSEL

0 dBm

50/125 μm step index fibre

Index matching fluid

70/150 μm pinhole

mode scrambler

Integrating sphere photodetector

nW Power Meter

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70 μm × 70 μm waveguide cross sections and 10 cm long
- Waveguide end facets diced but unpolished scatters light into cladding
- In the cladding power drops linearly at a rate of 0.011 dB/μm
- Crosstalk reduced to -30 dB for waveguides 1 mm apart
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Schematic Diagram Of Waveguide Crossings at 90° and at an Arbitrary Angle, $\theta$
- 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 \( \theta \),
  \[
  L_c = 1.0779 \cdot \theta^{-0.8727}.
  \]
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Optical Power Loss in 90° Waveguide Bends

Schematic diagram of one set of curved waveguides.

- Radius $R$, varied between $5.5 \text{ mm} < R < 35 \text{ mm}$, $\Delta R = 1 \text{ mm}$
- Light lost due to scattering, mode miss-match loss, radiation loss, reflection and back-scattering
- Illuminated by a MM fibre with a red-laser.

Light through a bent waveguide of $R = 5.5 \text{ mm} – 34.5 \text{ mm}$
Loss of Waveguide Bends

<table>
<thead>
<tr>
<th>Width (μm)</th>
<th>Optimum Radius (mm)</th>
<th>Minimum Loss (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>
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The input section $w_{in} = 50 \mu m$, and its length $l_{in} = 11.5$ mm

The tapered bend transforms the waveguide width from $w_{in}$ to $w_{out}$

The width of the tapered bends varies linearly along its length

Output straight waveguide length $l_{out} = 24.5$ mm.

Output widths $w_{out} = 10 \mu m, 20 \mu m, 25 \mu m, 30 \mu m$ and $40 \mu m$
Dashed lines correspond to the boundaries of the $w_{in} = 50 \, \mu m$ tapered bend.

Dotted lines correspond to the boundaries of the 25 $\mu m$ bend.

Tapered bend has more misalignment tolerance for a slight loss penalty.
The product of transmission and misalignment tolerance is a constant which increases linearly with TR such that the product = $0.650TR - 0.09$

This product is independent of the bend radius as experimental points almost coincide.
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System Demonstrator

Fully connected waveguide layout using design rules
Conclusions and Acknowledgement

- Characterised photolithographically manufactured acrylate polymer multimode waveguide by measuring the optical loss of key waveguide components.
- Design rules derived from the experimental measurement to assist optical system designers to optimise OPCB layout.

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Thanks for Your Attention