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

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

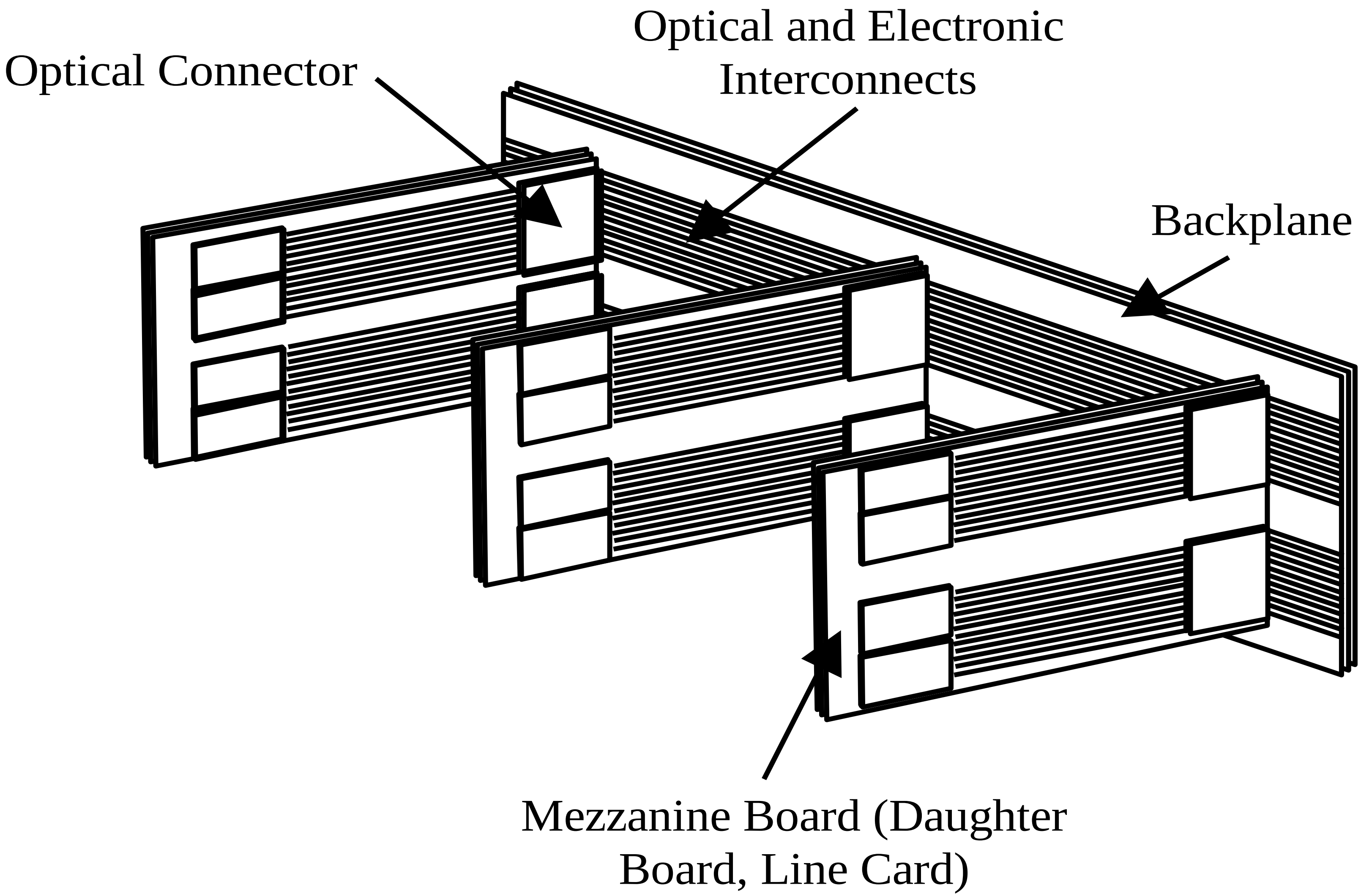
Outline

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.

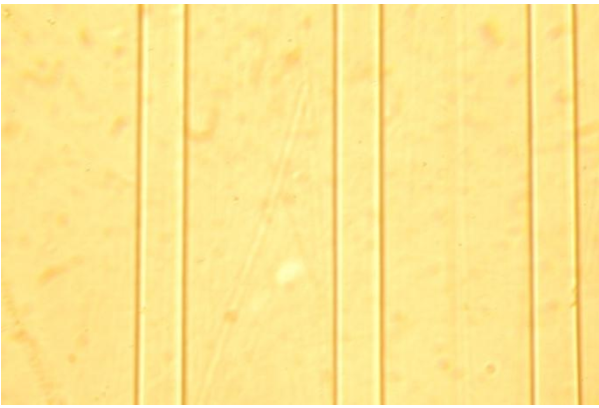
Demonstrator Schematic



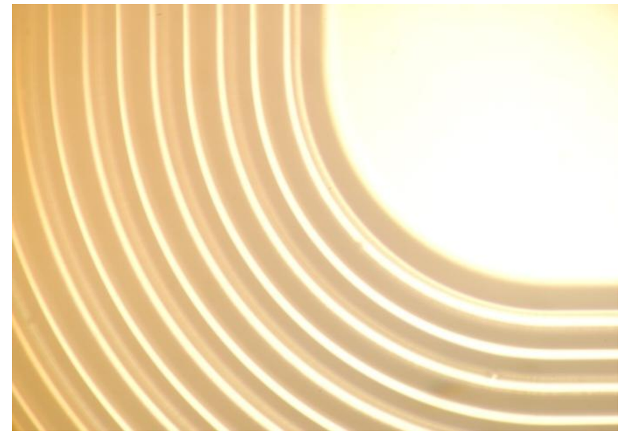
Outline

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

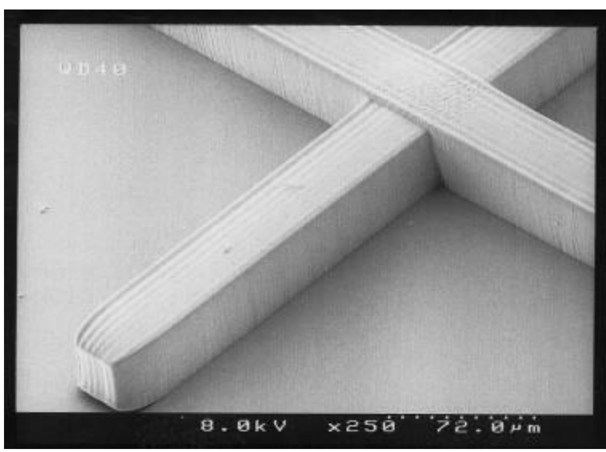
Fabrication Techniques and Waveguides Samples



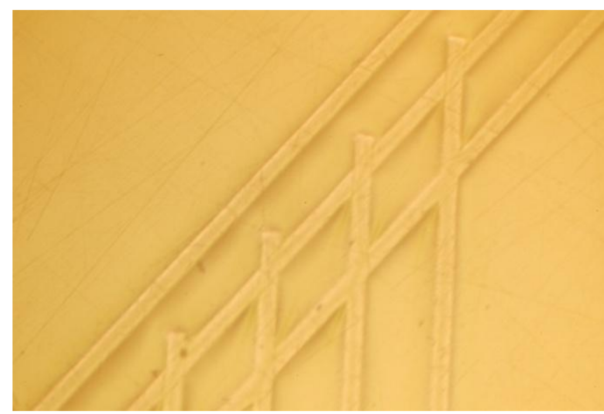
Straight waveguides – Optical InterLinks



90° Crossings – Dow Corning

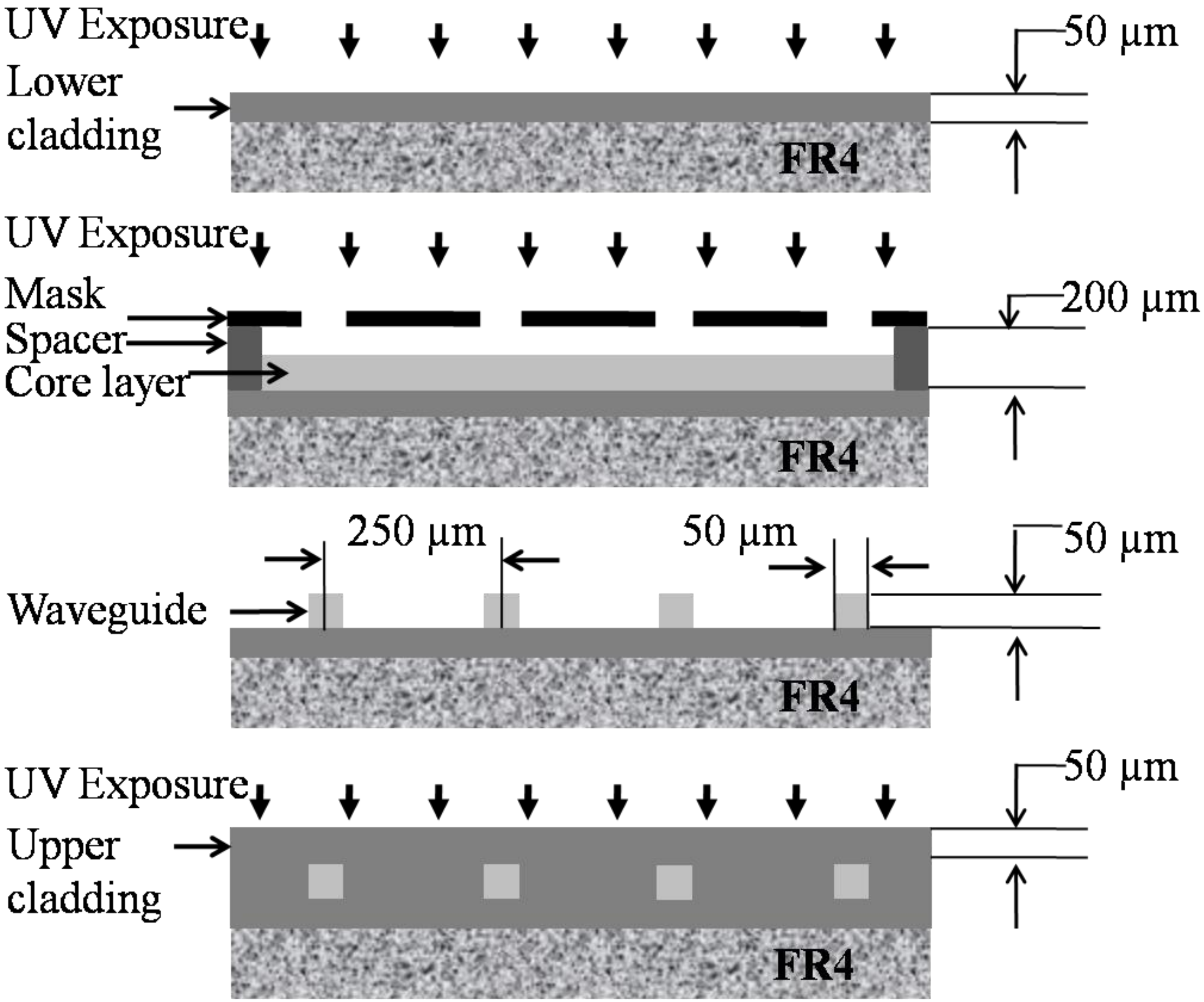


90° Crossings – Heriot Watt University

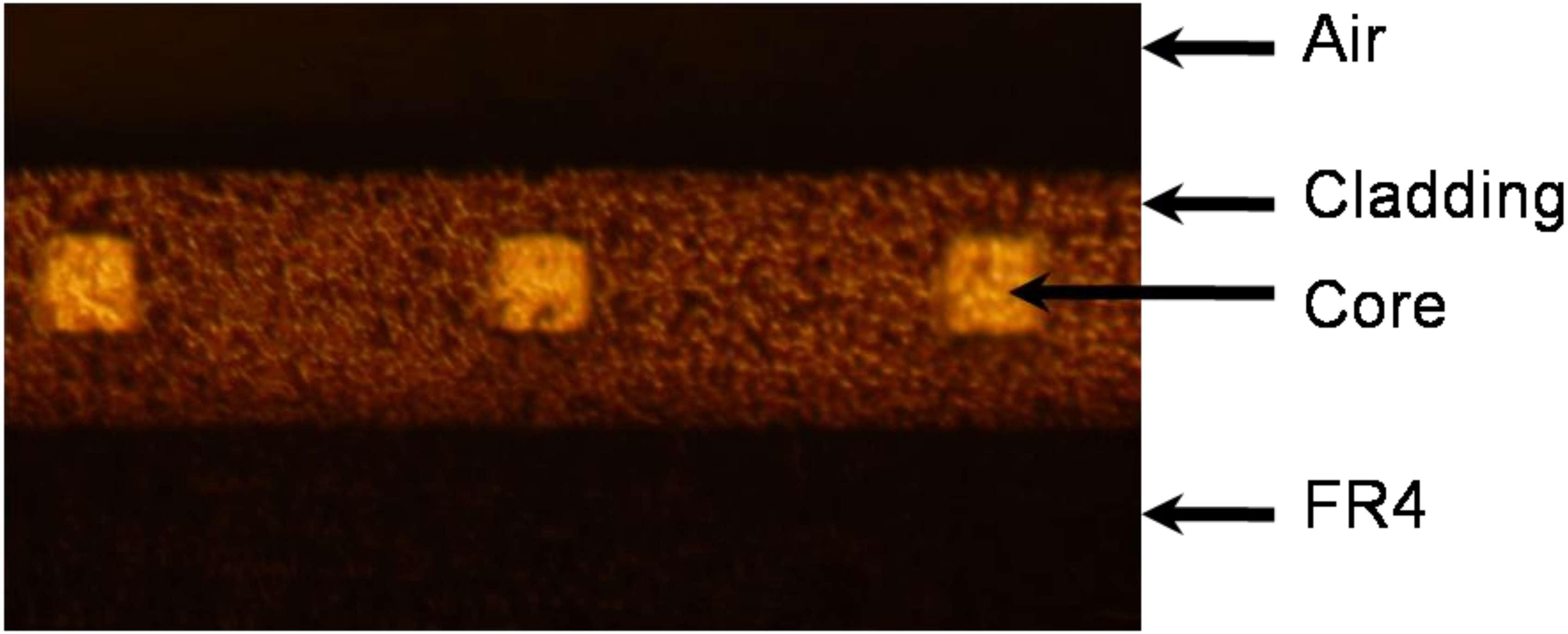


50° Crossings – Exxelis

Photolithographic Fabrication of Waveguides



End Facets of Waveguides

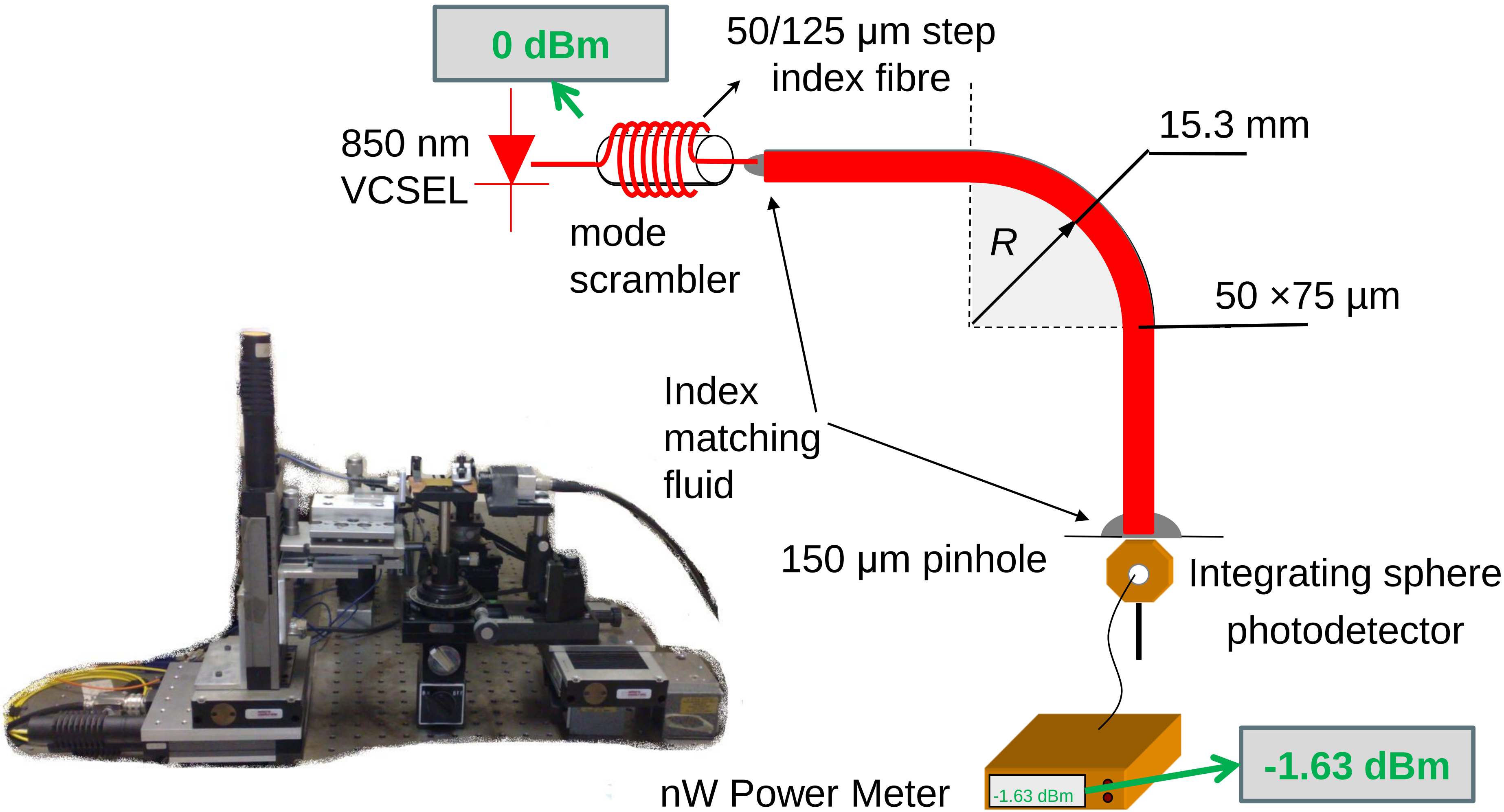


Through Nomarski Microscope with both front and back illumination

Outline

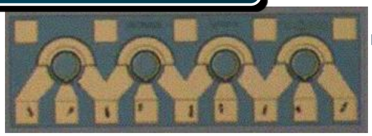
1. Motivation:
   - Optical versus Electronic interconnect
   - Demonstrator Structure
2. Waveguide fabrication techniques
3. Measurement technique
4. Crosstalk and loss measurement
   - Straight waveguides
   - Crossings
   - Bends
5. Optical system design

Optical Loss Measurement



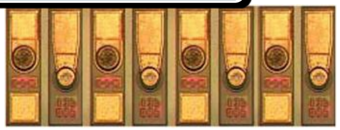
VCSEL Array for Crosstalk Measurement

PIN Array



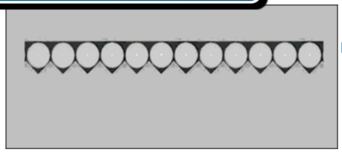
Source: Microsemi Corporation

VCSEL Array

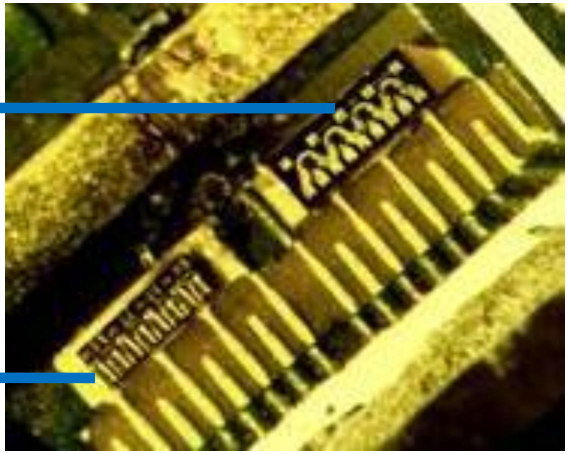


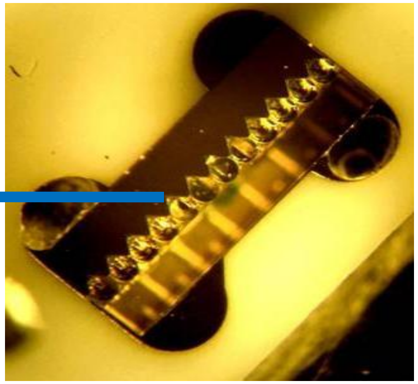
Source: ULM Photonics GmbH

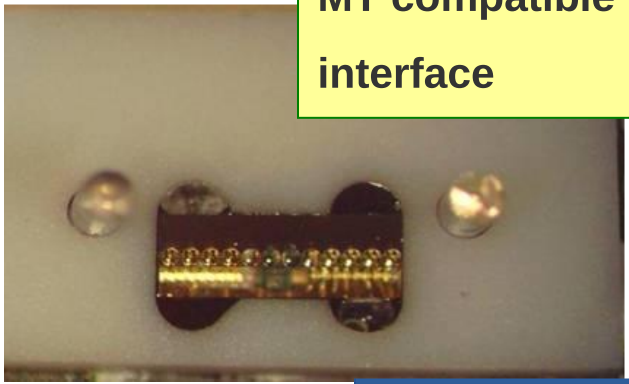
GRIN Lens Array



Source: GRINTech GmbH





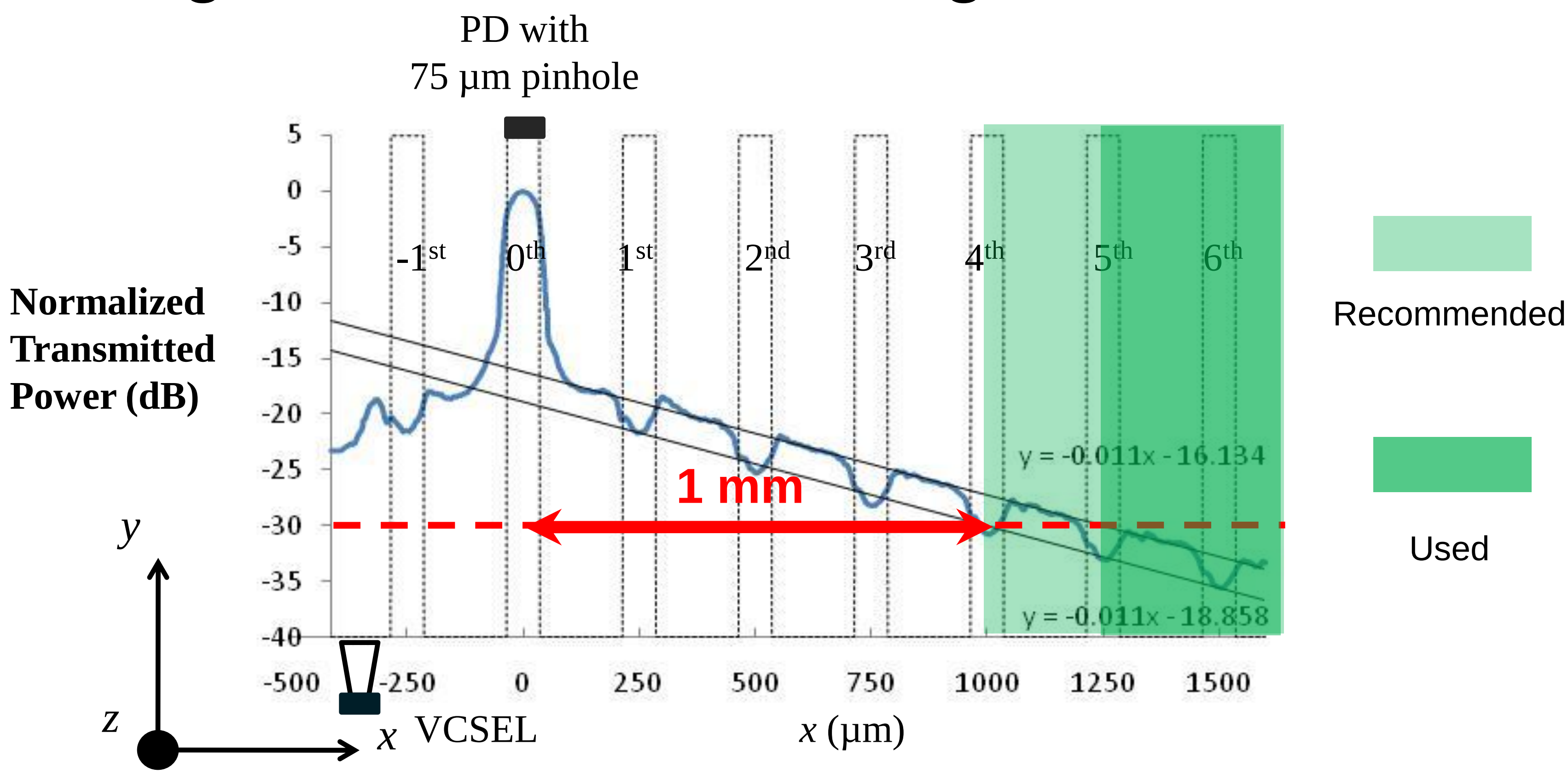


MT compatible interface

Outline

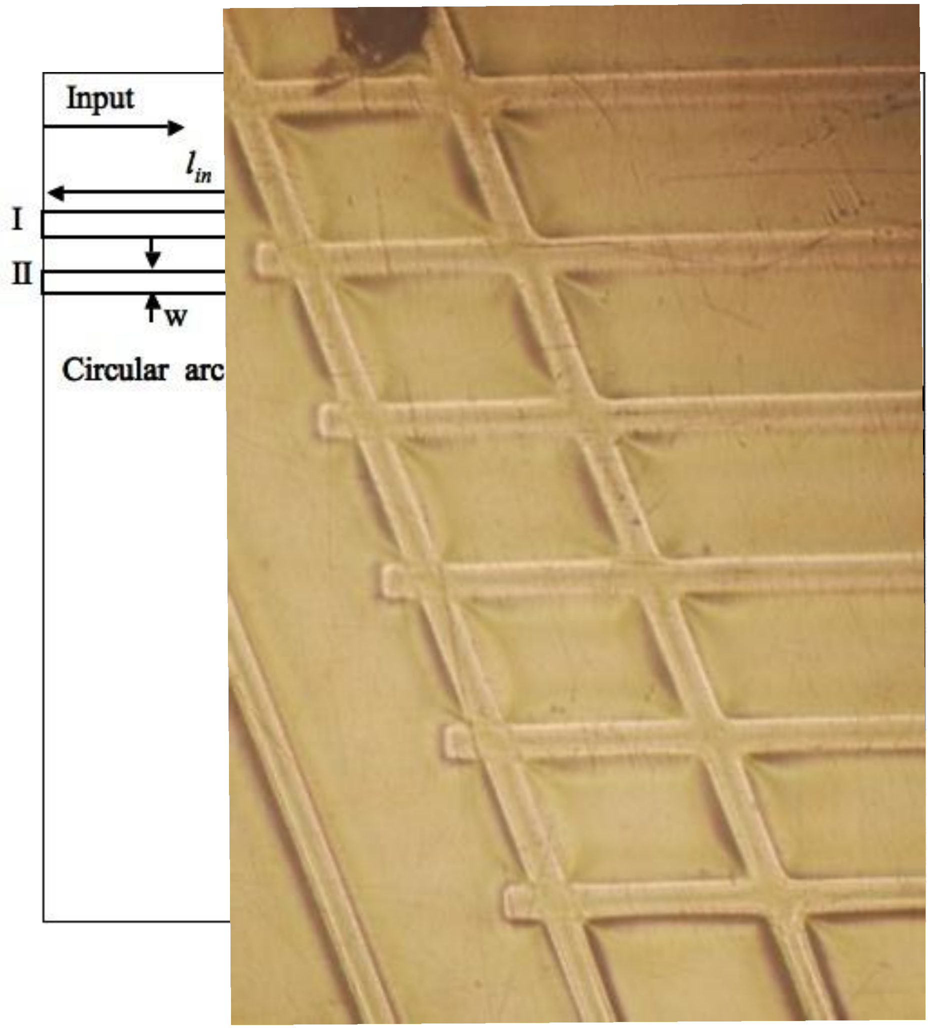
1. Motivation:
   - Optical versus Electronic interconnect
   - Demonstrator Structure
2. Waveguide fabrication techniques
3. Measurement technique
4. Crosstalk and loss measurement
   - Straight waveguides
   - Crossings
   - Bends
5. Optical system design

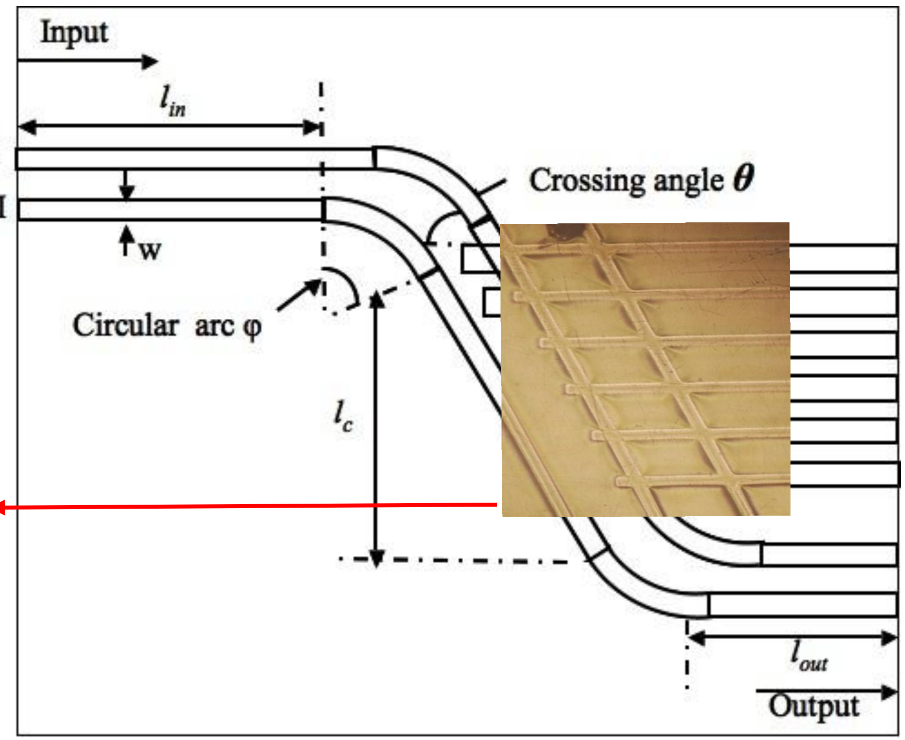
Design Rules for Inter-waveguide Cross Talk



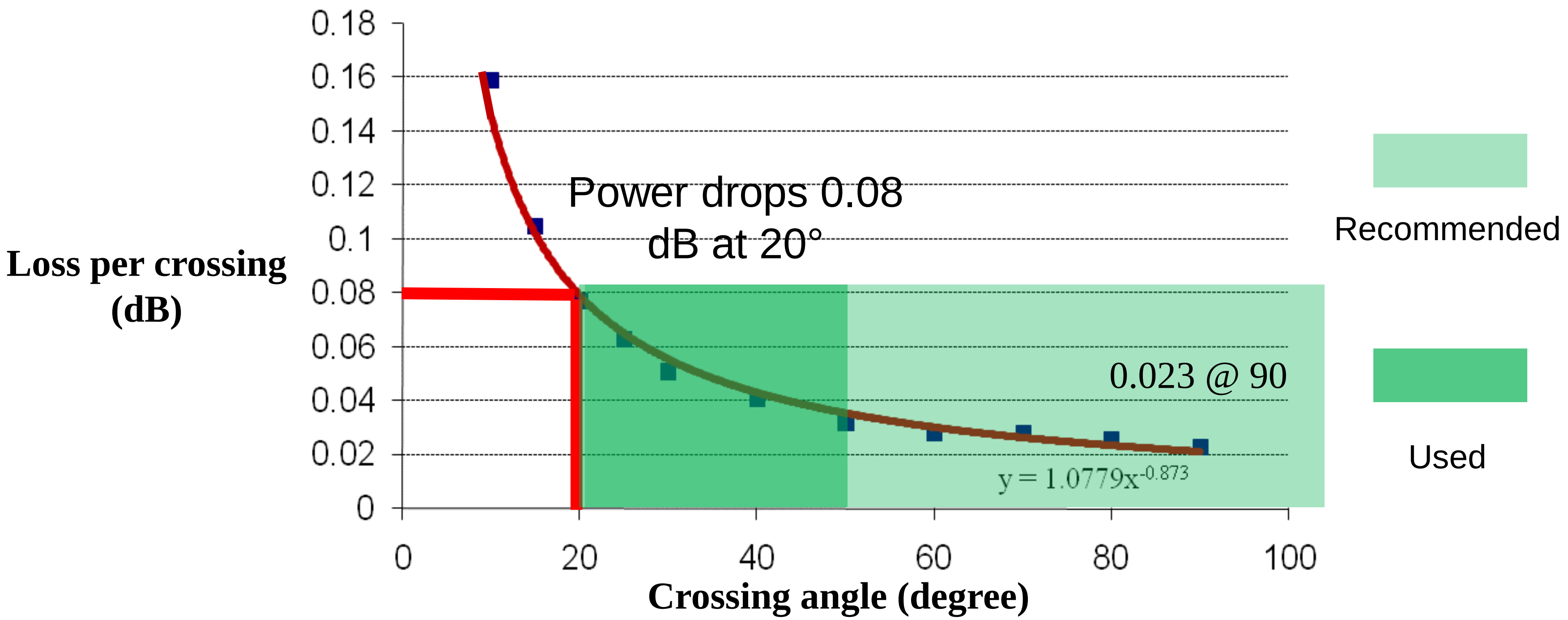
- 70 µm × 70 µm waveguide cross sections and 10 cm long
- In the cladding power drops linearly at a rate of 0.011 dB/µm
- Crosstalk reduced to -30 dB for waveguides 1 mm apart

Schematic Diagram Of Waveguide Crossings at 90° and at an Arbitrary Angle, θ



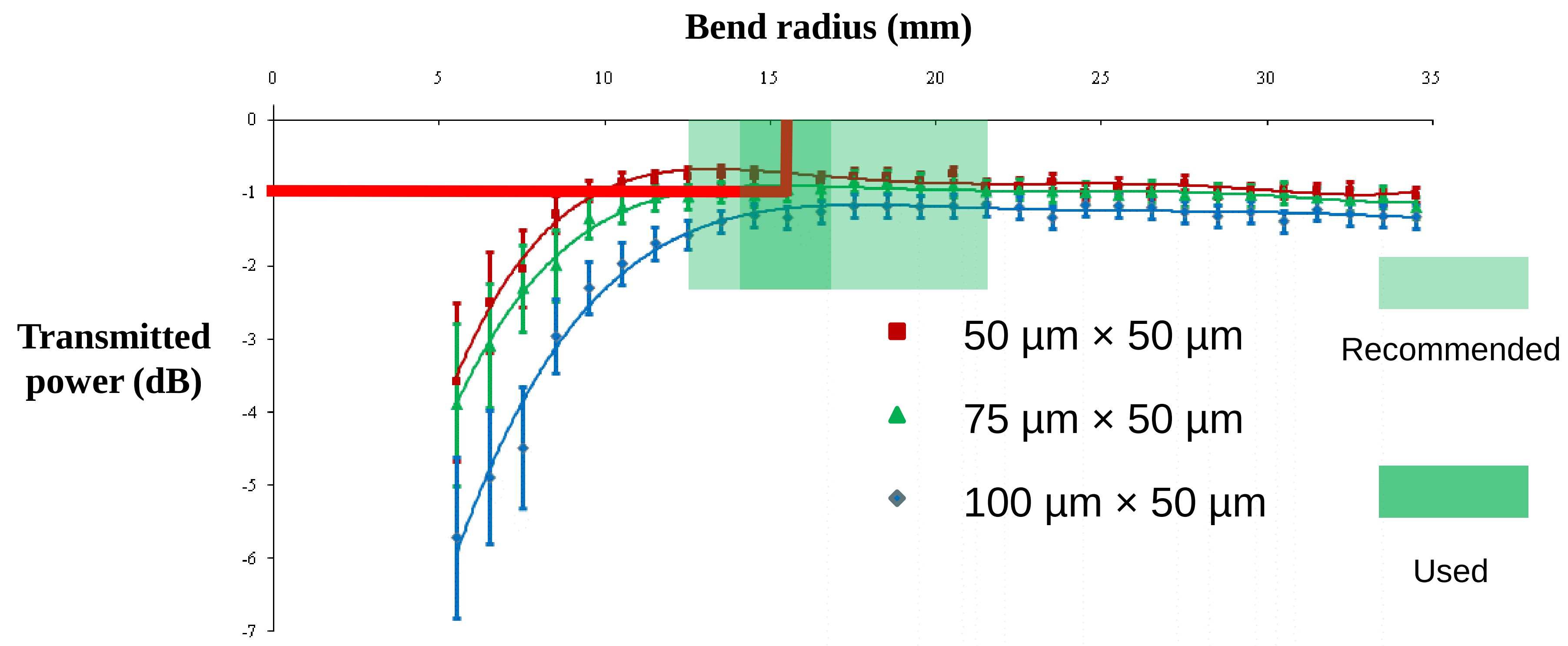


Design Rules for Arbitrary Angle Crossings



- 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 (θ), $L_c = 1.0779 \cdot \theta^{-0.8727}$.

Loss of Waveguide Bends



Width (µm)	Optimum Radius (mm)	Maximum Power (dB)
50	13.5	-0.74
75	15.3	-0.91
100	17.7	-1.18

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

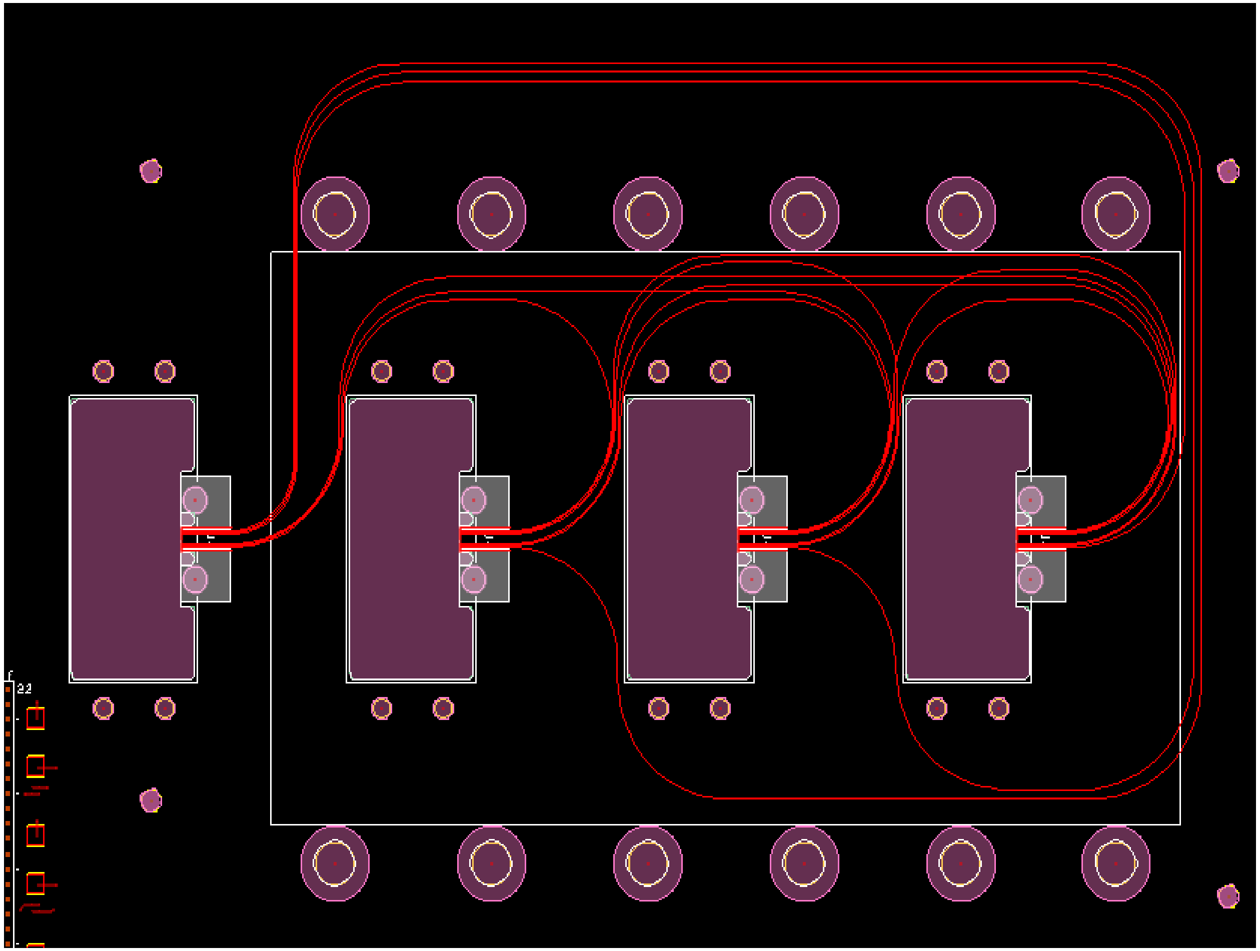
Power Budget

Input power (dBm/mW)	-2.07 / 0.62					
Coupling loss (dB)	4.4 at both input and output ends					
Propagation loss (dB/cm)	0.08					
	Bend 90°					
Radii (mm)	15.000	15.250	15.500	15.725	16.000	16.250
Loss per bend (dB)	0.94	0.91	0.94	0.94	0.95	0.95
	Crossings					
Crossing angles (°)	22.27	29.45	36.23	42.10	47.36	
Loss per crossing (dB)	0.078	0.056	0.047	0.041	0.037	
Min. detectable DC power (dBm/mW)	-15 / 0.03					
Min. DC power no BER at 2^{31} (dBm/mW)	-12 / 0.06					

Calculated Waveguides Output

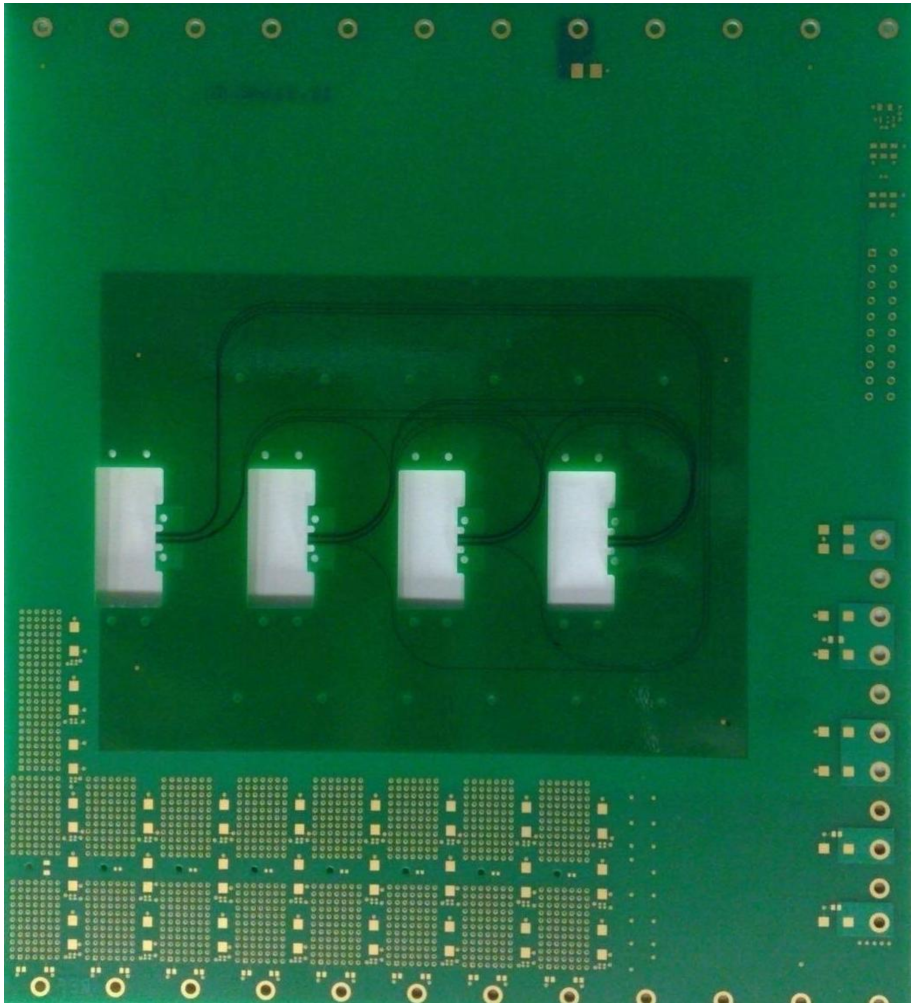
	No. Crossings	No. Bends	Straight (cm)	Calculated output without index matching (dBm)	Calculated output with index matching (dBm)
1	0	4	2.17	9.71	7.31
2	0	4	2.17	9.71	7.31
3	0	4	2.14	9.72	7.32
4	3	4	2.24	10.00	7.60
5	5	4	2.04	10.09	7.69
6	3	4	5.95	10.22	7.82
7	3	4	5.78	10.25	7.85
8	2	4	6.80	10.24	7.84
9	4	4	9.67	10.66	8.26
10	0	4	12.99	10.89	8.49
11	0	6	16.30	13.10	10.70
12	0	6	20.19	13.48	11.08

System Demonstrator



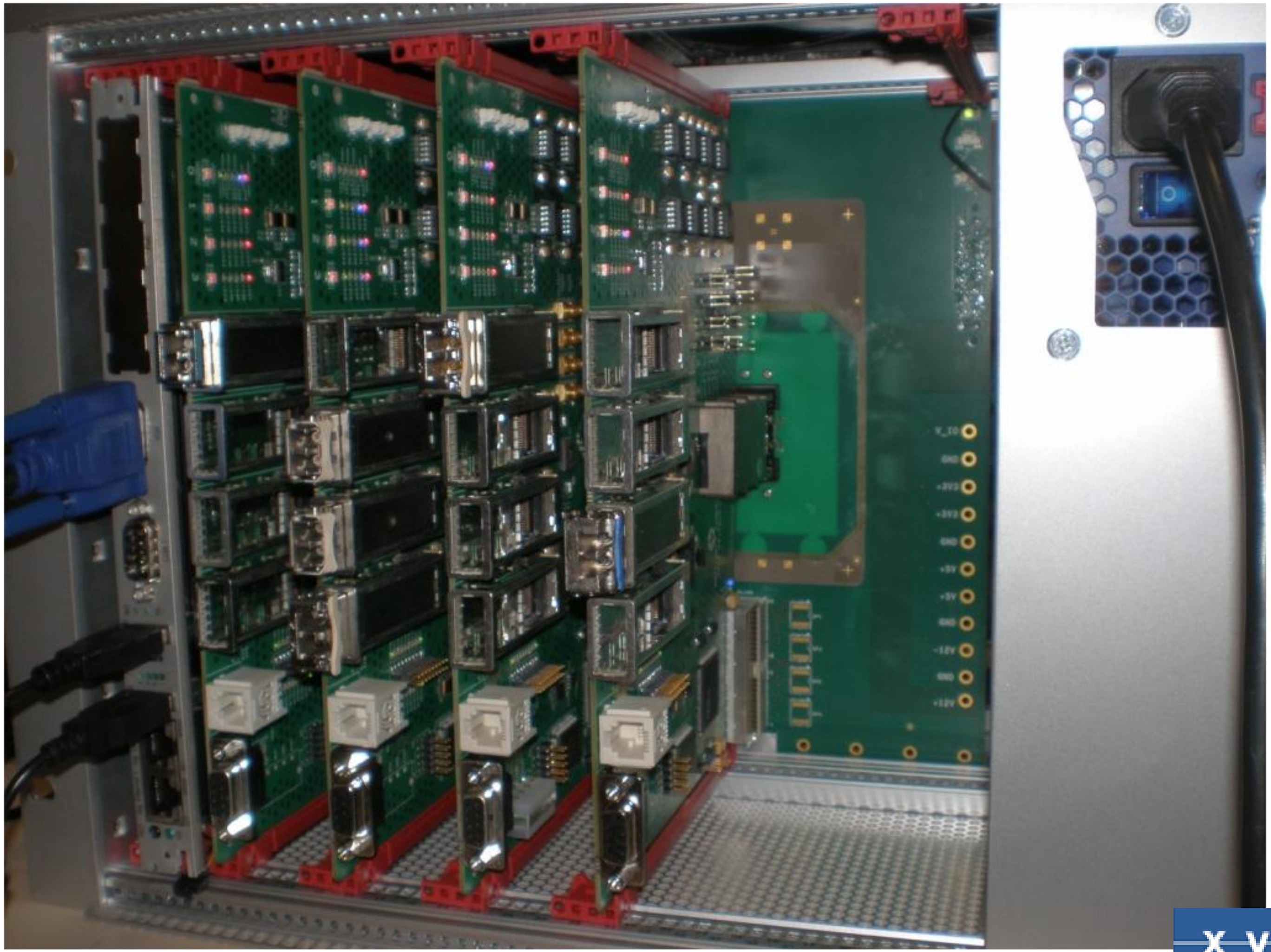
Fully connected waveguide laid out using design rules

Demonstrator Dummy Board

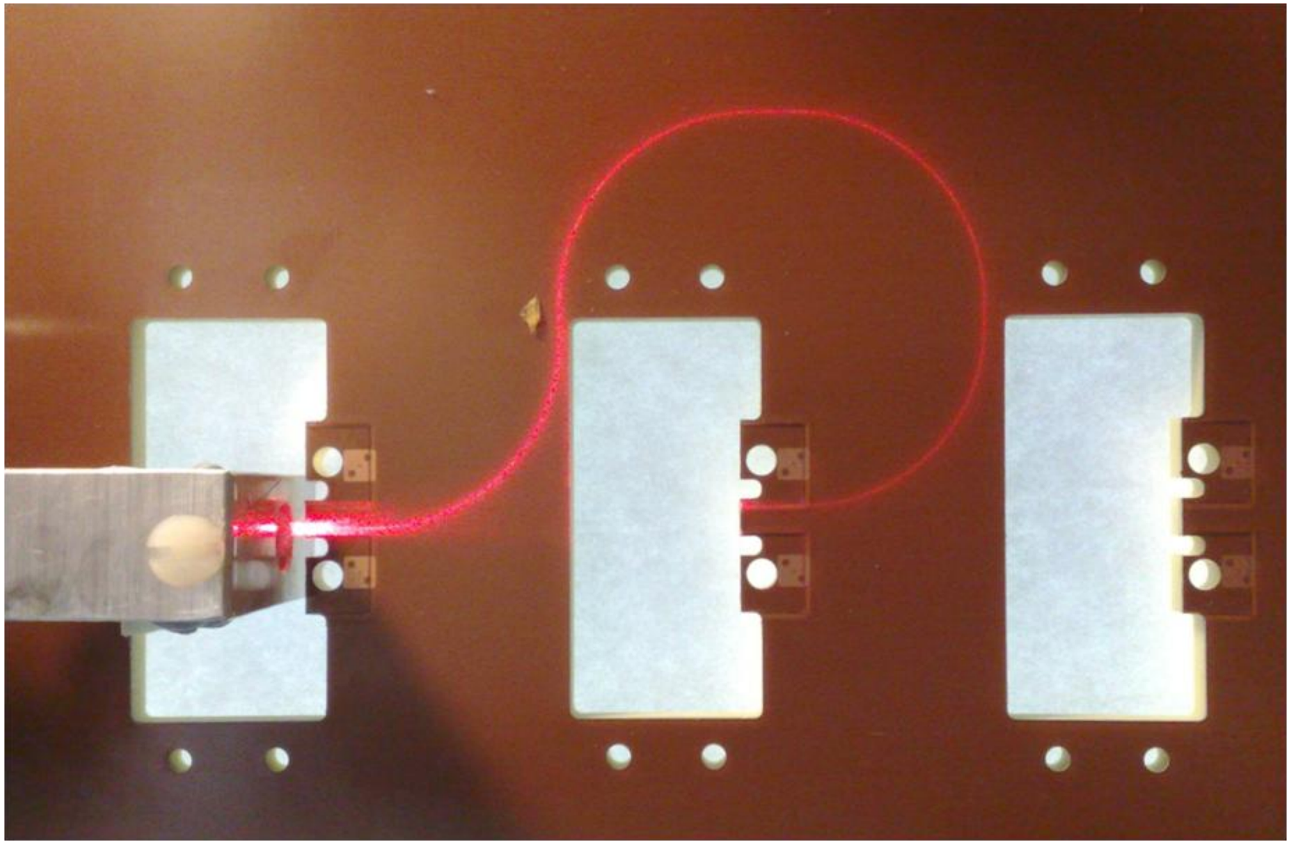


Waveguides were printed out using solder resist for visualization

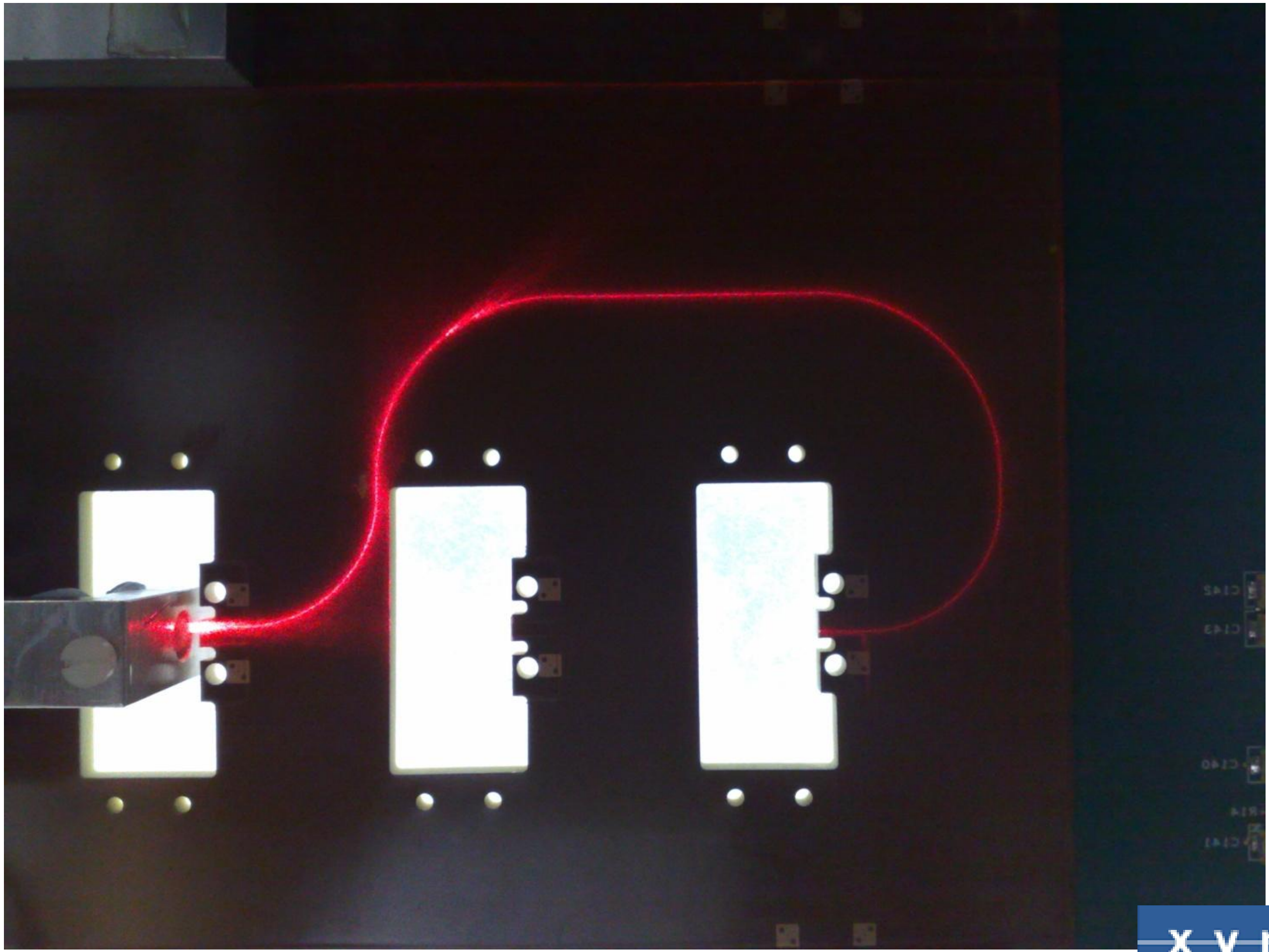
Demonstrator with Optical Interconnects



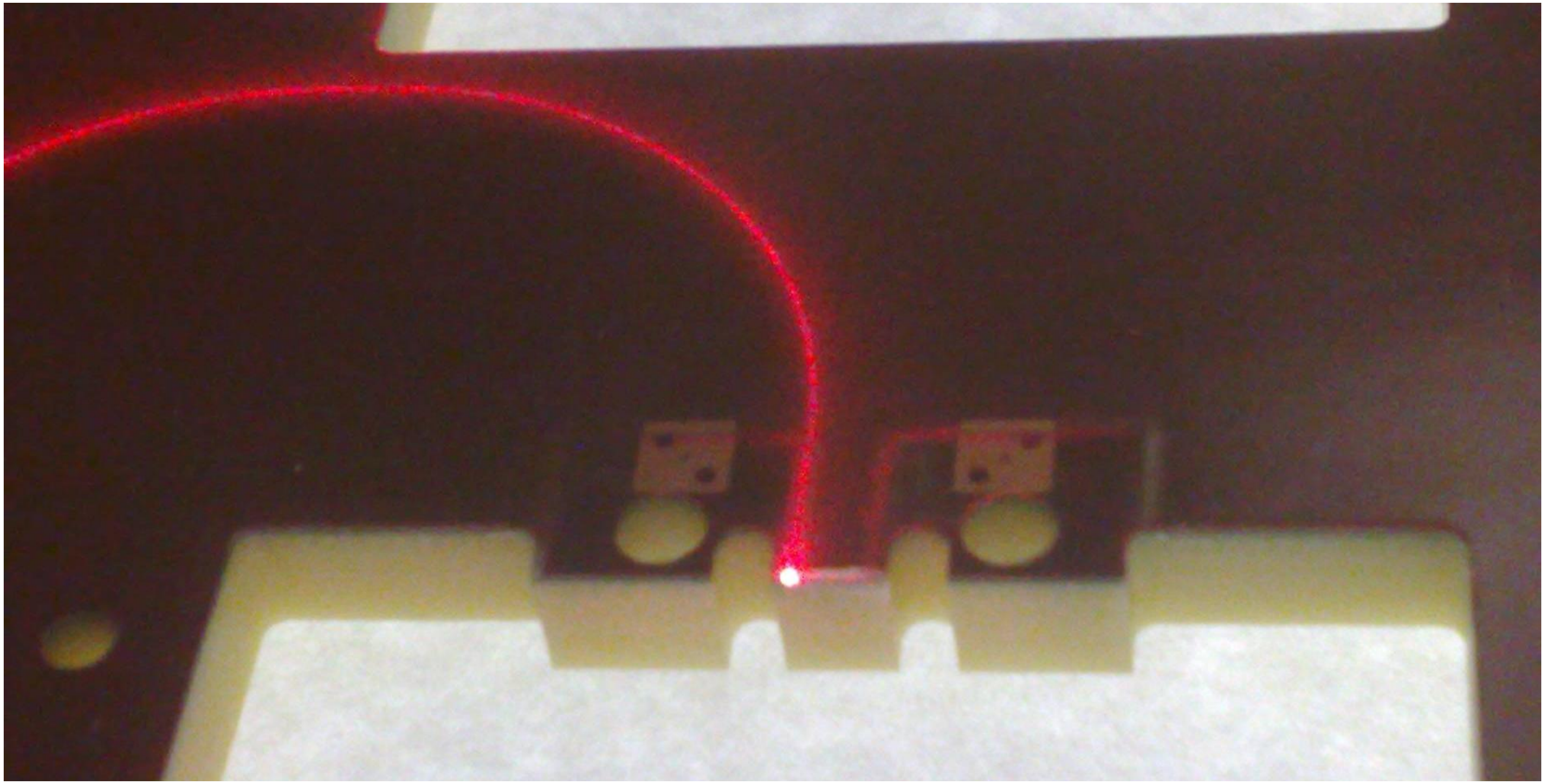
The Shortest Waveguide Illuminated by Red Laser



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 I*eMRC 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?