Optical Waveguide Modelling, Measurement and Design for Optical Printed Circuit Board

Part of the IeMRC OPCB Flagship Project

K. Wang, D. R. Selviah, I. Papakonstantinou, F. A. Fernández and H. Baghsiahi
Department of Electronic & Electrical Engineering, University College London (UCL), Torrington Place, London WC1E 7JE
Email: d.selviah@ee.ucl.ac.uk Phone: +44 20 7679 3056

University College London (UCL) is technical leader of the whole project. We work closely with all the partners in the consortium and are responsible for
- Designing the layout of the waveguide patterns
- Characterising waveguides by modelling and measurement
- Deriving design rules for optical PCB
- Designing commercially realisable connectors.

- Waveguides were lithographically made of Truemode® polymer
- The refractive index of core was 1.556 and cladding was 1.5264 gives NA = 0.302
- Lithographic process was optimised for 50 μm thick waveguides
- Waveguides measured were 50 μm thick unless otherwise stated
- Different manufacturing technologies: photolithography, laser-writing, laser ablation, extrusion, and inkjet printing will be characterised later in this project.

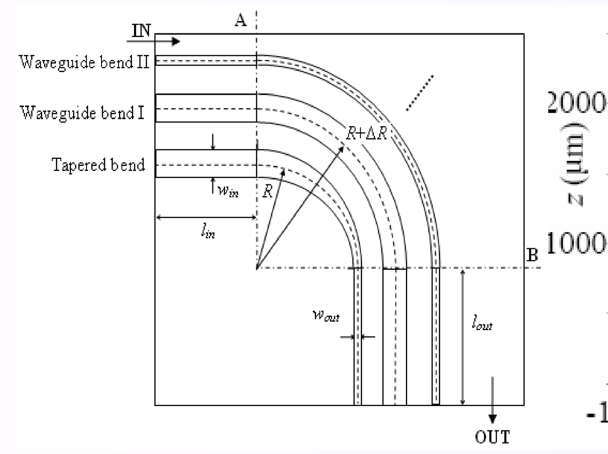

Fig. 1. schematic diagram of one set of waveguide bends

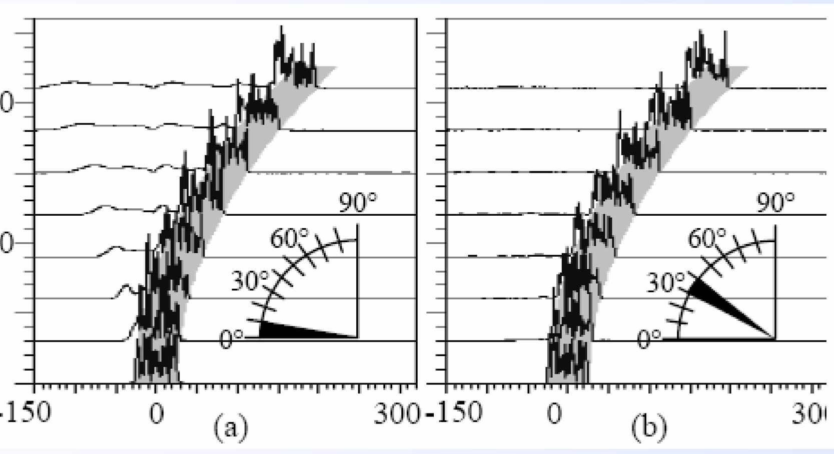

Fig. 2. beam propagation method modeling of optical field in bend segments

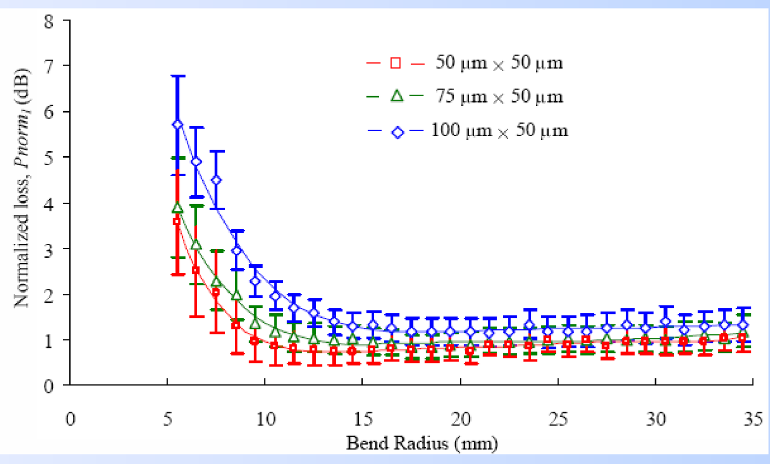

Fig. 3. loss of waveguide bends for three widths w = 50 μm, 75 μm and 100 μm

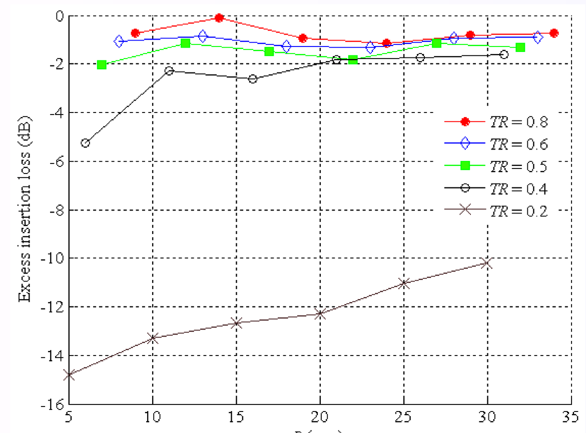

Fig. 4. calibrated insertion loss

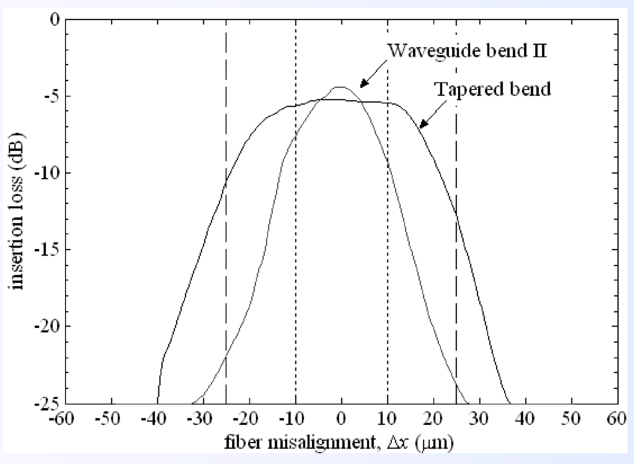

Fig. 5. insertion loss for a tapered bend and a straight bend

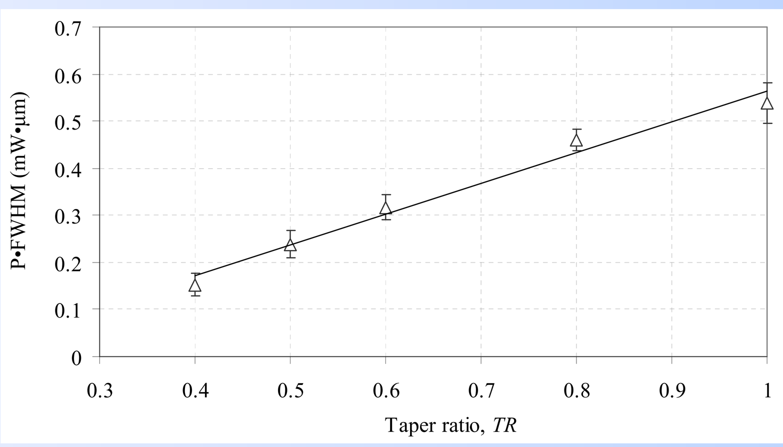

Fig. 6. maximum coupling efficiency times FWHM

Waveguide Bends, tapers and tapered bends design rules

- A 11.5 mm straight input section and a 24.5 mm output section connected to each 90° bends
- Input light from an 845 nm VCSEL was launched into a 50/125 μm step index MM fiber with $NA = 0.2$
- Light lost was due to scattering, transition loss, radiation loss and reflection
- Larger angles >33° have slower rate of increase of loss of 0.016 dB/°

Width (μm)	optimum Radius (mm)	Minimum Loss (dB)
50	13.5	0.74
75	15.3	0.91
100	17.7	1.18

- Any taper ratios TR ≥ 0.4 are suitable for a real backplane
- There is a trade off between insertion loss and misalignment tolerance
- The product of these is a constant which increases linearly with TR
- The product = 0.650TR - 0.09
- The product of insertion efficiency times misalignment tolerance of normal bends is independent on bend radius.

Waveguide crossings design rules

- Light from an 845 nm VCSEL was launched into a MM fiber with $NA = 0.123$
- A new method was used to measure loss per crossing and achieving a consistent result with that of other workers
- 0.023 dB per crossing was achieved at 90° crossings
- Output power dropped down 0.5% at each 90° crossing
- The loss per crossing (Lc) has an approximate power relationship with crossing angles (θ), which is $Lc = 1.0779 \cdot \theta^{-0.8727}$.

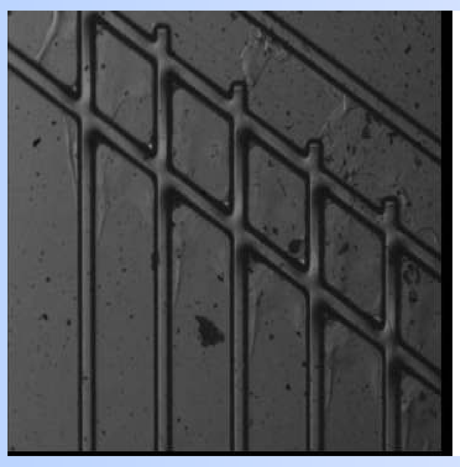

Fig. 7. SEM crossings

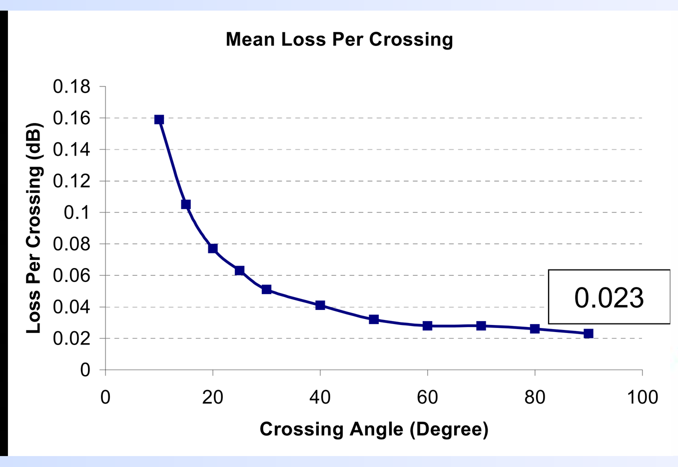

Fig. 8. experiment crossing loss

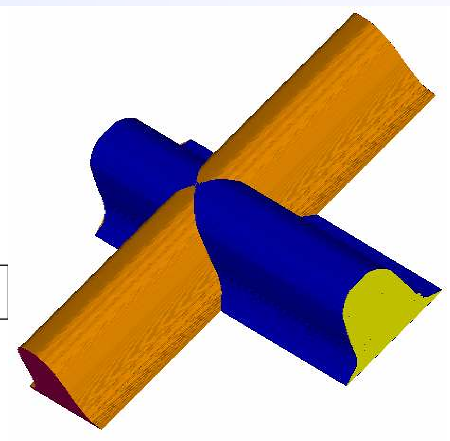

Fig. 9. 90° crossing model

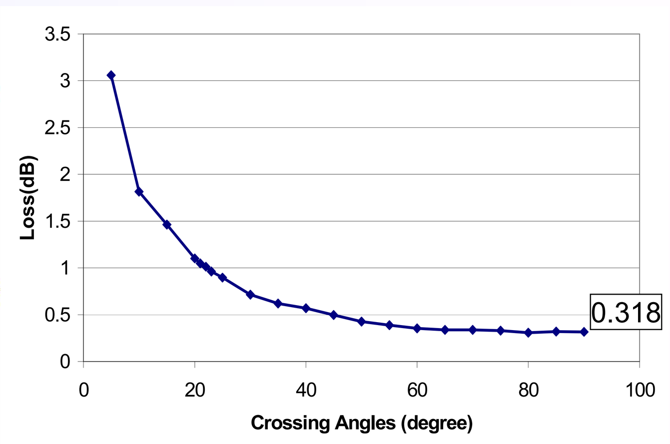

Fig. 10. modelled crossing loss

Characterisation and measurement

- Crosstalk and bit error rate were measured
- 850 nm VCSEL mounted with GRIN-lens was directly coupled with waveguides
- The cross section of waveguide was 70 μm × 70 μm
- In the cladding power drops linearly at a rate of 0.011 dB/μm
- -30 dB power drop achieved when waveguides with 1000 μm pitch
- Dicing, polishing and surface roughness were investigated
- SEM, AFM, laser-reflection microscope and white light-reflection microscope were used
- The standard deviation of side wall roughness was within 9 nm to 74 nm, while polished end surface was within 26 nm 192 nm.

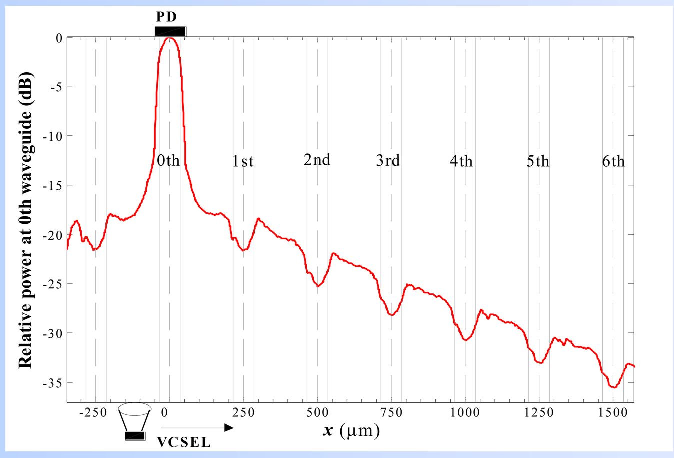

Fig. 11. crosstalk

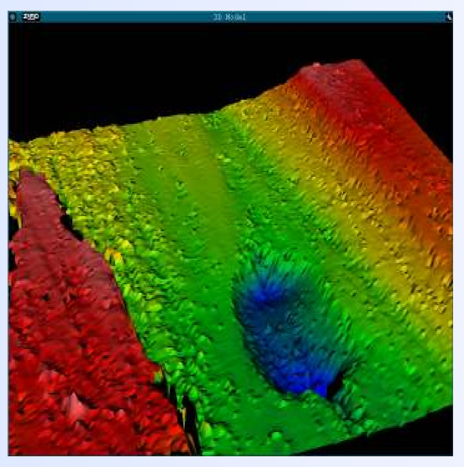

Fig. 12. waveguide cross-section under ZYGO's optical profiler

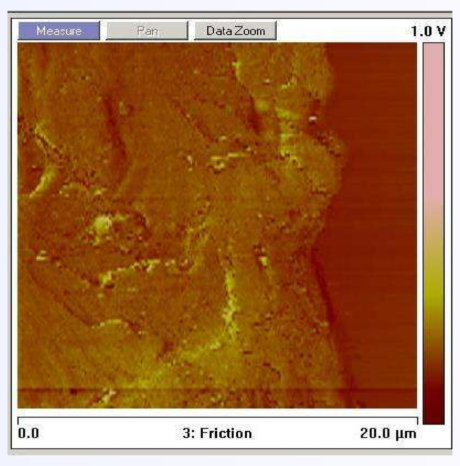

Fig. 13. waveguide core cross-section under AFM

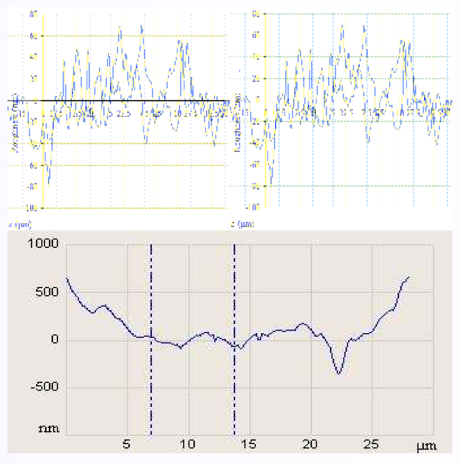

Fig. 14. side wall and polished surface scan

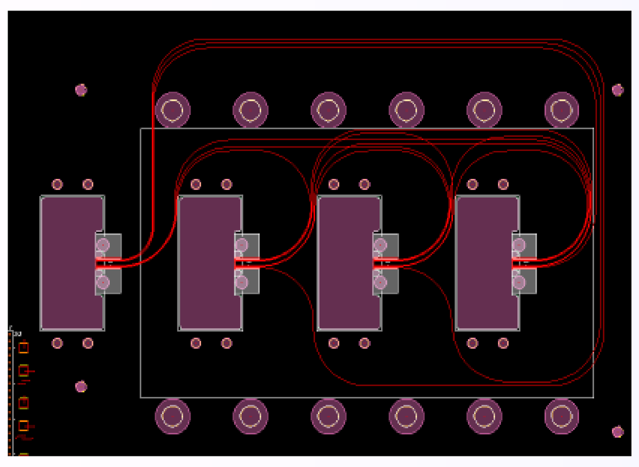

Fig. 15. System waveguide layout

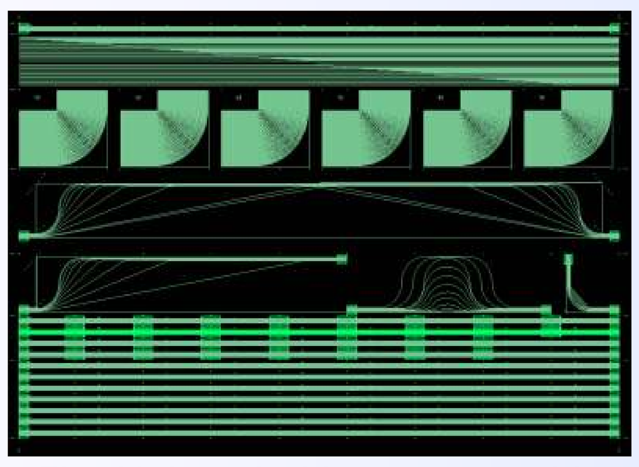

Fig. 16. board with test waveguide patterns

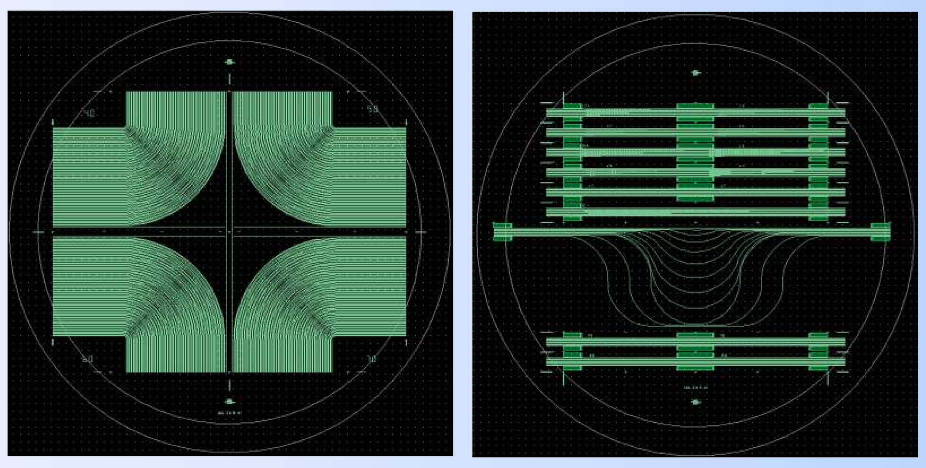

Fig. 17. 6" board with test components to be manufactured by different techniques

Waveguide and system design

- Design rules were used to layout optical system back plane by using Cadence
- The same layouts will be manufactured by different technologies for direct comparison
- 19 inch board made in Stevenage Circuits Ltd using its technique compatible with existing PCB manufacturing lines
- 6 inch board received from Exxelis made lithographically.

Training

Apart from the technical training in numerical modelling and experimental work received by the RA and PhD student during the course of the project, there has been a number of specific training actions:

- PhD student trained in comprehensive VHDL course in Duolos Ltd
- Research fellow and PhD student attended CSEL business courses in London Business School
- The research fellow attended an intellectual property workshop in UCL, a FPGA workshop in RAL and a high bit rate data measurement workshop in Agilent Technology Ltd
- Investigator attended workshop on Technology Transfer for Academics in UCL.

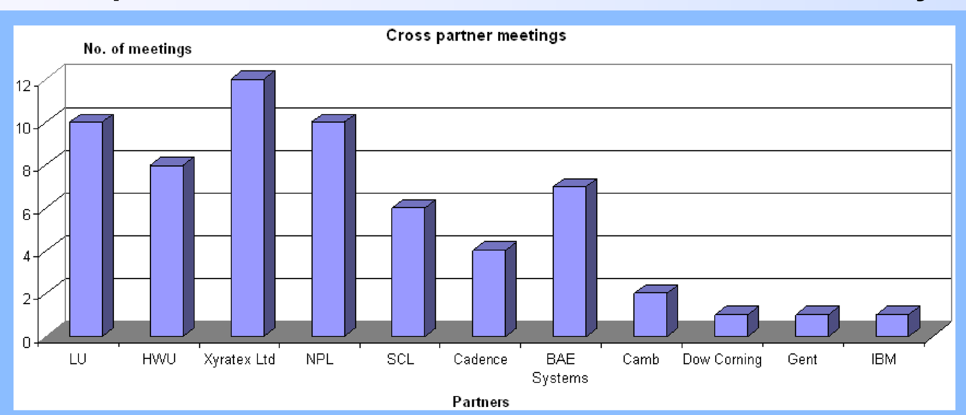

Fig. 18. UCL works closely with other partners in the consortium

Publications

- Selviah,D., et al., An Optical Wavelength Division Multiplexed Multiplexer/Demultiplexer for an Optical Printed Circuit Board and a Method of Manufacturing, 2006 (Patent)
- Selviah,D., et al., International Symposium on Photonic Packaging, Munich, 2006
- Papakonstantinou,I., et al., Transition, radiation and propagation loss in polymer multimode waveguide bends. Optics Express 15(2), 669-679. 2007
- Papakonstantinou,I., et al.,Low cost, precision, self-alignment technique for coupling laser and photodiode arrays to waveguide arrays. IEEE Transactions on Advanced Packaging, 2007
- Led presentation of progress at IeMRC conference in September, 2007
- Selviah,D., Invited Paper: Measurement Challenges for Optical Printed Circuit Boards, OFMC, NPL, 2007
- Selviah,D., UKDL, Korean Trade Visit, Department of Business, Enterprise and Regulatory Reform, 2008
- Papakonstantinou,I., et al., Insertion Loss and Source Misalignment Tolerance in Tapered Waveguide Bends. IEEE Photonics Technology Letters, 2008 (Paper submitted)
- Selviah,D., Handbook of Optical Materials, Devices and Systems. American Scientific Publishers, USA on Polymer Multimode Optical Waveguide Devices and Systems, 2008 (Book chapter)
- Selviah,D., et al., 19th IEEE LEOS Workshop on High Speed Interconnections within Digital System, 2008

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