Innovative Optical and Electronic Interconnect Printed Circuit Board Manufacturing Research

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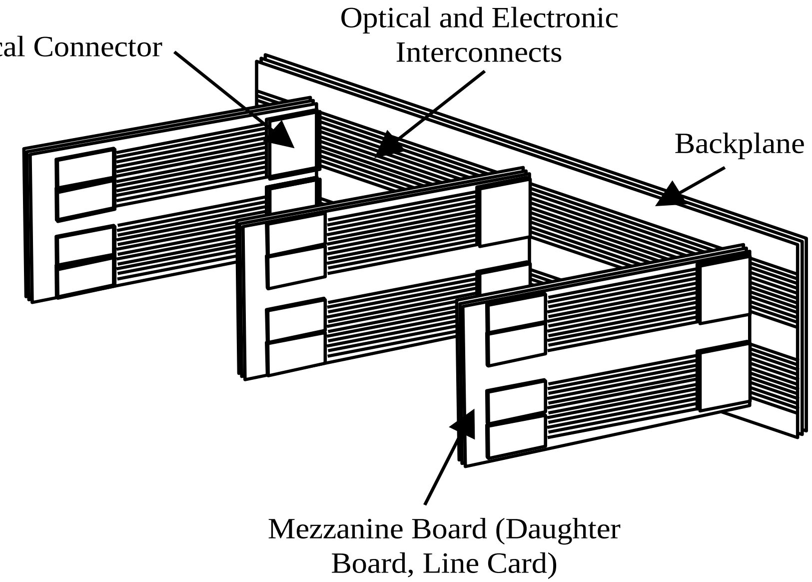
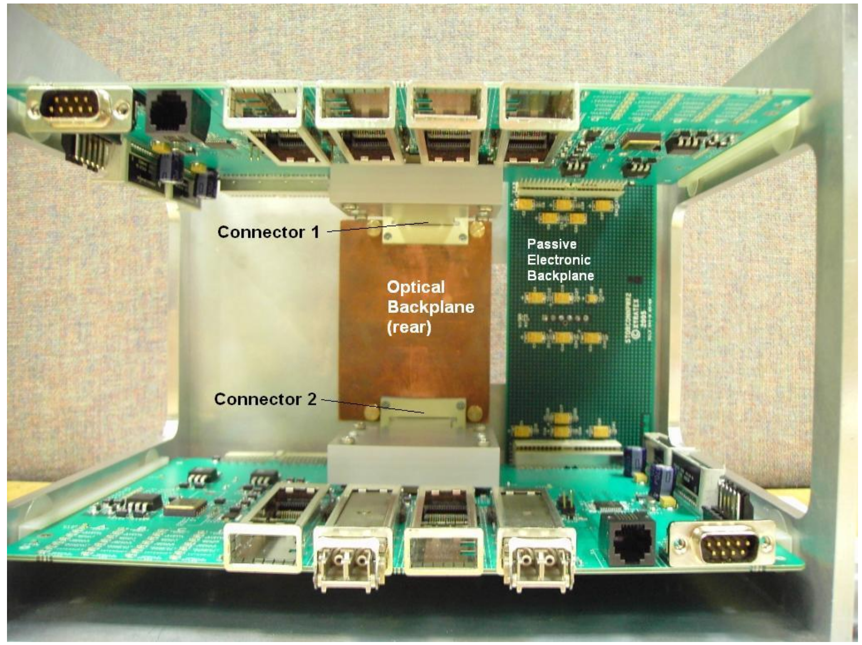
Outline

- Electronic versus Optical interconnects
- The OPCB project
- OPCB University Research Overview
  - Heriot Watt
  - Loughborough
  - UCL
- System Demonstrator

- Details of the research are presented in the individual university partners papers in this conference
- We-A-1 UCL
- We-P-16 Heriot Watt
- Th-P-9 2 papers UCL, Loughborough





Copper Tracks versus Optical Waveguides for High Bit Rate Interconnects

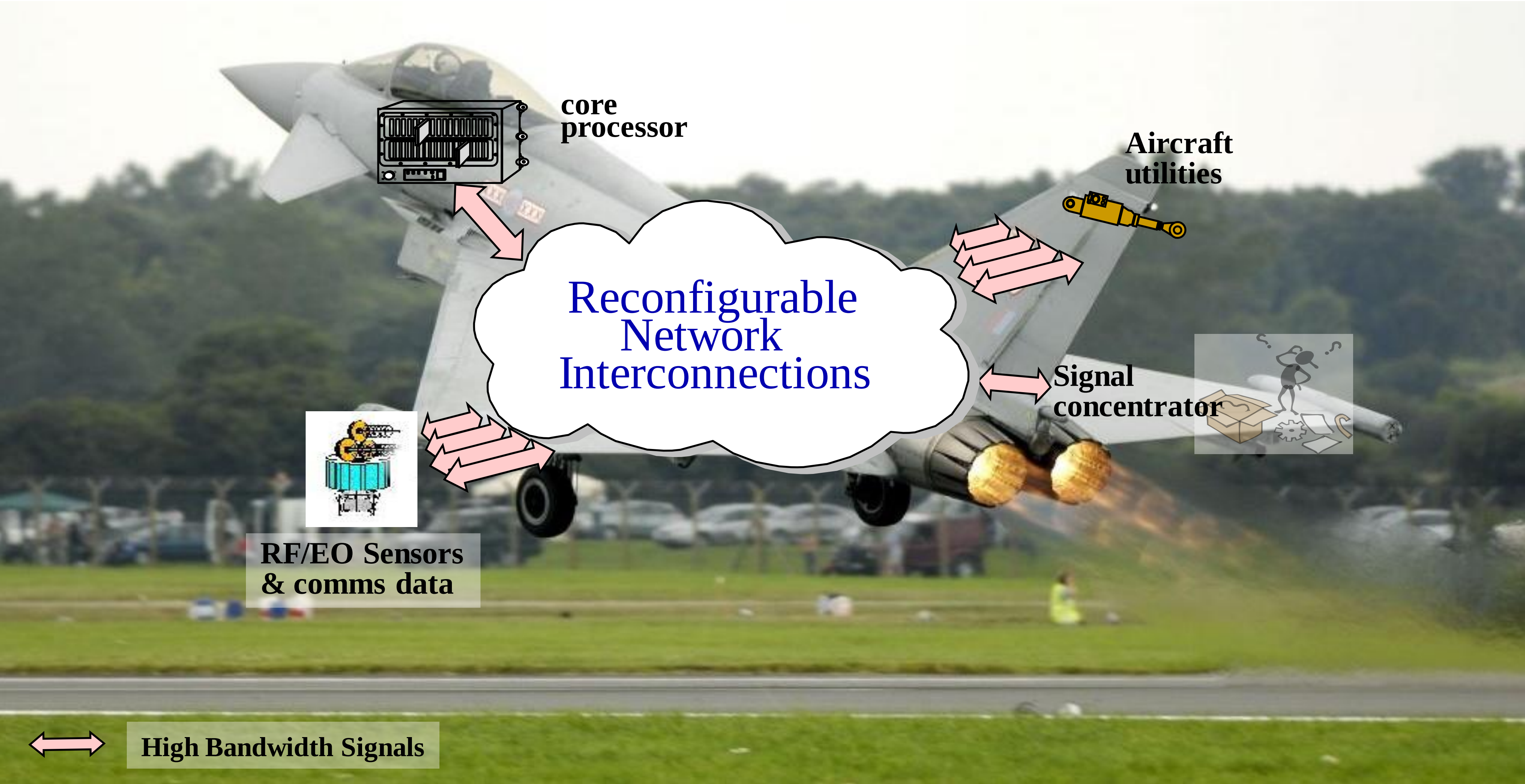
- Copper Track
  - EMI Crosstalk
  - Loss
  - Impedance control to minimize back reflections, additional equalisation, costly board material

- Optical Waveguides
  - Low loss
  - Low cost
  - Low power consumption
  - Low crosstalk
  - Low clock skew
  - WDM gives higher aggregate bit rate
  - Cannot transmit electrical power

On-board Platform Applications

BAE SYSTEMS

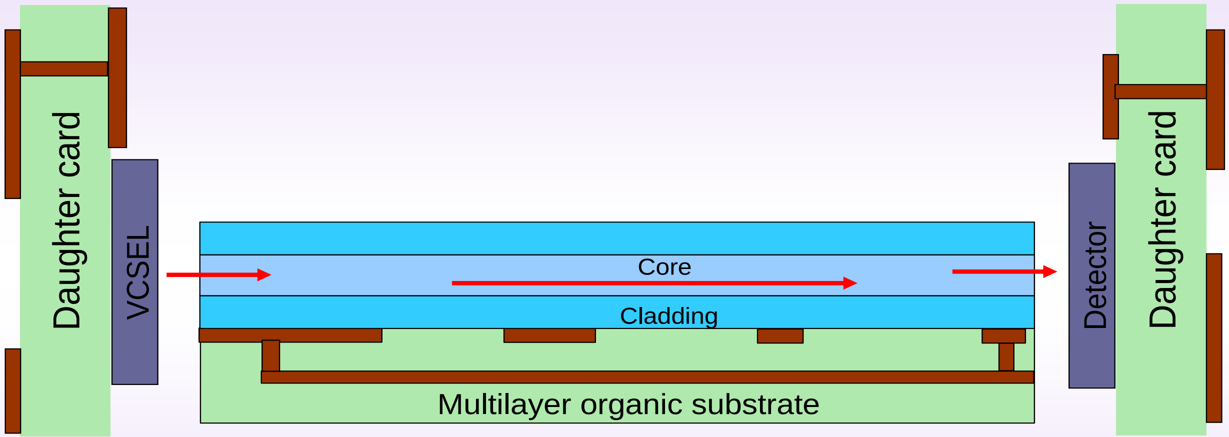
On-board Platform Applications



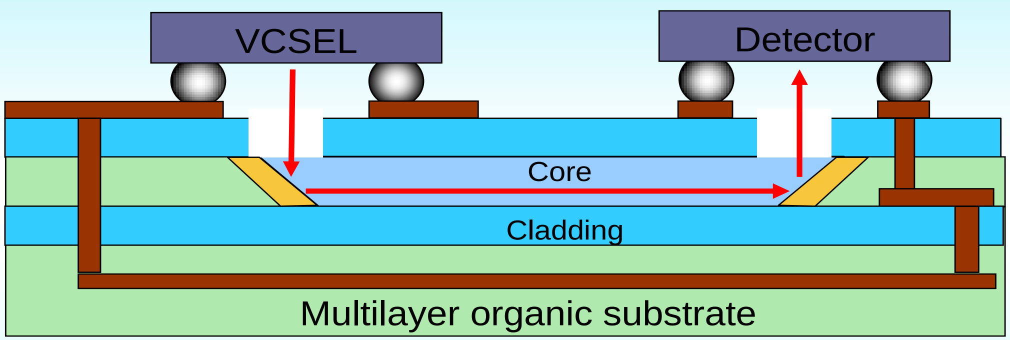
The Integrated Optical and Electronic Interconnect PCB Manufacturing (OPCB) project

- Hybrid Optical and Electronic PCB Manufacturing Techniques
- 8 Industrial and 3 University Partners led by industry end user
- Multimode waveguides at 10 Gb/s on a 19 inch PCB
- Project funded by UK Engineering and Physical Sciences Research Council (EPSRC) via the Innovative Electronics Manufacturing Research Centre (IeMRC) as a Flagship Project
- 2 years into the 3 year, £1.3 million project

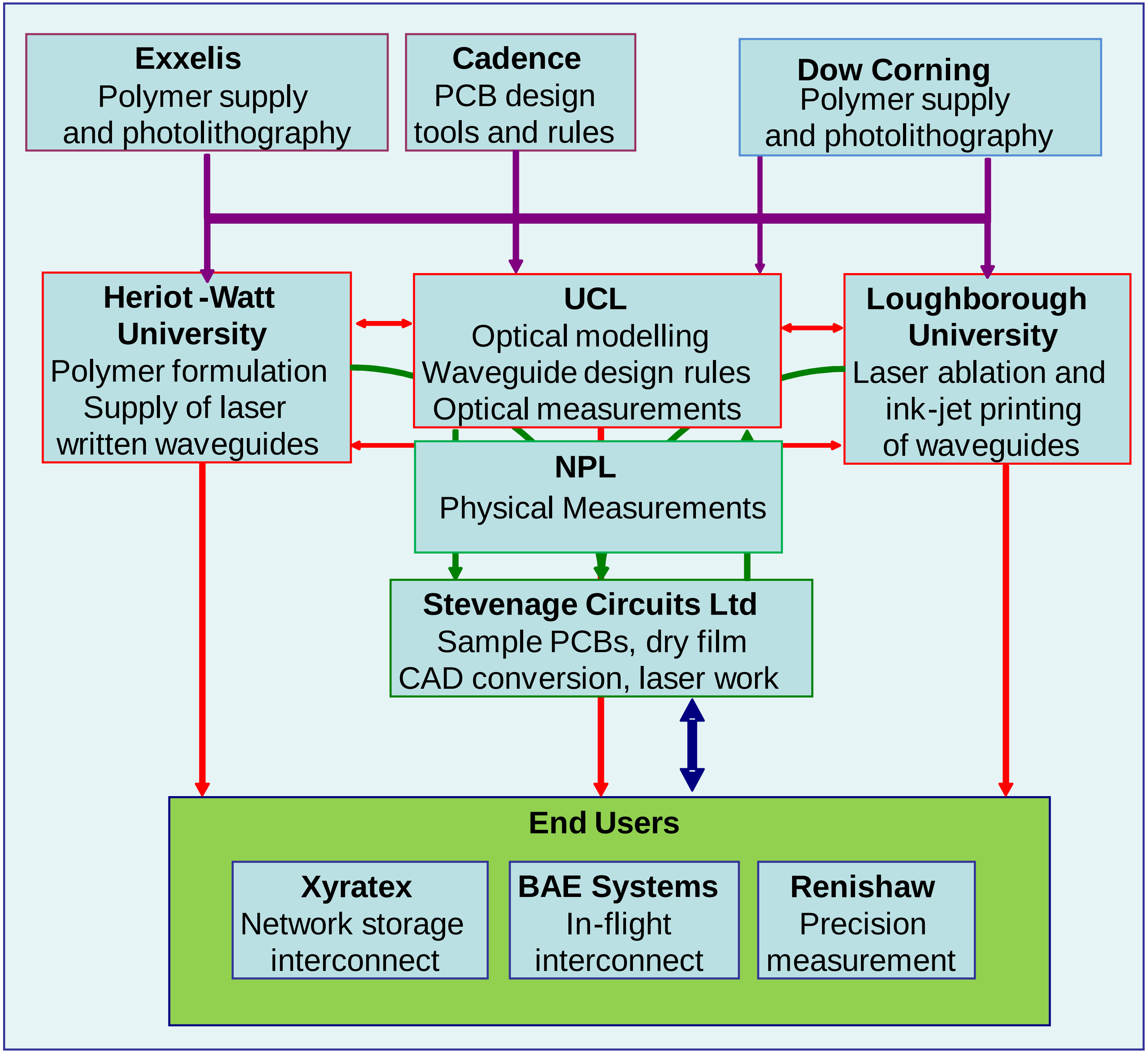
Integration of Optics and Electronics



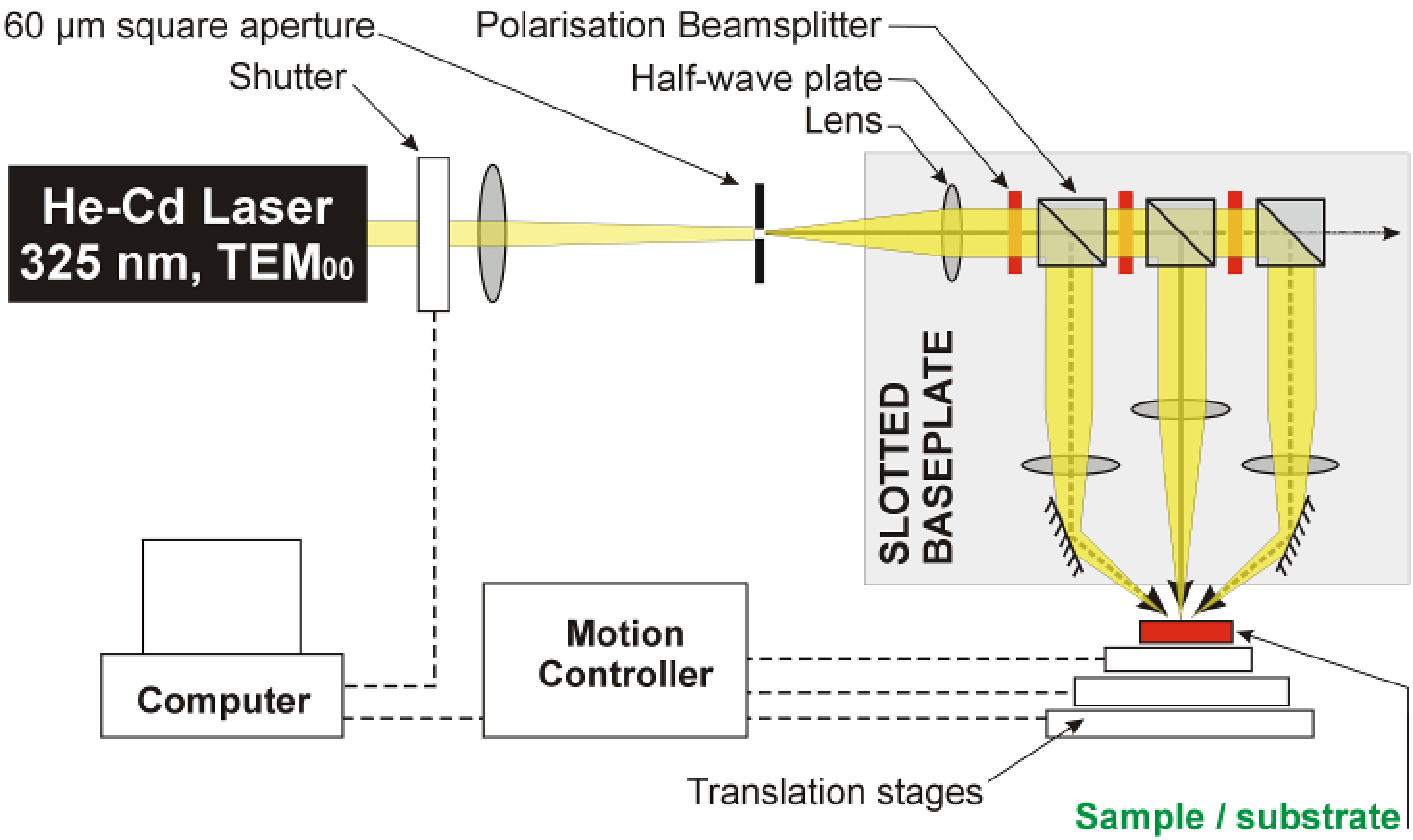
- Backplanes
  - Butt connection of “plug-in” daughter cards
  - In-plane interconnection
- Focus of OPCB project

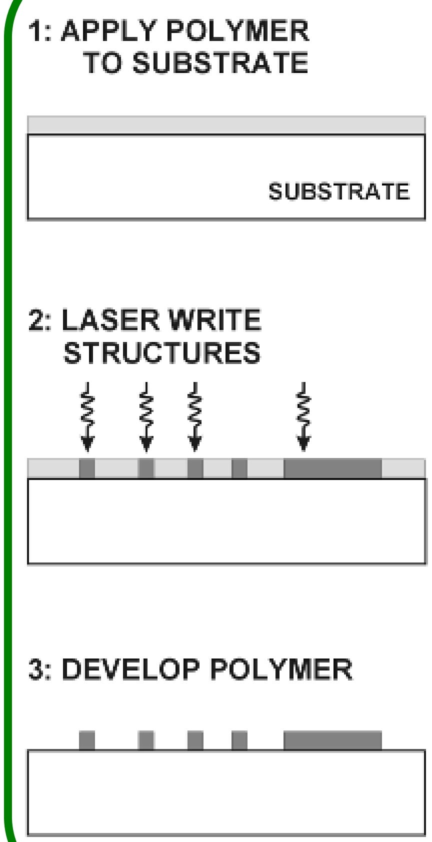


- Out-of-plane connection
  - 45 mirrors
  - Chip to chip connection possible


Exxelis
Polymer supply
and photolithography
Cadence
PCB design
tools and rules
Dow Corning
Polymer supply
and photolithography
Heriot -Watt
University
Polymer formulation
Supply of laser
written waveguides
UCL
Optical modelling
Waveguide design rules
Optical measurements
Loughborough
University
Laser ablation and
ink-jet printing
of waveguides
NPL
Physical Measurements
Stevenage Circuits Ltd
Sample PCBs, dry film
CAD conversion, laser work
End Users
Xyratex
Network storage
interconnect
BAE Systems
In-flight
interconnect
Renishaw
Precision
measurement

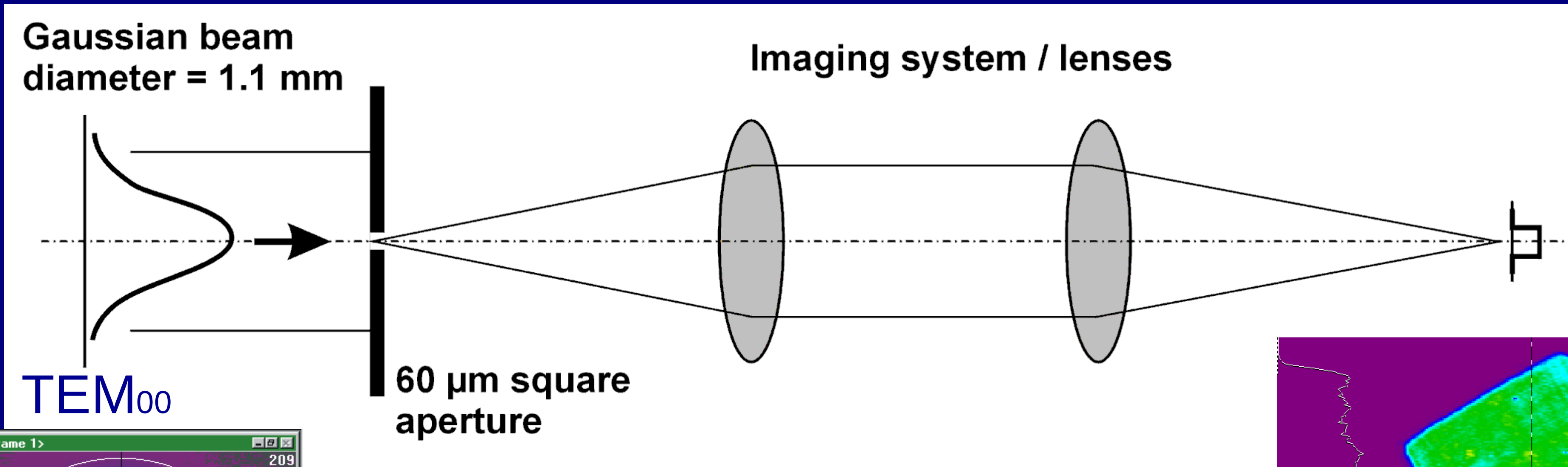
Direct Laser-writing Setup: Schematic

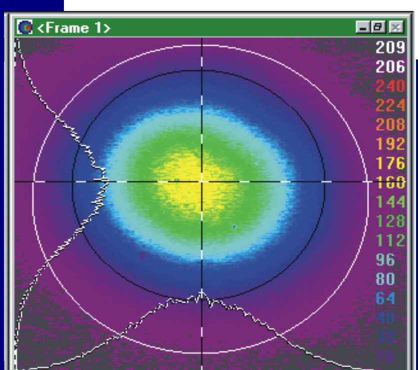


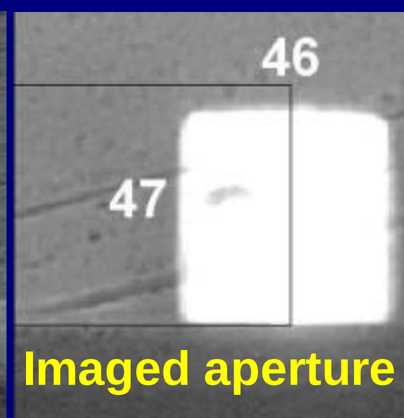


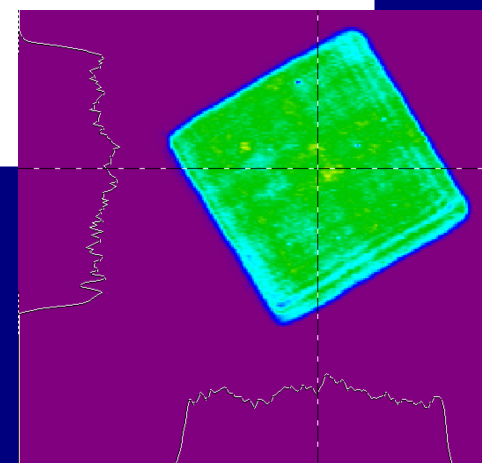
- **Slotted baseplate** mounted vertically over translation, rotation & vertical stages; components held in place with magnets
- By using two opposing 45º beams we minimise the amount of substrate rotation needed

Writing sharply defined features
– flat-top, rectangular laser spot







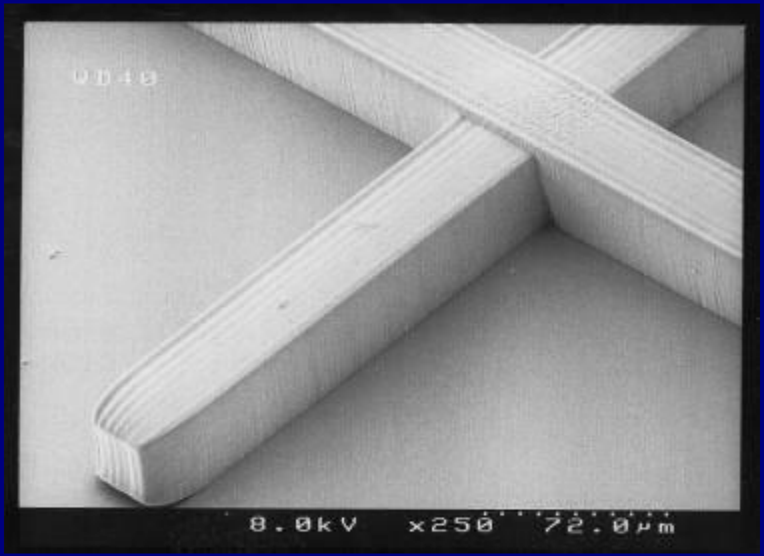


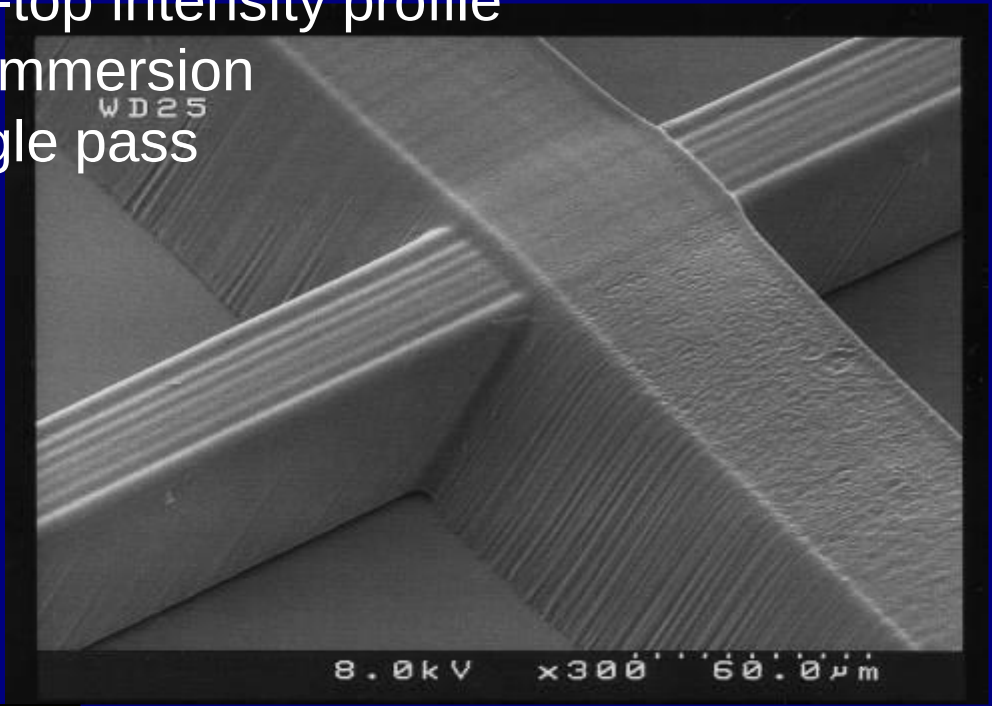
Images of the resulting waveguide
core cross-sections

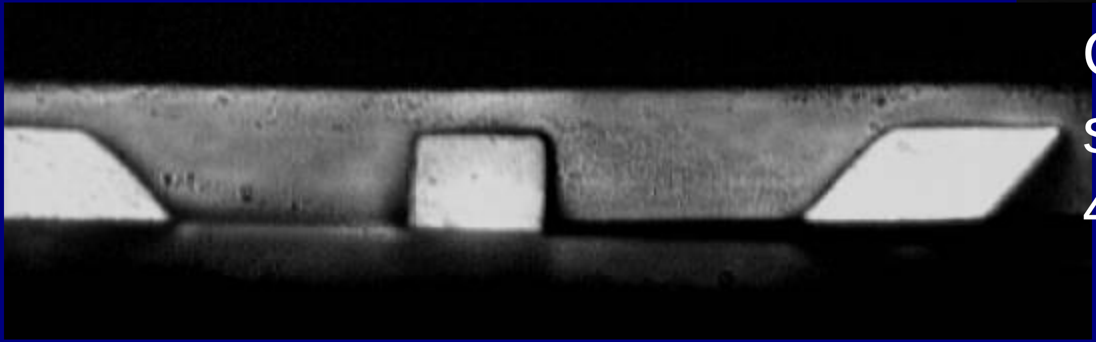
Laser written polymer structures

SEM images of polymer structures written using imaged 50 µm square aperture (chrome on glass)

- Writing speed: ~75 µm / s
- Optical power: ~100 µW
- Flat-top intensity profile
- Oil immersion
- Single pass





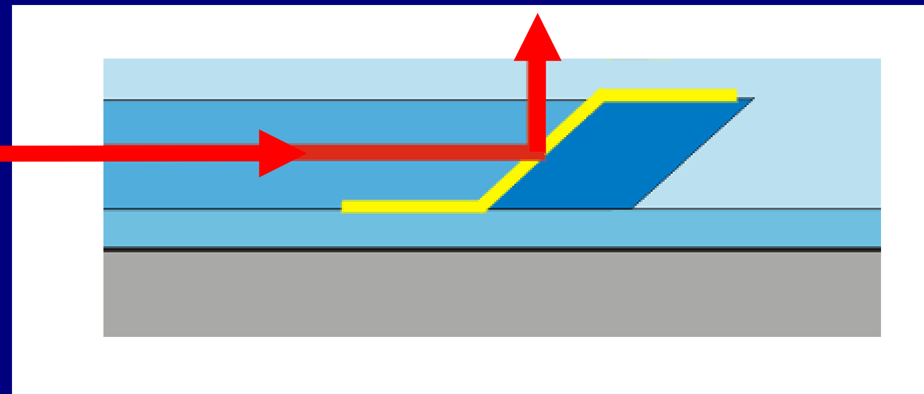


Optical microscope image showing end on view of the 45º surfaces

Waveguide terminated with 45-deg mirror

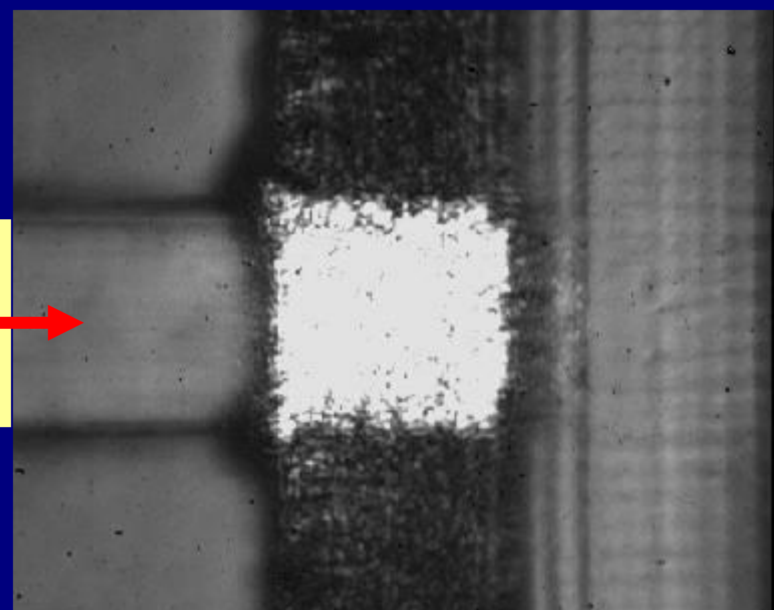
Out-of-plane coupling,

using 45-deg mirror (silver)



Microscope image looking
down on mirror
coupling light towards camera

OPTICAL INPUT



Current Results

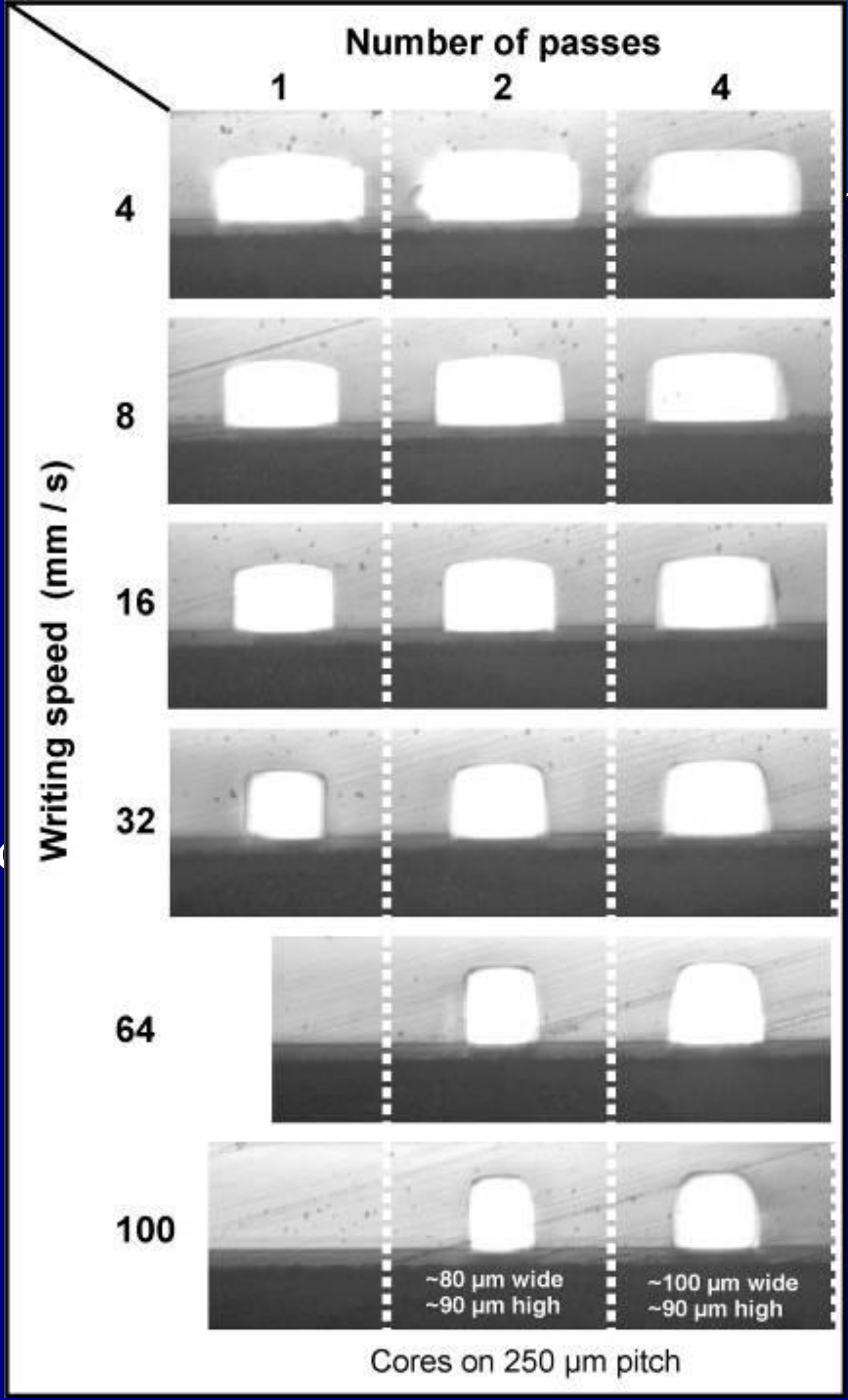
Laser-writing Parameters:

- Intensity profile: Gaussian
- Optical power: ~8 mW
- Cores written in oil

Polymer:

- Custom multifunctional acrylate photo-polymer
- Fastest "effective" writing speed to date: 50 mm/s

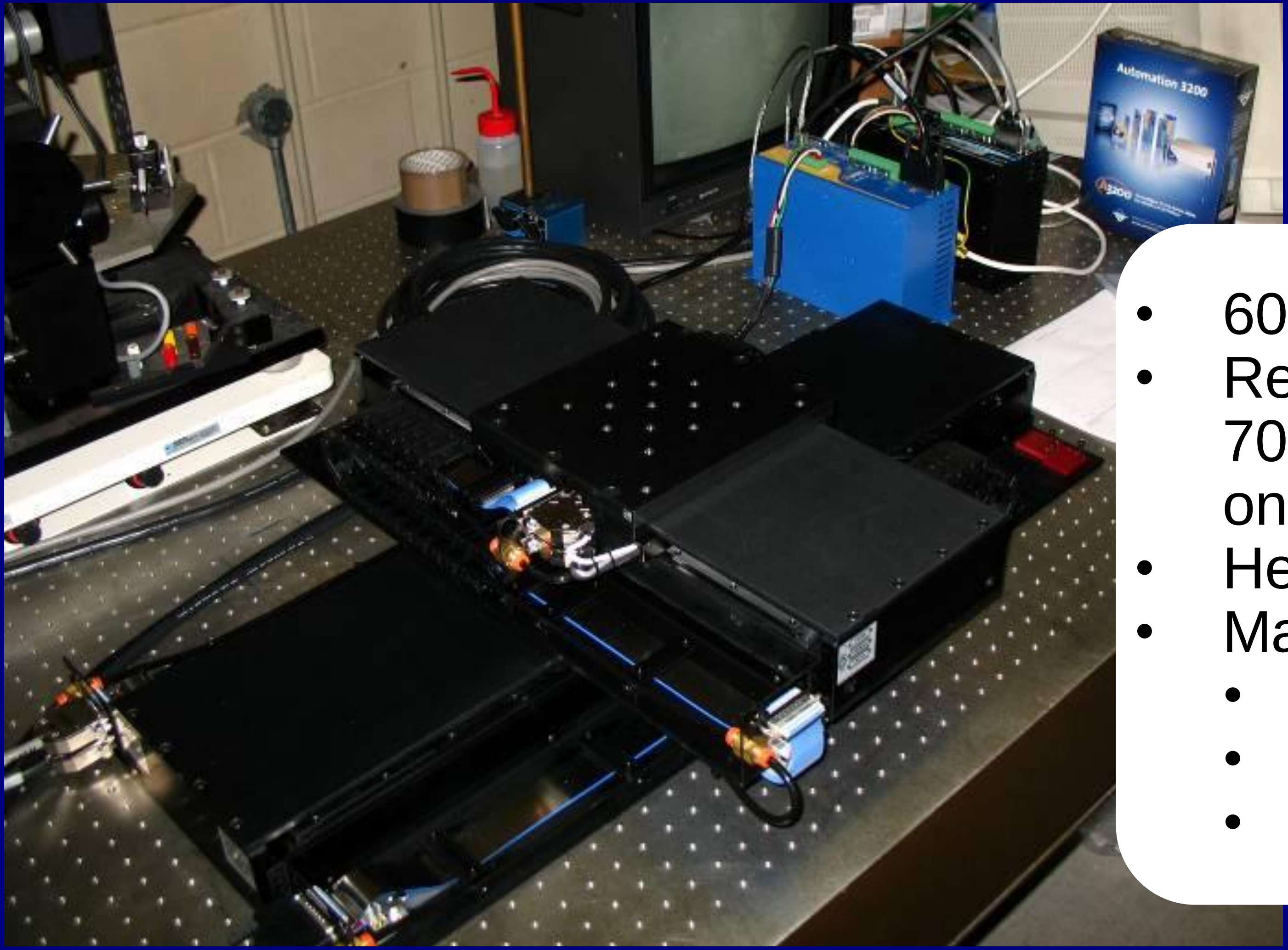
(Substrate: FR4 with polymer undercladding)



Large Board Processing: Writing

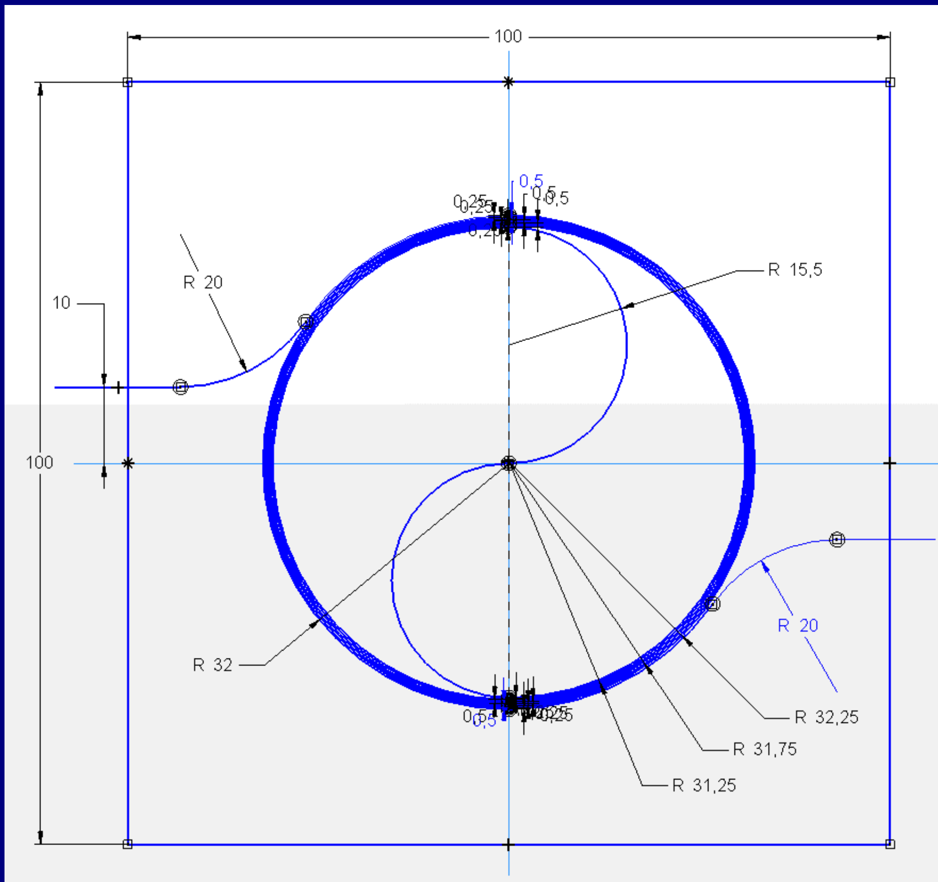
HERIOT WATT UNIVERSITY

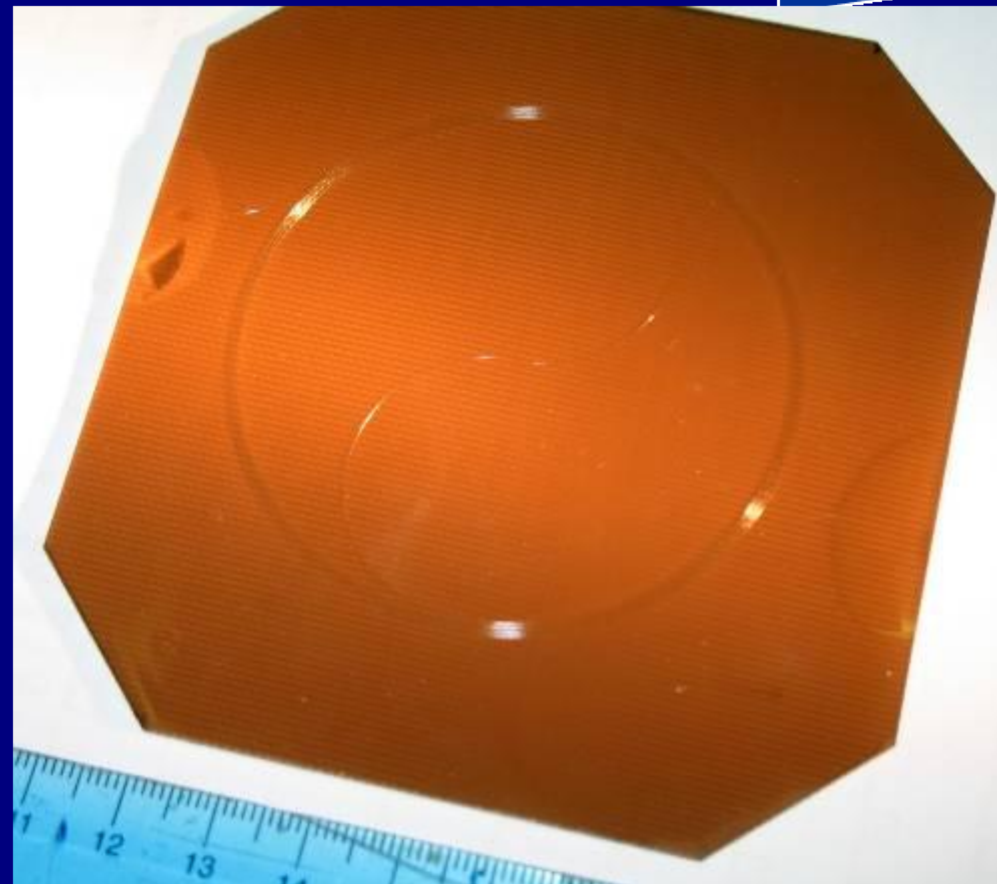
- Stationary “writing head” with board moved using Aerotech sub-µm precision stages
- Waveguide trajectories produced using CAD program



- 600 x 300 mm travel
- Requires a minimum of 700 x 1000 mm space on optical bench
- Height: ~250 mm
- Mass:
  - 300 mm: 21 kg
  - 600 mm: 33 kg
  - Vacuum tabletop

Large Board Processing: Writing

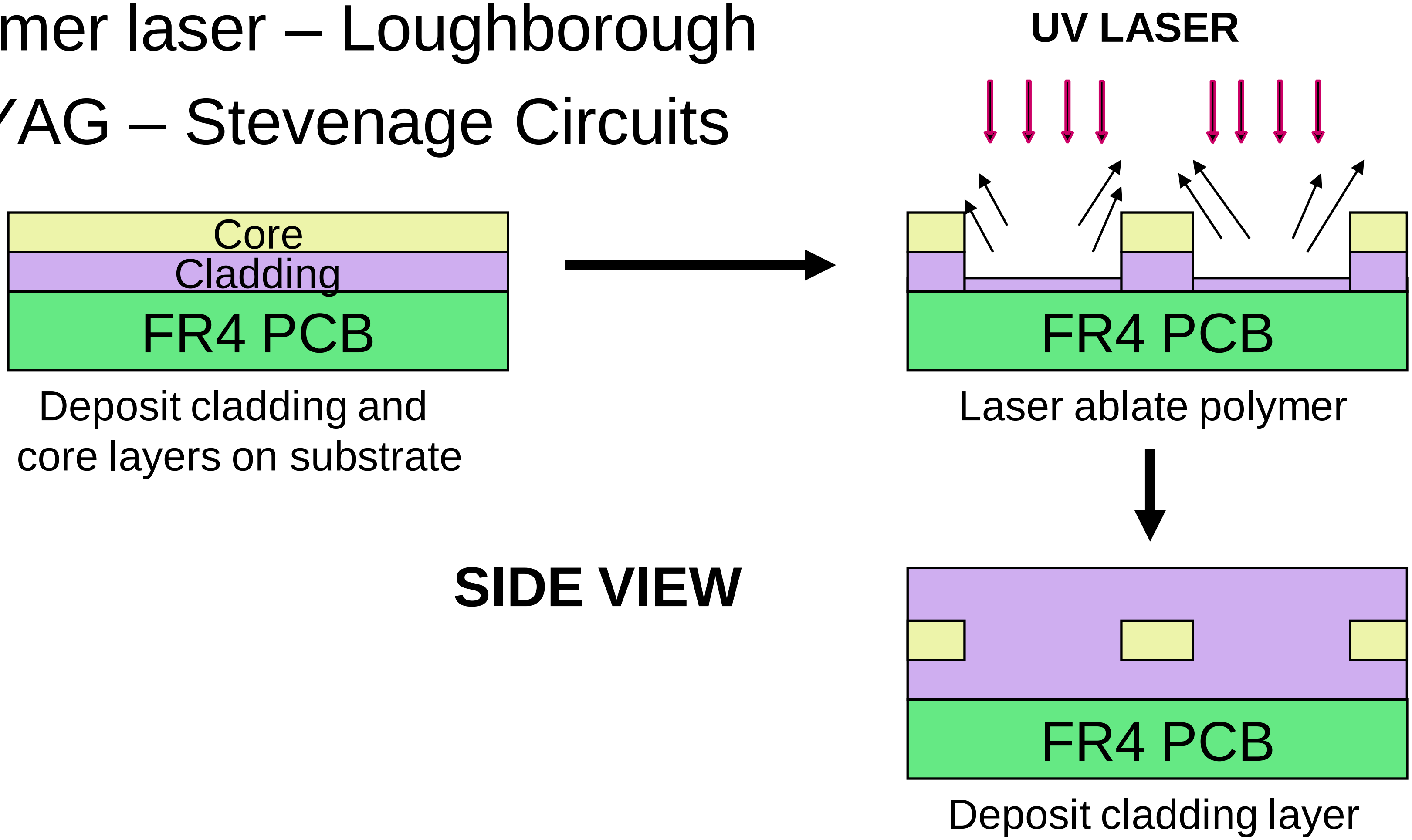




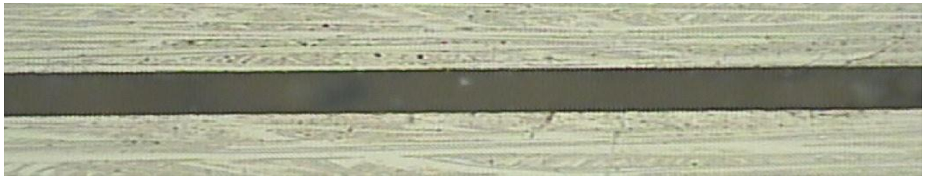
The spiral was fabricated using a Gaussian intensity profile at a writing speed of 2.5 mm/s on a 10 x 10 cm lower clad FR4 substrate. Total length of spiral waveguide is **~1.4 m**. The spiral was upper cladded at both ends for cutting.

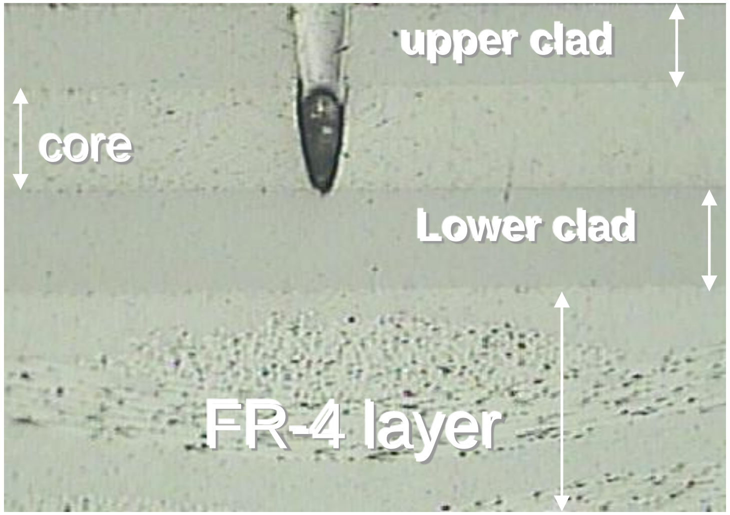
Laser Ablation for Waveguide Fabrication

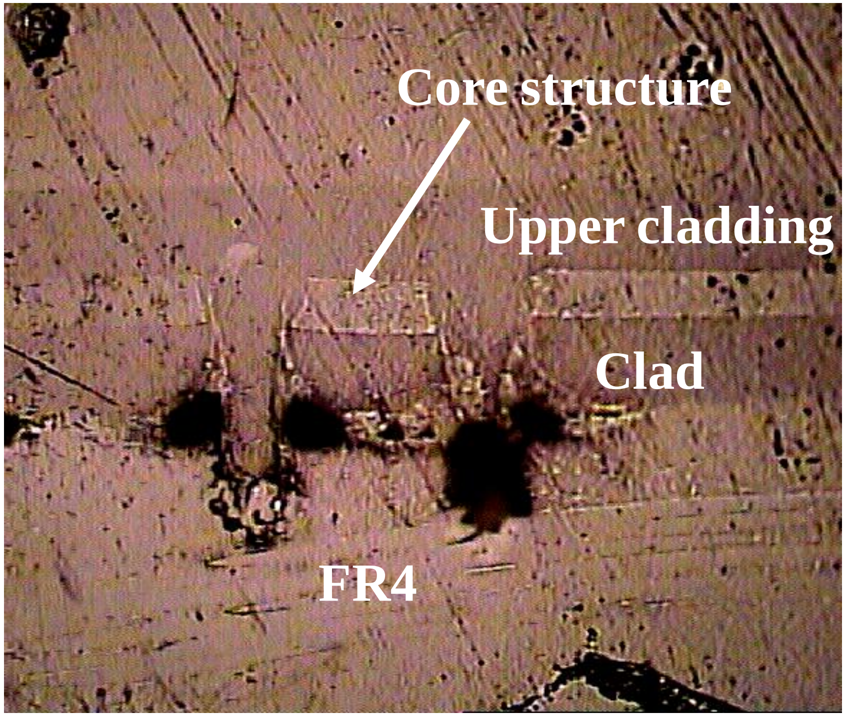
- Ablation to leave waveguides
- Excimer laser – Loughborough
- Nd:YAG – Stevenage Circuits



Nd:YAG Ablation

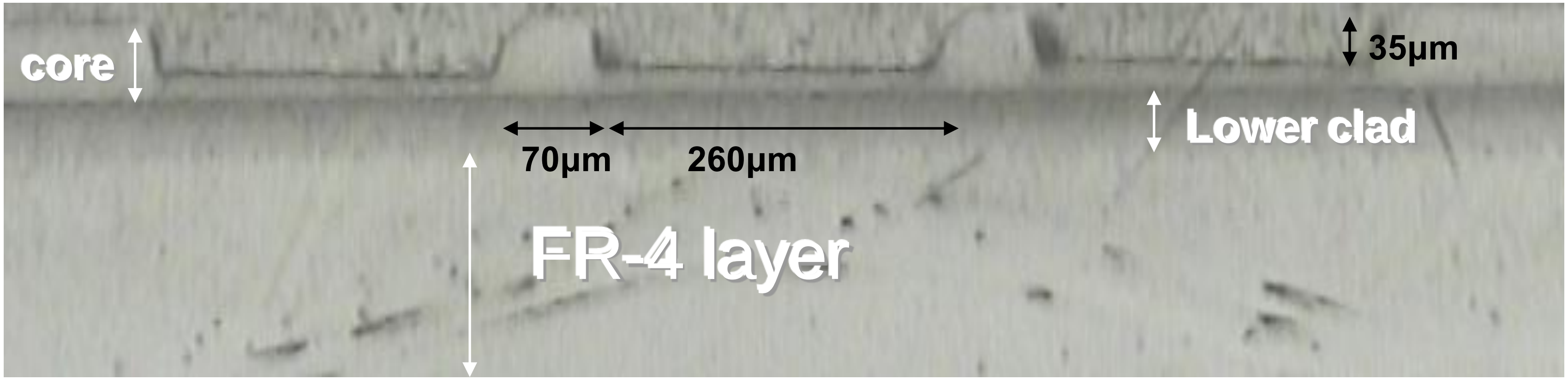






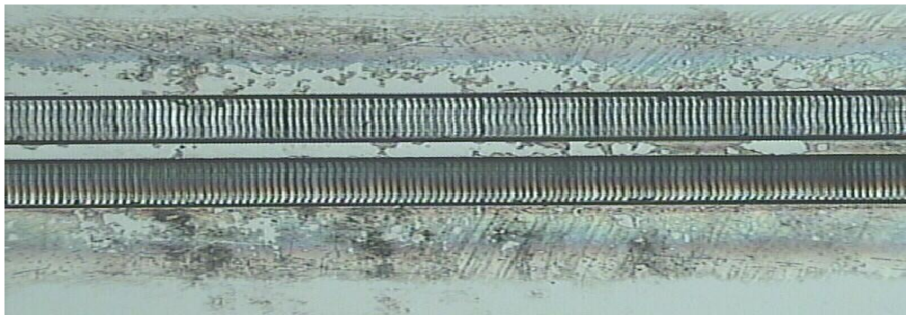
- Nd:YAG laser based at Stevenage Circuits
- Grooves machined in optical polymer and ablation depth characterised for machining parameters
- Initial waveguide structures prepared

Excimer Laser Ablation



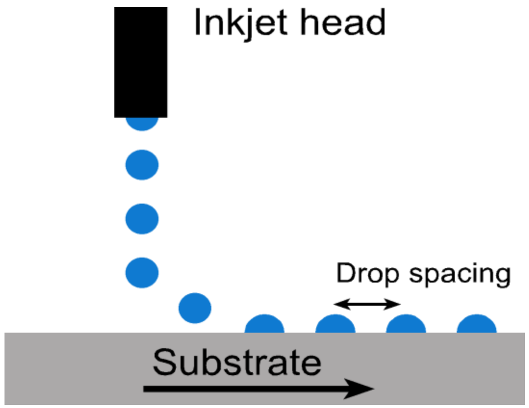
Cross-section

- Straight structures machined in polymer
- Future work to investigate preparation of curved mirrors for out of plane interconnection

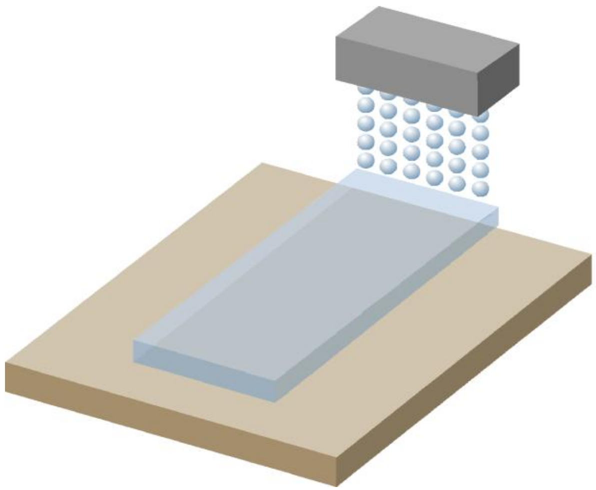


Plan View

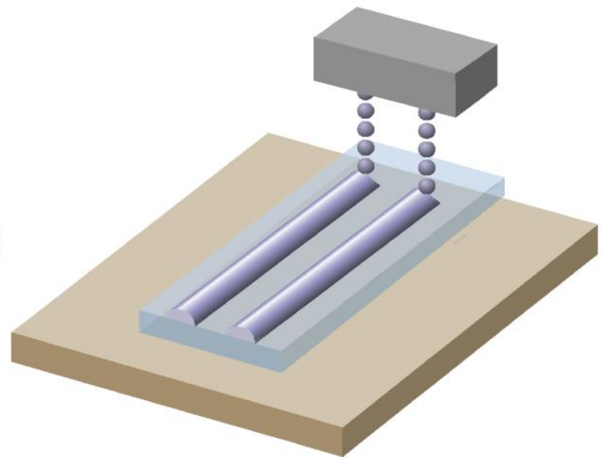
Inkjetting as a Route to Waveguide Deposition



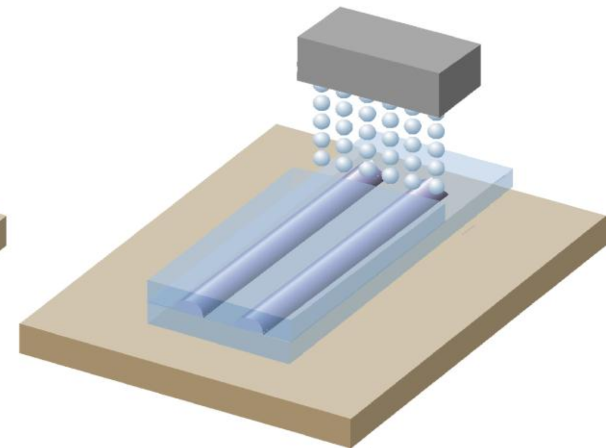
- Print polymer then UV cure
- Advantages:
  - controlled, selective deposition of core and clad
  - less wastage: picolitre volumes
  - large area printing
  - low cost



Deposit Lower Cladding



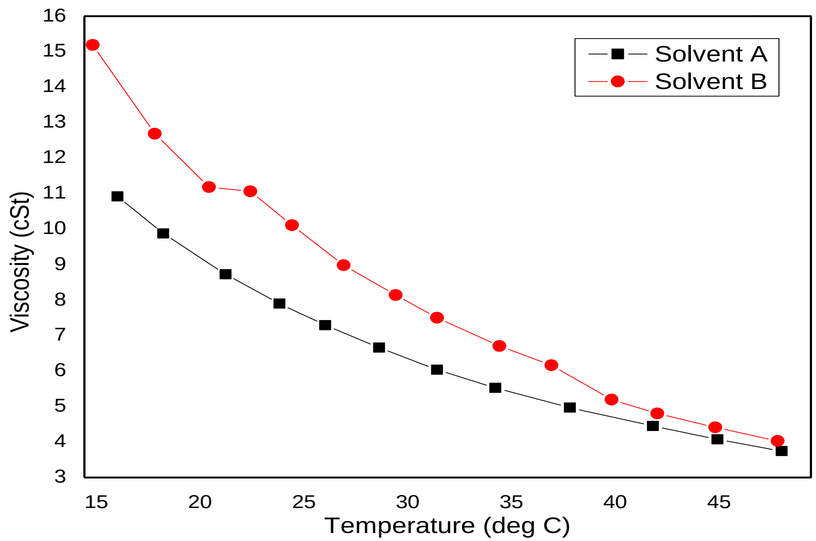
Deposit Core

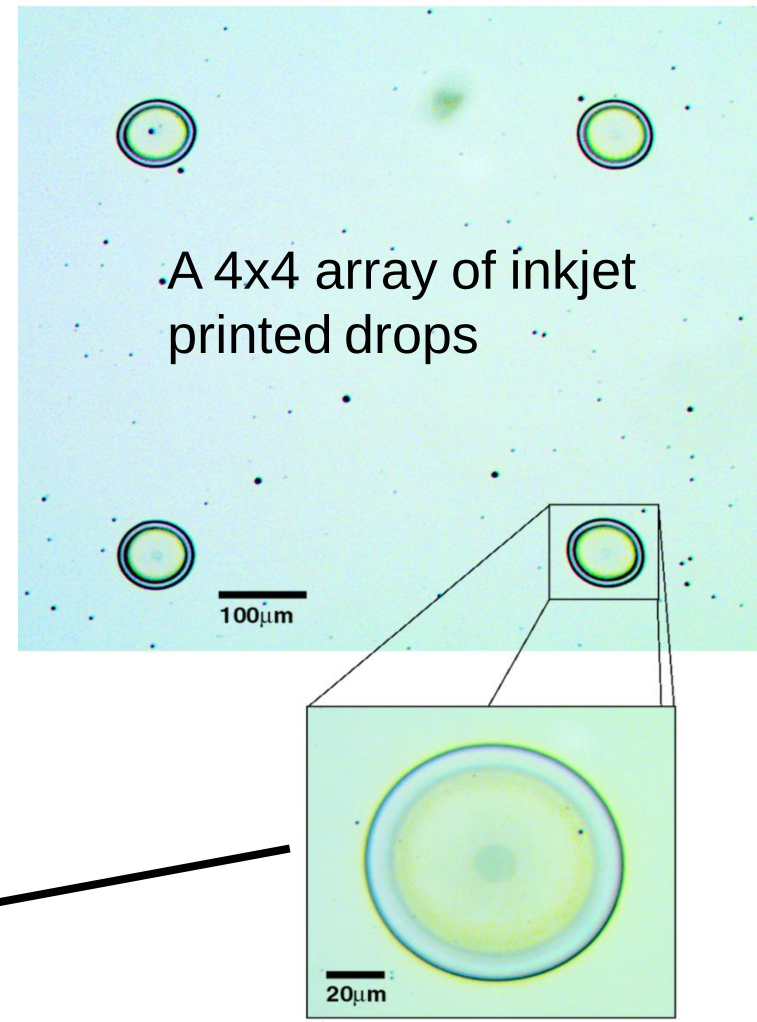


Deposit Upper Cladding

Challenges of Inkjet Deposition

- Viscosity tailored to inkjet head via addition of solvent
- “Coffee stain” effects

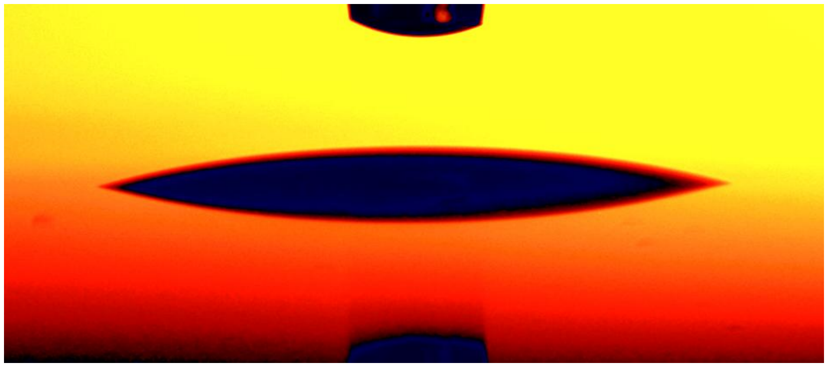


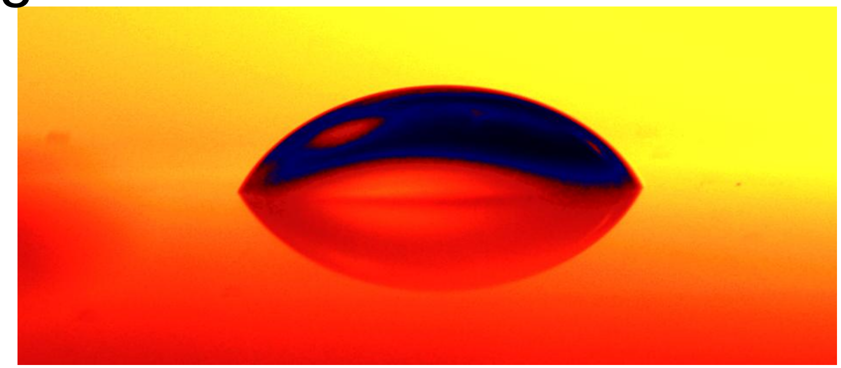


Cross-section of dried droplet
“coffee-stain” effect

Changing Surface Wettability

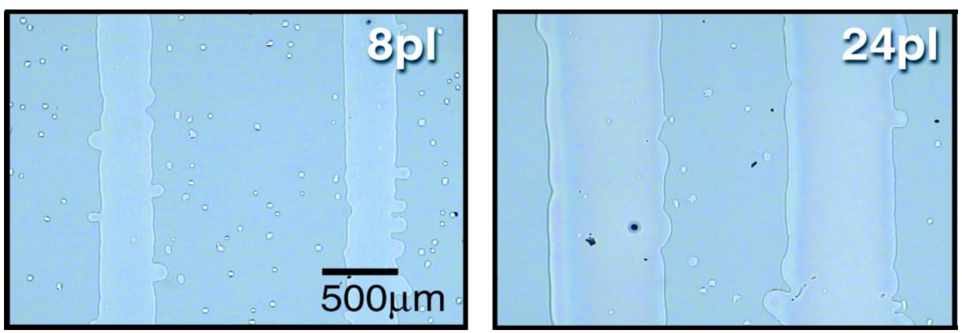
Contact Angles



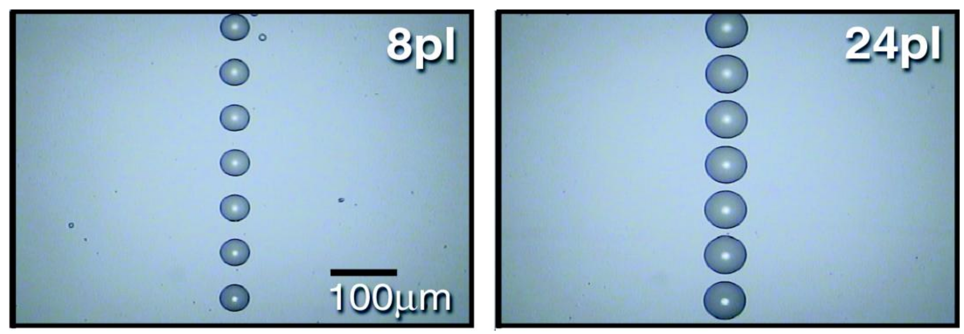


Core material on cladding

Core material on modified glass surface (hydrophobic)



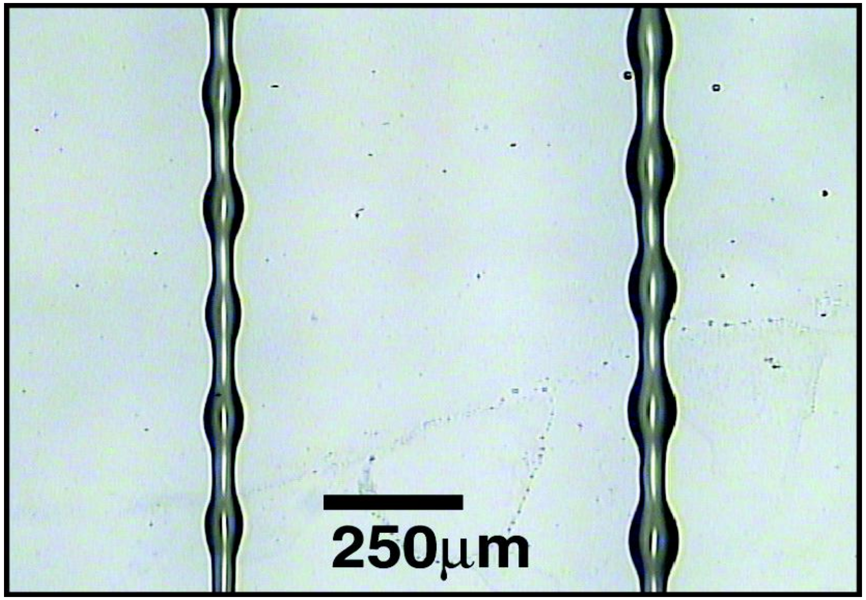
Large wetting - broad inkjetted lines



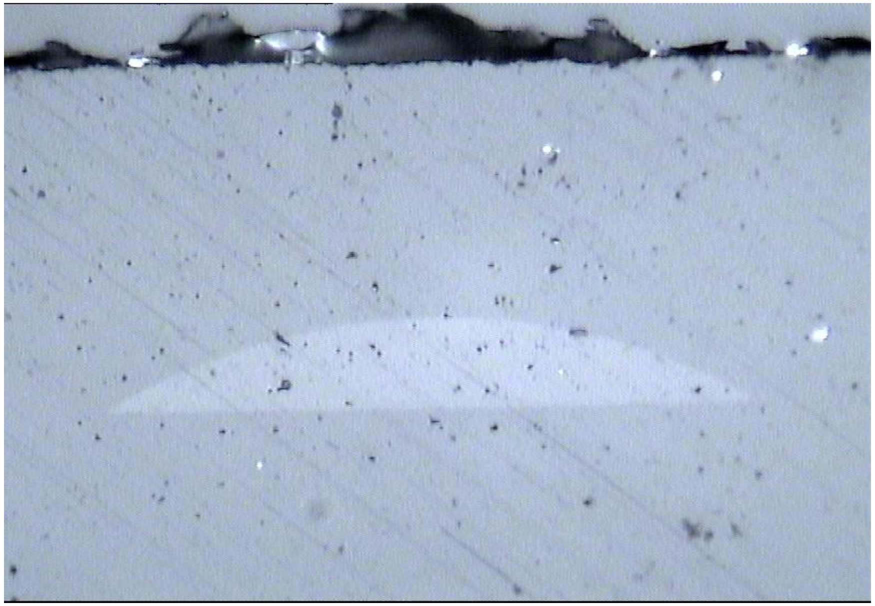
Reduced wetting – discrete droplets

Identical inkjetting conditions - spreading inhibited on modified surface

Towards Stable Structures



Stable line structures with periodic features

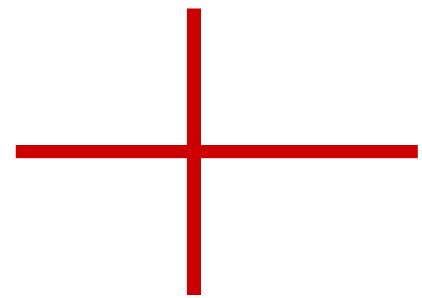


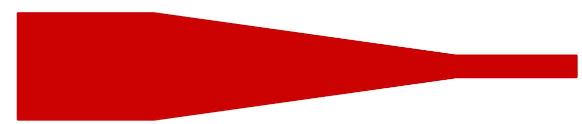
Cross section of inkjetted core material surrounded by cladding (width 80 microns)

A balance between wettability, line stability and adhesion

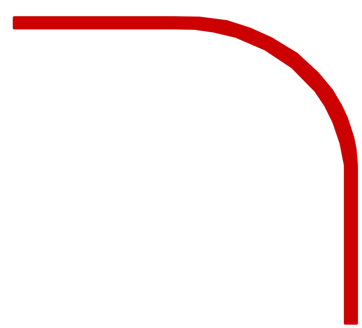
Waveguide components and measurements

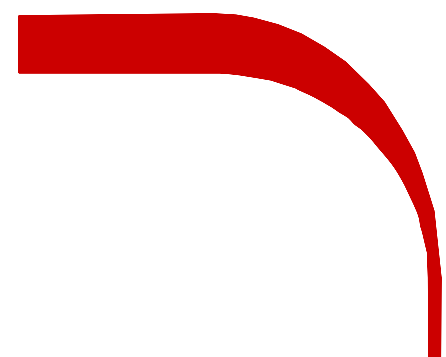
- Straight waveguides 480 mm x 70 µm x 70 µm
- Bends with a range of radii
- Crossings
- Spiral waveguides
- Tapered waveguides
- Bent tapered waveguides



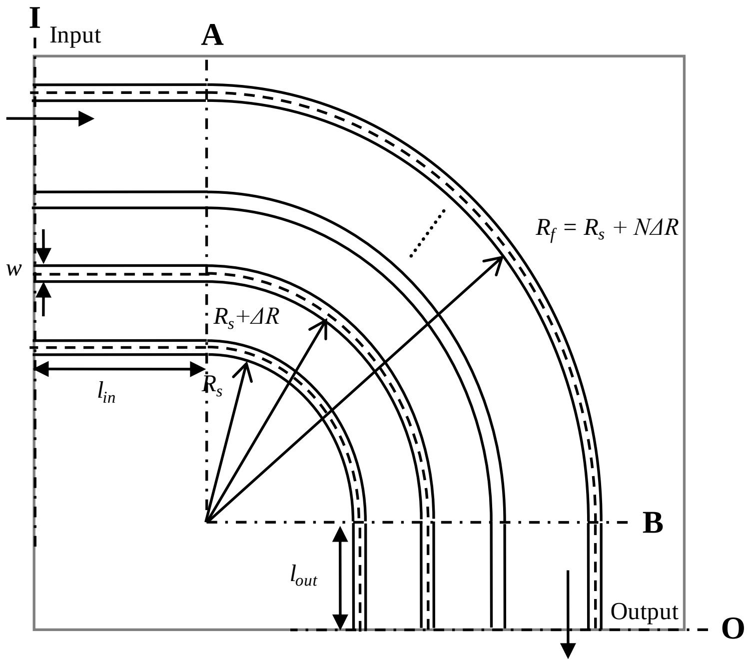


- Loss
- Crosstalk
- Misalignment tolerance
- Surface Roughness
- Bit Error Rate, Eye Diagram

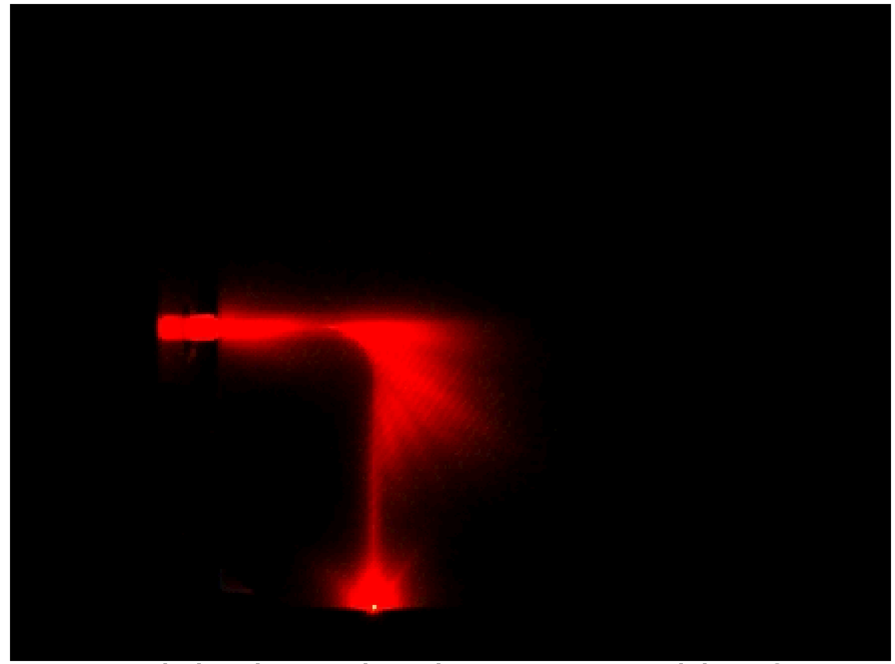




Optical Power Loss in 90 Waveguide Bends



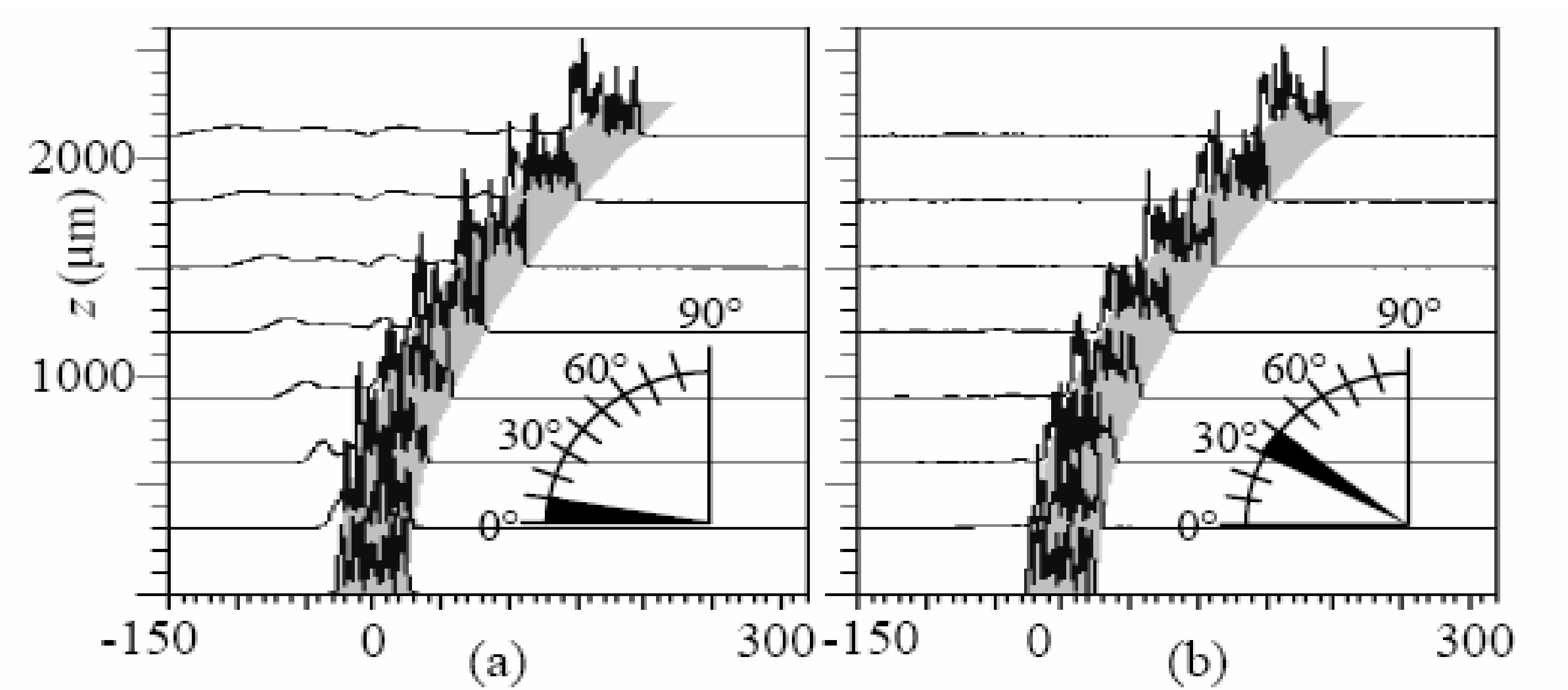
Schematic diagram of one set of curved waveguides.



Light through a bent waveguide of R = 5.5 mm – 34.5 mm

- Radius R, varied between 5.5 mm < R < 35 mm, ΔR = 1 mm
- Light lost due to scattering, transition loss, bend loss, reflection and back-scattering
- Illuminated by a MM fiber with a red-laser.

BPM, beam propagation method modeling of optical field in bend segments

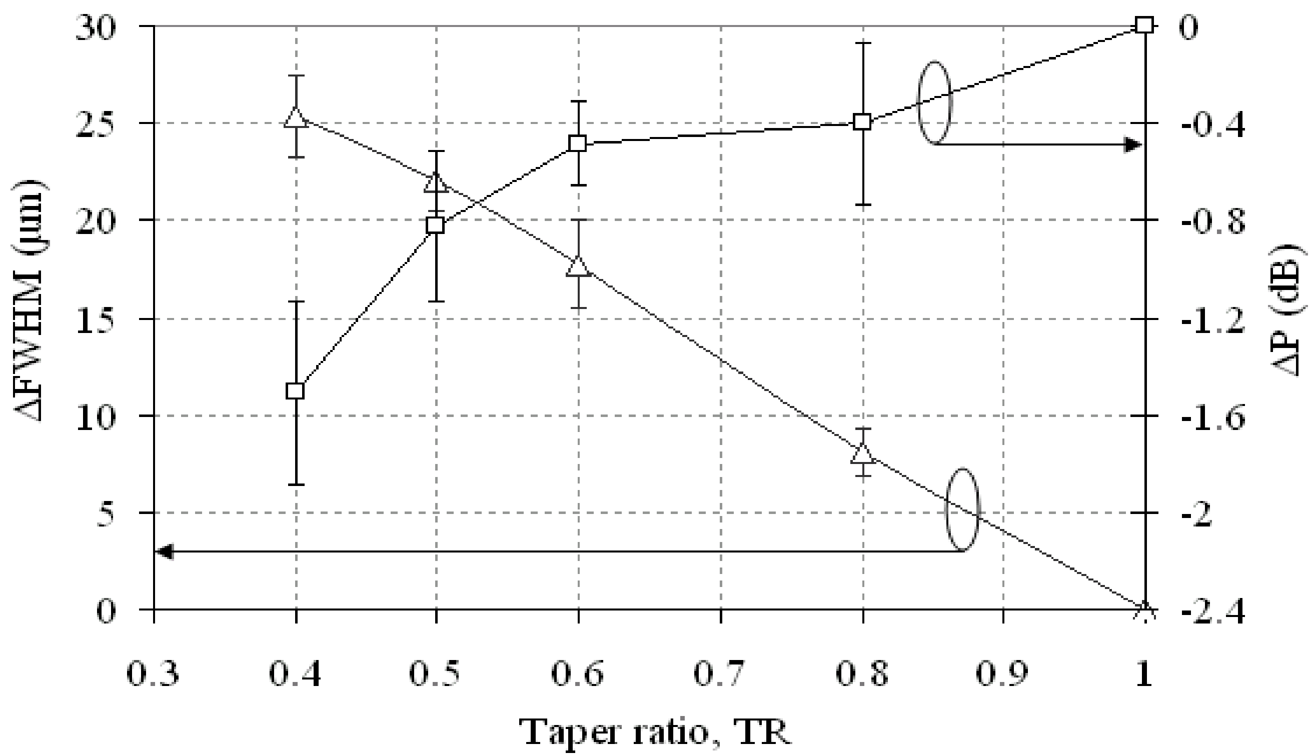


w = 50 μm, R = 13 mm

(left picture) in the first segment (first 10°).

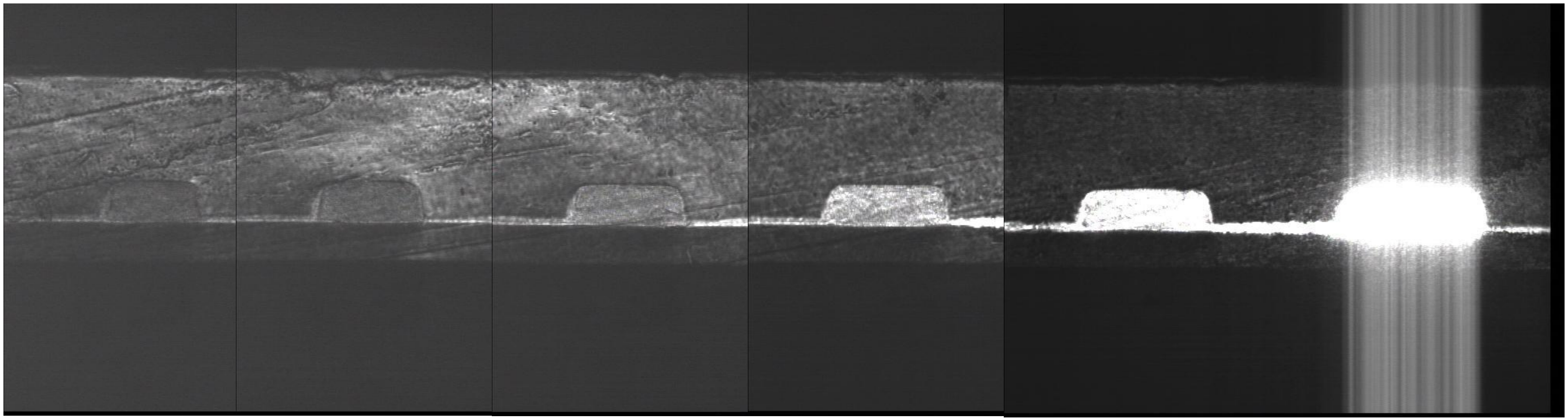
(right picture) in the 30° to 40° degree segment.

Differences in misalignment tolerance and loss as a function of taper ratio



- Graph plots the differences between a tapered bend and a bend
- There is a trade off between insertion loss and misalignment tolerance

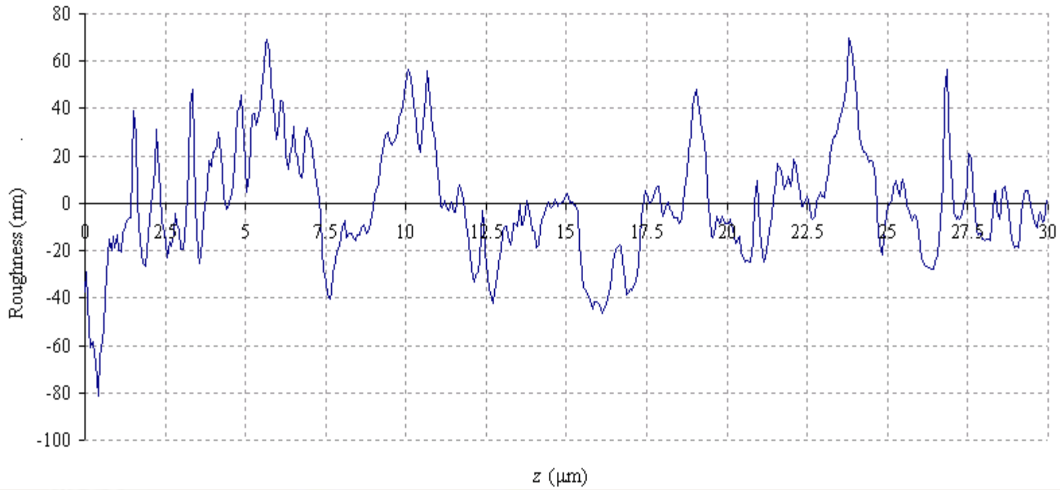
Crosstalk in Chirped Width Waveguide Array



100 µm 110 µm 120 µm 130 µm 140 µm 150 µm

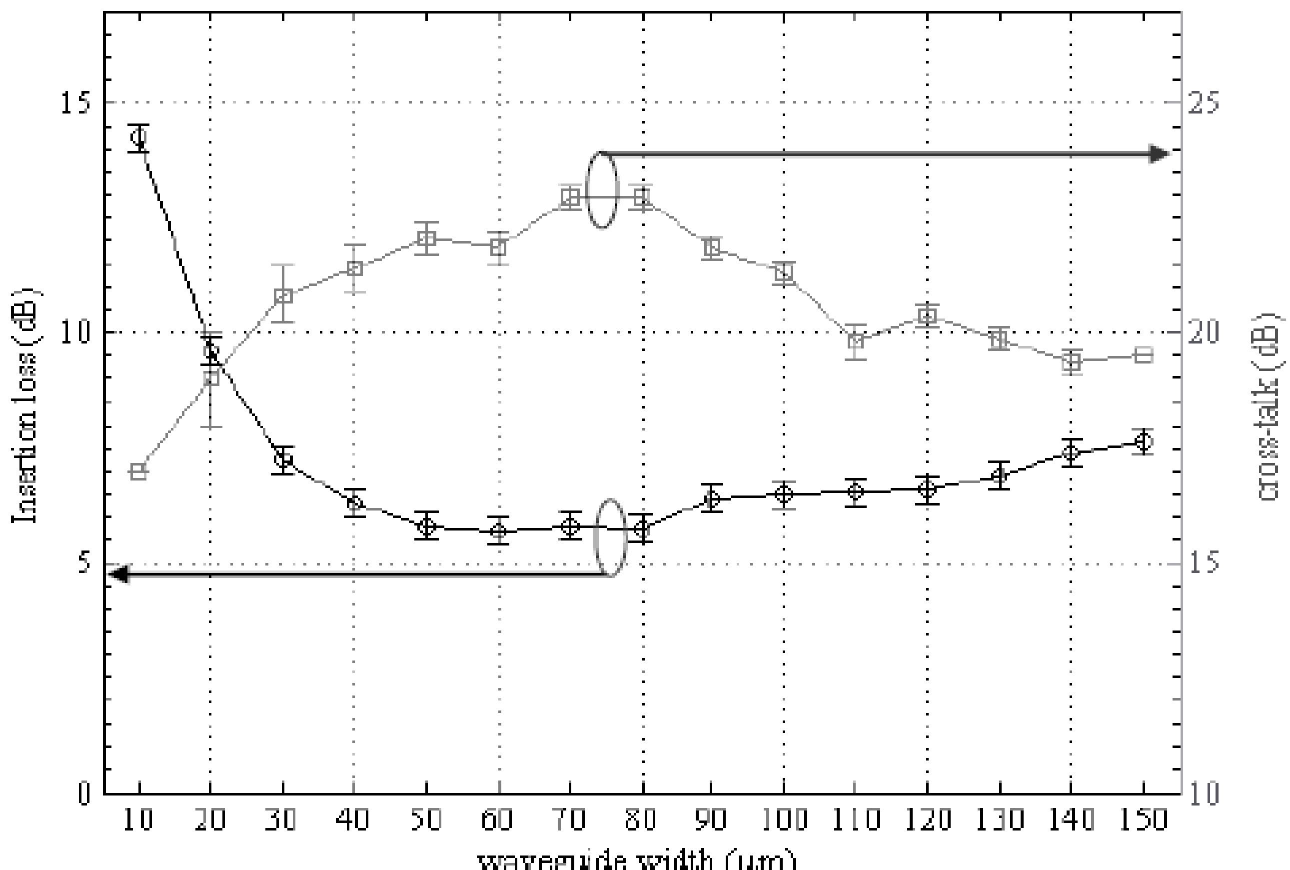
- Light launched from VCSEL imaged via a GRIN lens into 50 µm x 150 µm waveguide
- Photolithographically fabricated chirped with waveguide array
- Photomosaic with increased camera gain towards left

Surface roughness



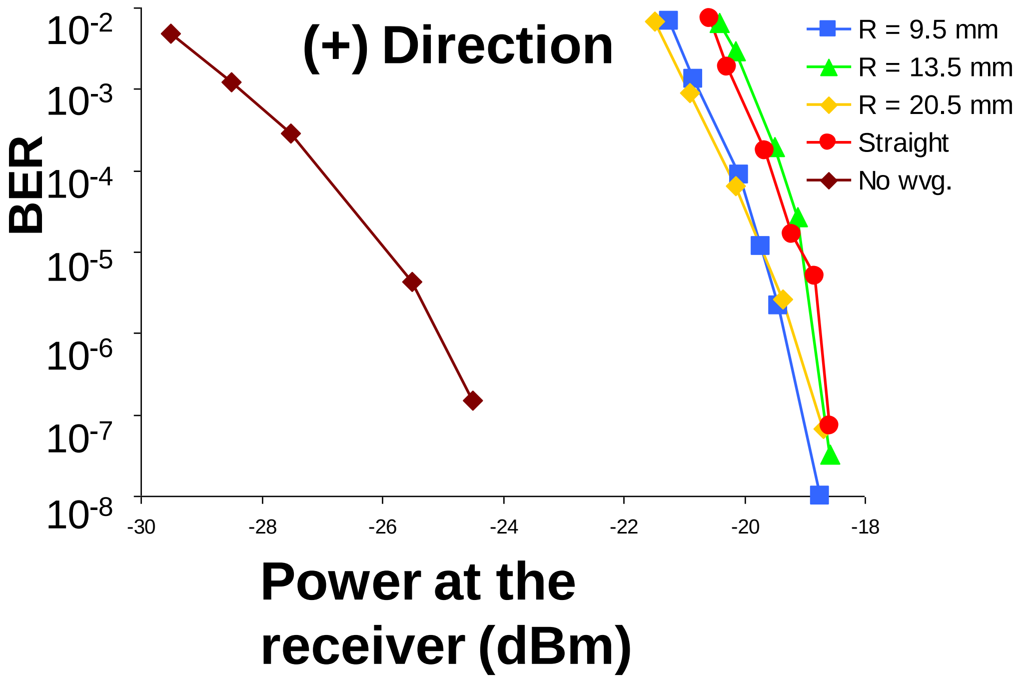
- RMS side wall roughness: 9 nm to 74 nm
- RMS polished end surface roughness: 26 nm to 192 nm.

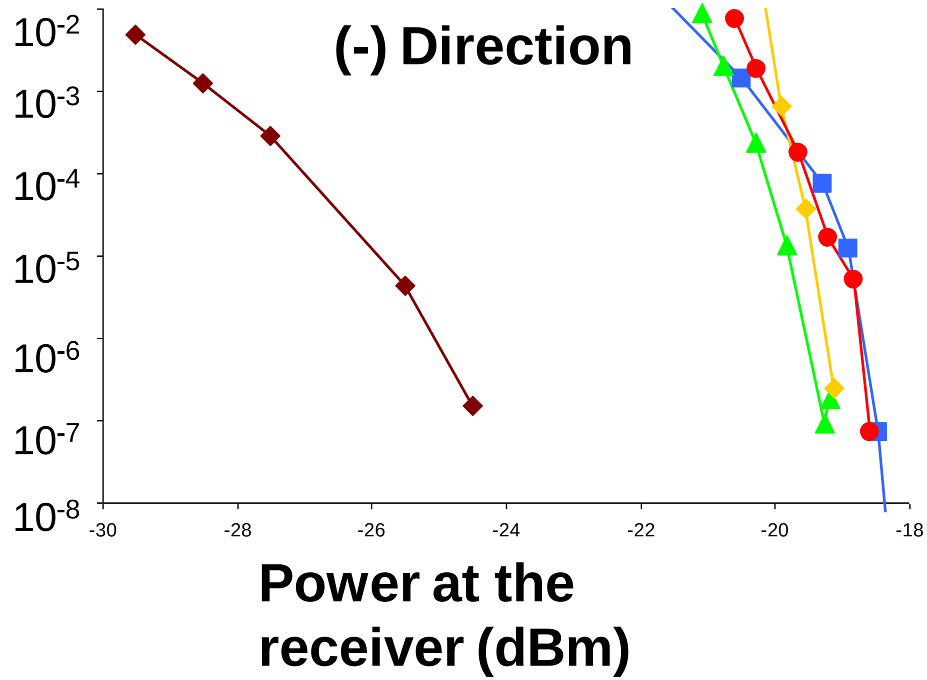
Design rules for waveguide width depending on insertion loss and cross-talk



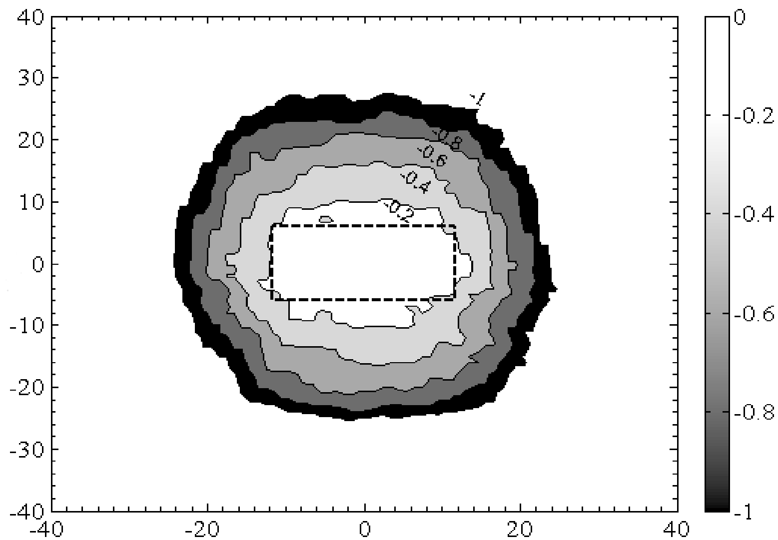
6~7dB for a 70 μm width waveguide

Bit error rate for laterally misaligned 1550 nm 2.5 Gb/s DFB laser

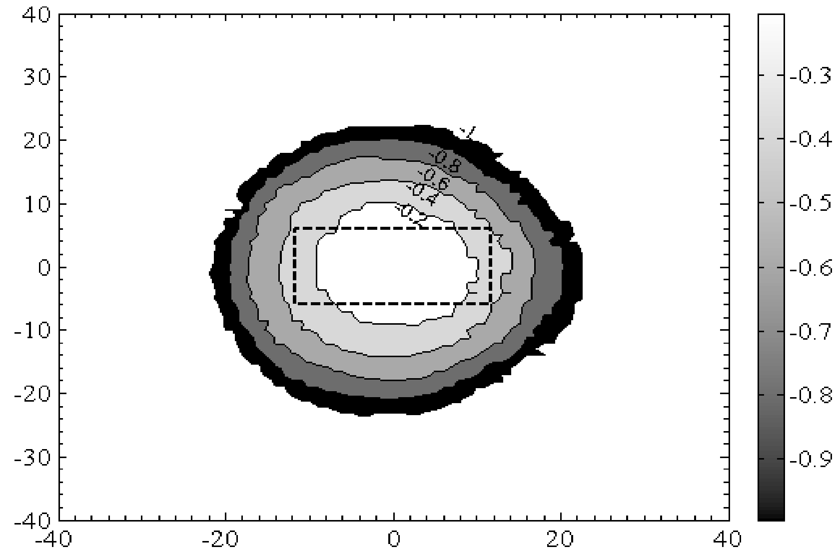




Contour map of VCSEL and PD misalignment



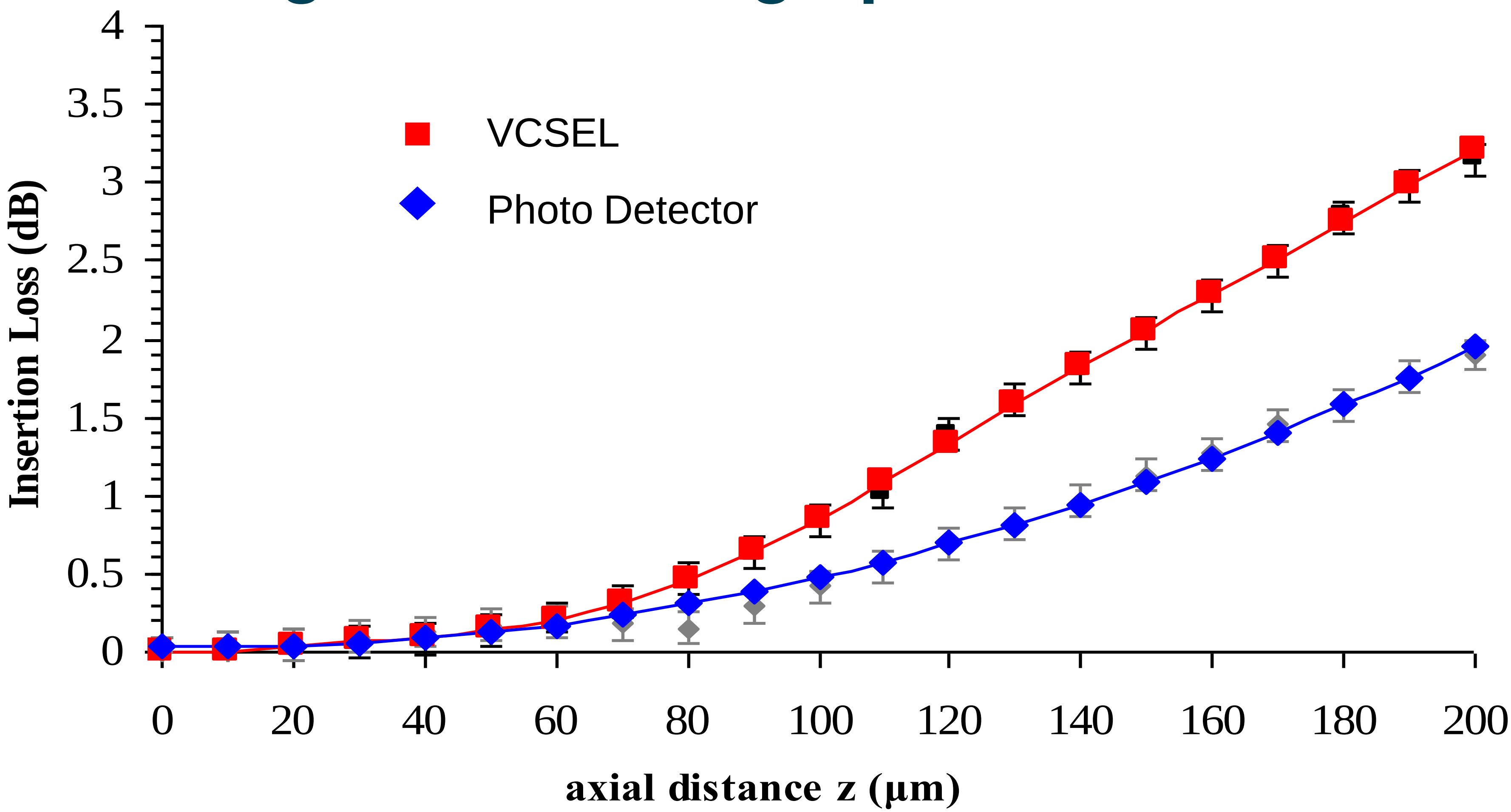
(a) Contour map of relative insertion loss compared to the maximum coupling position for VCSEL misalignment at z = 0.



(b) Same for PD misalignment at z = 0. Resolution step was $\Delta x = \Delta y = 1$ µm.

- Dashed rectangle is the expected relative insertion loss according to the calculated misalignments along x and y.
- The minimum insertion loss was 4.4 dB, corresponded to x = 0, y = 0, z = 0

Coupling Loss for VCSEL and PD for misalignments along optic axis



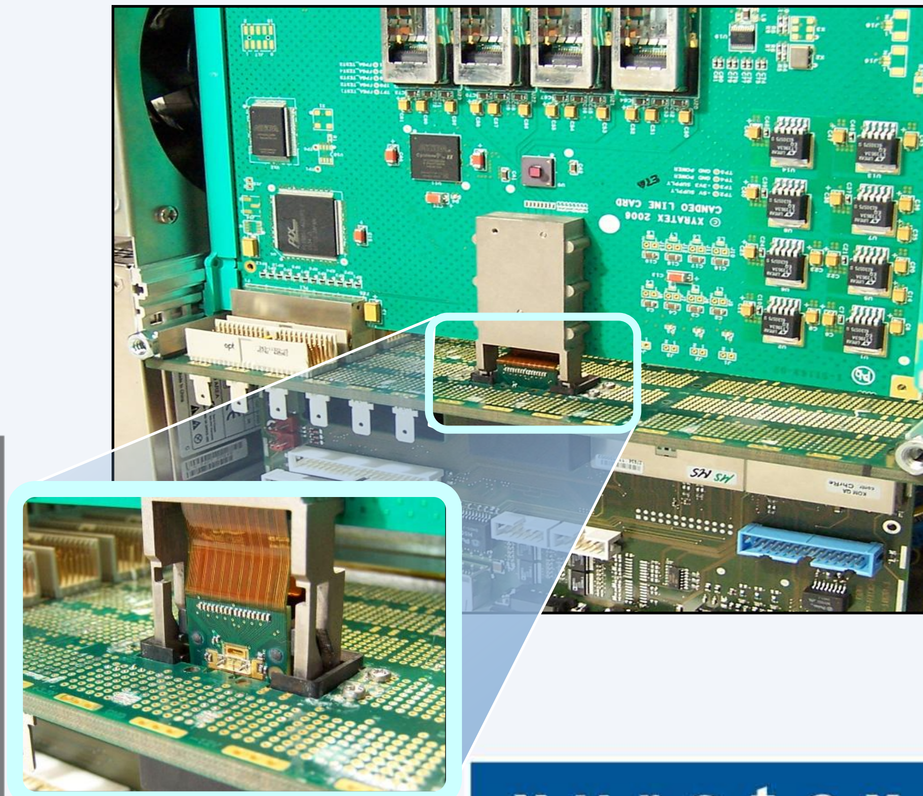
PARALLEL OPTICAL PCB CONNECTOR MODULE

Parallel optical transceiver circuit

- ❑ Small form factor quad parallel optical transceiver
- ❑ Microcontroller supporting I^{2}C interface
- ❑ Samtec "*SEARAY™*" open pin field array connector
- ❑ Spring loaded platform for optical engagement mechanism
- ❑ Custom heatsink for photonic drivers

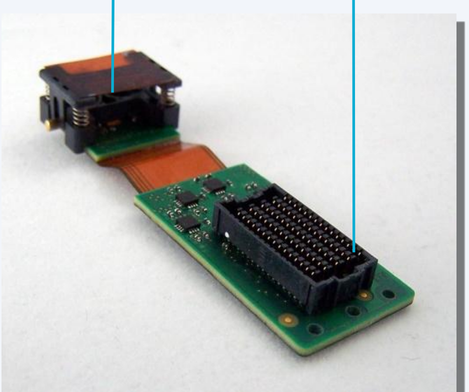
Backplane connector module

- ❑ Samtec / Xyratex collaborate to develop optical PCB connector
- ❑ 1 stage insertion engagement mechanism developed
- ❑ Xyratex transceiver integrated into connector module

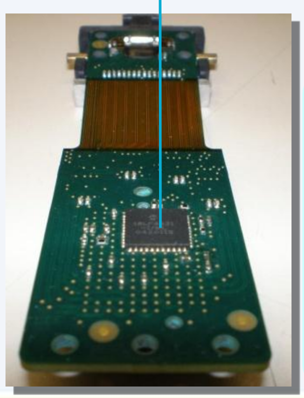


Spring loaded platform

Samtec field array connector

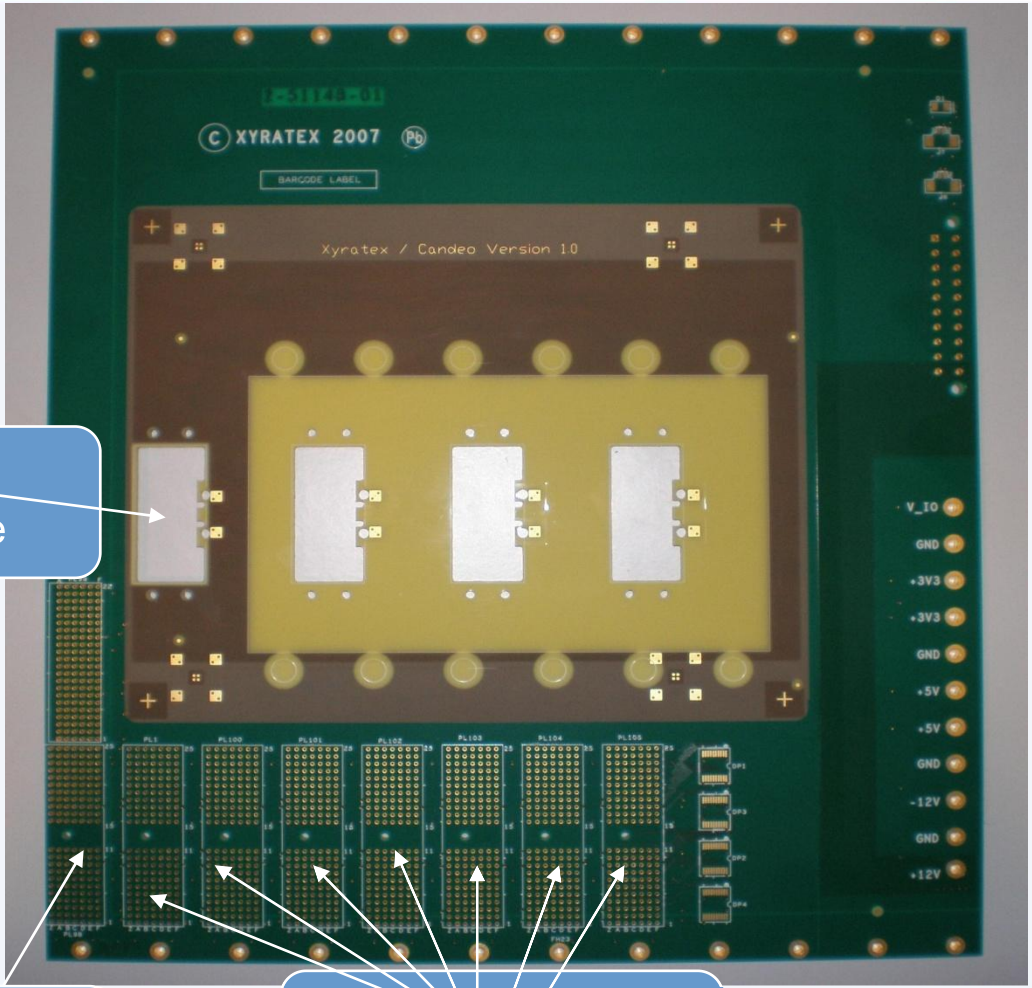


Microcontroller



Hybrid Electro-Optical Printed Circuit Board

- ❑ Standard Compact PCI backplane architecture
- ❑ 12 electrical layers for power and C-PCI signal bus and peripheral connections
- ❑ Electrical C-PCI connector slots for SBC and line cards
- ❑ 1 polymeric optical layer for high speed 10 GbE traffic
- ❑ 4 optical connector sites
- ❑ Dedicated point-to-point optical waveguide architecture



xyratex

ELECTRO-OPTICAL BACKPLANE

<u>Hybrid Electro-Optical Printed Circuit Board</u>

- ❑ Standard Compact PCI backplane architecture
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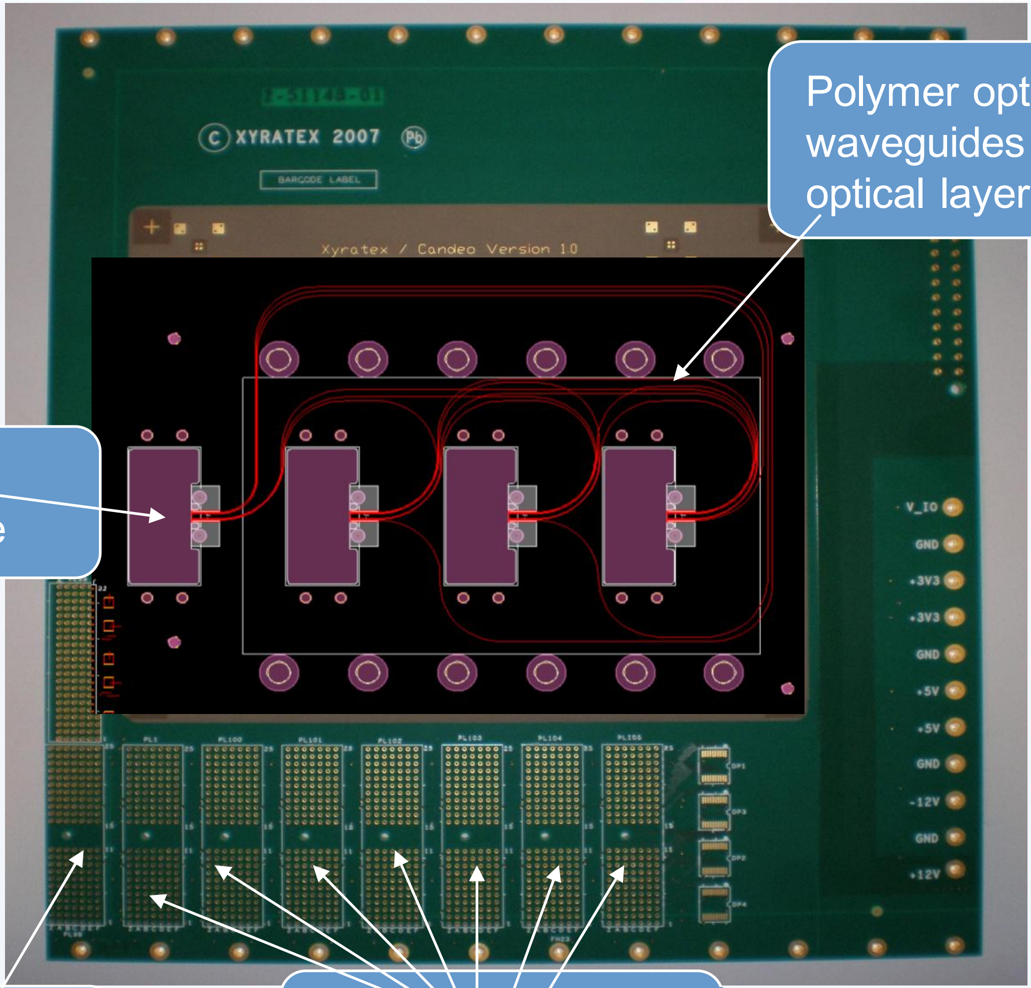

Acknowledgments

- **BAE Systems:**
  - Henry White
- **Stevenage Circuits Ltd. (SCL):**
  - Dougal Stewart, Jonathan Calver, Jeremy Rygate, Steve Payne
- **EPSRC and all partner companies for funding**

- Details of the research are presented in the individual university partners papers in this conference
- We-A-1 UCL Poster all day
- We-P-16 Heriot Watt
- Th-P-9 2 papers UCL, Loughborough

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Program

» System Design

09:30-09:40	Welcome *Henning Schröder* Fraunhofer IZM Berlin, Germany
09:40-10:10	Optical Interconnect Applications for Multimode Siloxane Components *Ian H. White* University of Cambridge, Cambridge, UK
10:10-10:40	Design Rules for Polymer Waveguides and Measurement Mechniques *Kai Wang* University College London, London, UK
10:40-11:10	CAD of Board-Level Optical Interconnects *Jürgen Schrage* Siemens C-Lab, Paderborn, Germany
10:40-11:10	Coupling Light to and from Optical Boards *Peter van Daele* University of Gent, Gent, Belgium
11:40-12:30	Lunch break

» Components

12:30-01:00	240 Gbit/s Parallel Optical Transmission Using Double Layer Waveguides in Thin Glass Sheets *Henning Schröder* Fraunhofer IZM Berlin, Germany
01:00-01:30	Flexible Optical Interconnects *Geert van Steenberge* University of Gent, Gent, Belgium
01:30-02:00	Refractive Index Profiling of Polymer Planar Optical Waveguides Using Optical Coherence Tomography *David Ives* National Physical Laboratory, Middlesex, UK
02:00-02:30	Ink Jet Printing of Optical Waveguide Material *John Chappell and David Hutt* Loughborough University, Loughborough, UK
02:30-03:20	Coffee break

» Integration Technologies

03:20-03:50	Transfer of Polymer Waveguide Fabrication Processes to a Commercial PCB Foundry *Dougal Stewart* Stevenage Circuits Limited, Stevenage, UK
03:50-04:20	Board-Level Optical Interconnects for Computing Applications *Bert Offreins* IBM Research Labs, Rüschlikon, Switzerland
04:20-04:50	Pluggable Interconnect Technology for Electro-Optical PCBs *Richard Pitwon* Xyratex, Hampshire, UK
04:50-05:20	Optoelectronic Printed Circuit Board Realised by Two Photon Absorption Structuring *Gregor Langer* AT&S AG, Leoben, Austria
05:20-05:30	Final Remarks *Henning Schröder* Fraunhofer IZM Berlin, Germany

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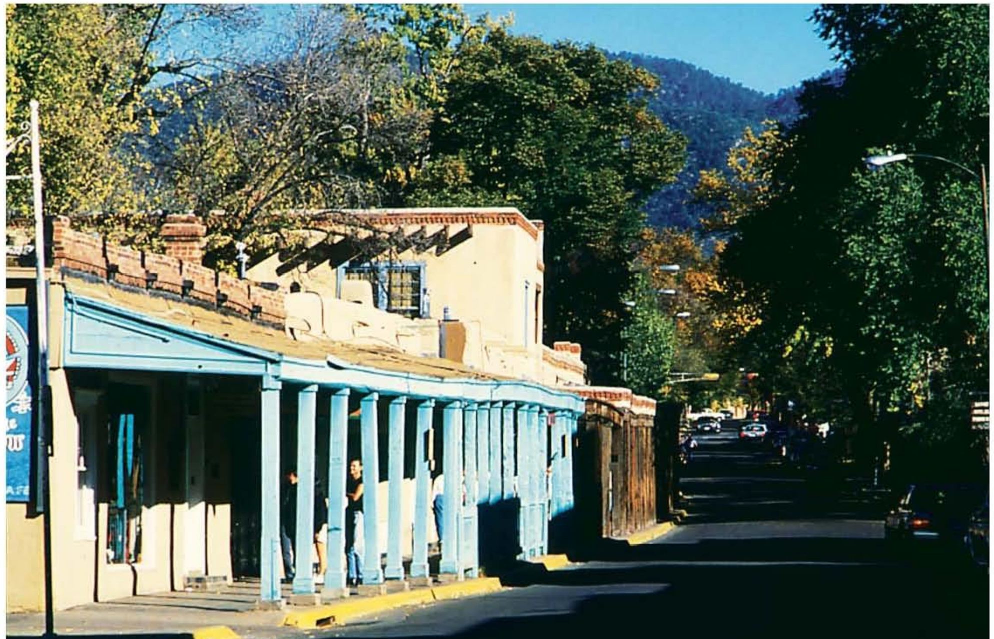

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