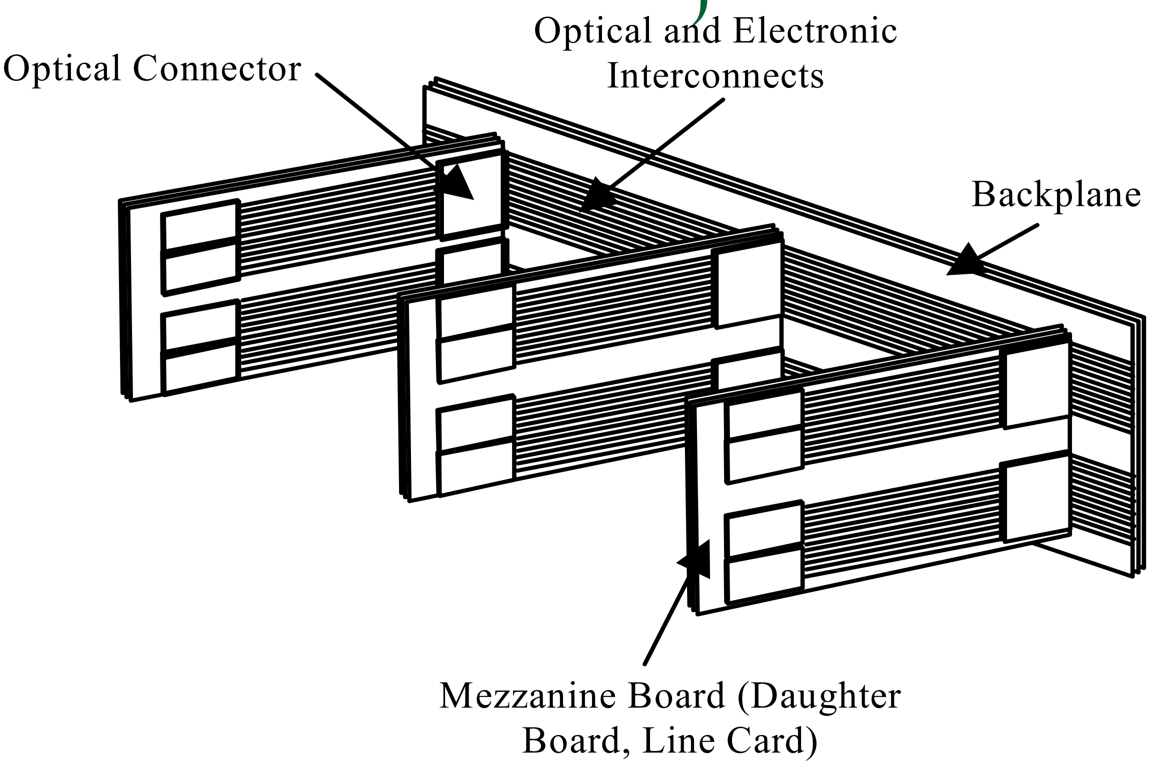
Integrated Optical and Electronic Interconnect PCB Manufacturing
(OPCB)

I*e*MRC Flagship Project

IeMRC Conference 5th September 2007

Overview of the Project

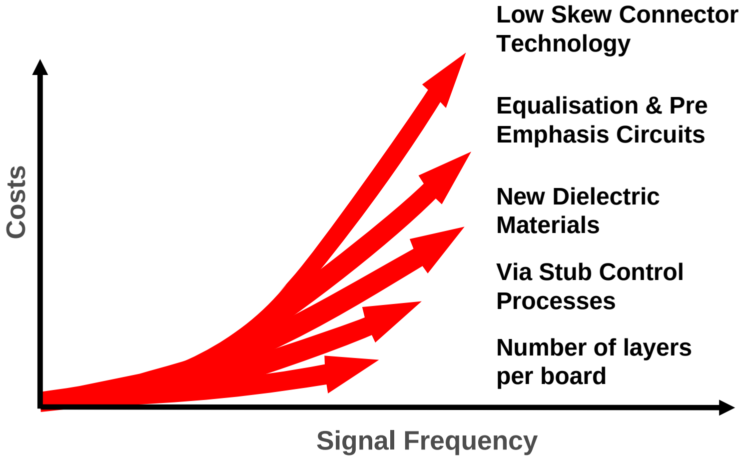


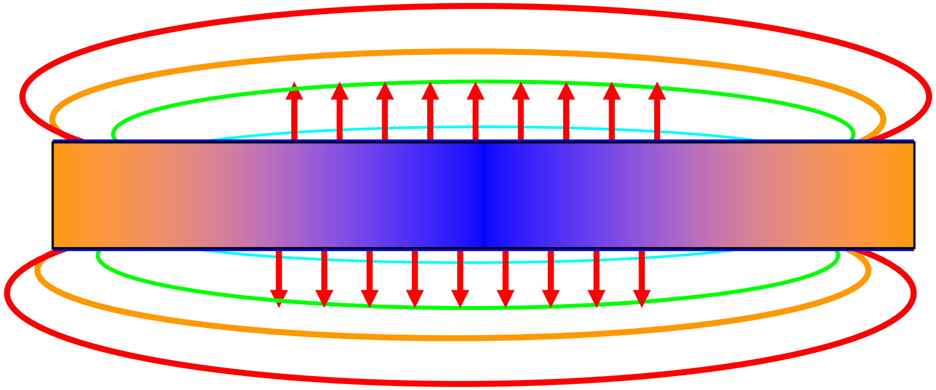
- Integration of optical waveguides with electrical printed circuit boards (PCBs)
- Integrated Optical and electrical interconnected PCB (OPCB) for backplanes and daughter cards
- High bit rate (10 Gb/s), error-free, reliable, dense connections
- CAD design tools, Fabrication Techniques, Optical-Electrical connectors

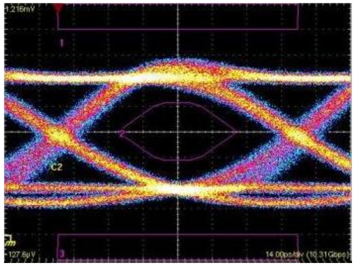
Cost Implications of High Speed Copper Communication

Copper 'pipeline' corrupts high speed signals:

- Crosstalk
- Reflections
- Signal dissipation
- "Skin effect"
- 'Electro Magnetic Compatibility' Issues

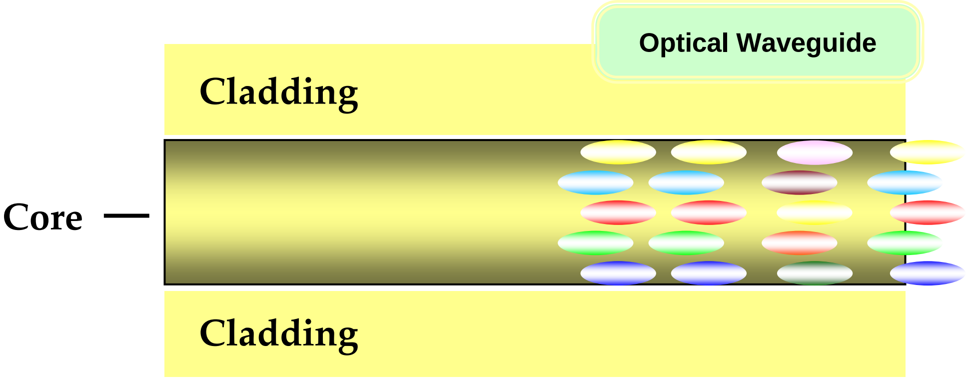


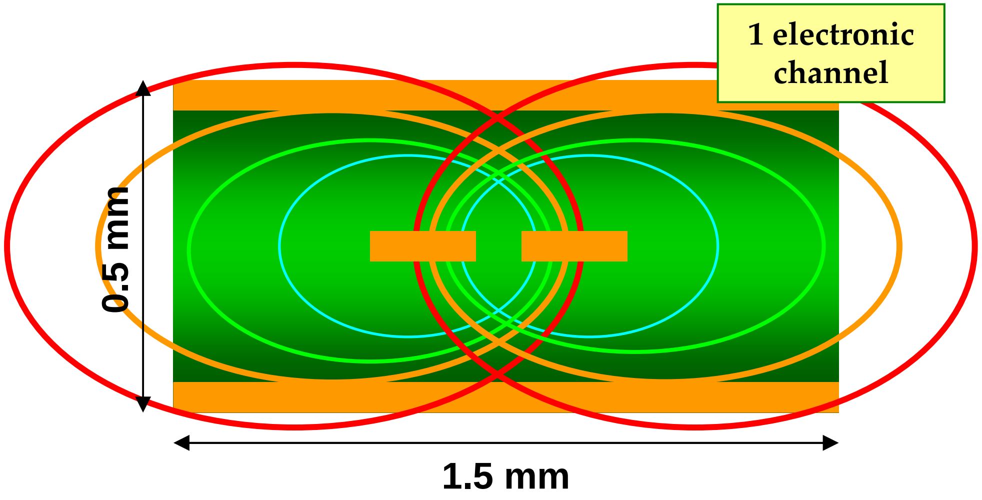


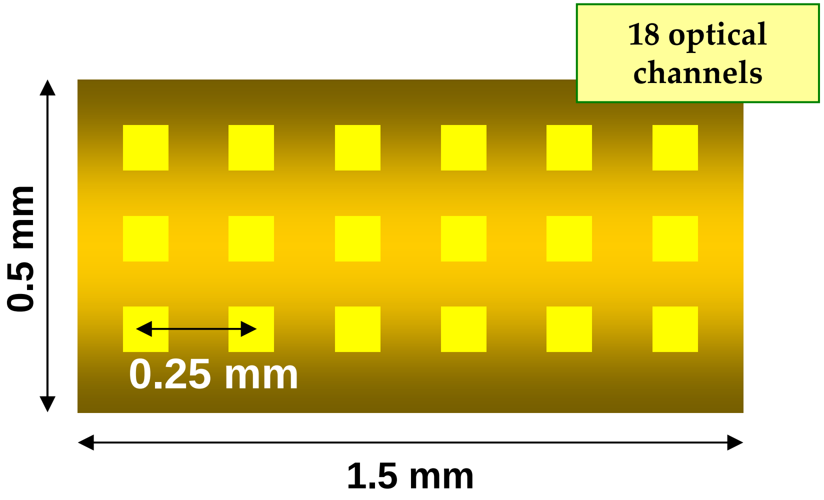


THE LIGHT ALTERNATIVE

- Optical signal pipelines possible
- Fit more optical channels on the board
- Send data faster down each optical ‘pipeline’
- Send optical data further (absorption permitting)
- No interfering radiation leaking outside the box
- Send multiple signals simultaneously (WDM)







Aims

1. Establish waveguide design rules
   - Build into commercial CAD layout software to ease the design of OPCBs and to ensure widespread use.
   - Understand the effect of waveguide wall roughness and cross sectional shape on loss and bit error rate.
2. Develop low cost, PCB compatible manufacturing techniques for OPCBs
   - Compare the commercial and technological benefits of several high and low risk manufacturing technologies
   - Environmental testing, reproducibility
3. Design an optical-electrical connector
   - Low cost, dismountable, passive, self-aligning, mid-board, multichannel, duplex, long life

Project Partners

Academic Partners

UCL (Lead) – Optical modelling & characterisation
Heriot-Watt University – Laser writing and polymer chemistry
Loughborough University – Laser ablation, ink jet printing, flip-chip assembly

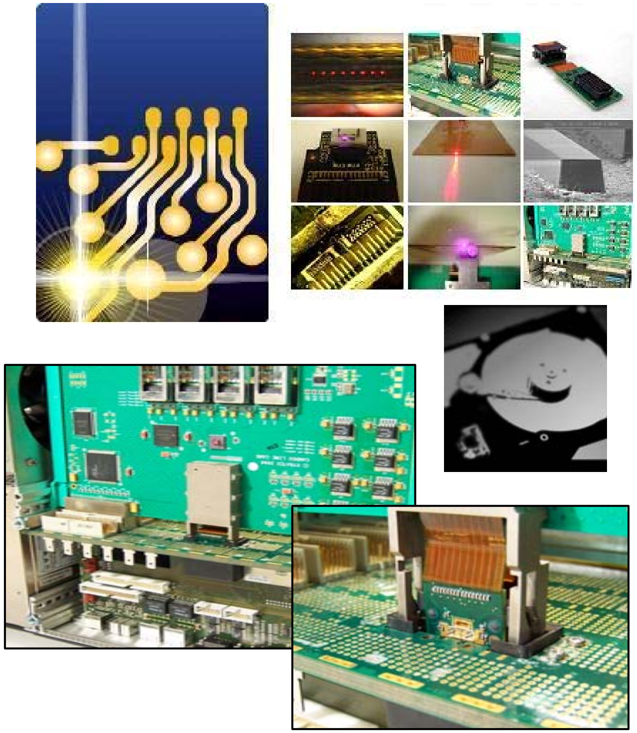
Industrial Partners

Xyratex (Lead) – End user – mass data storage
BAE Systems – End user – aerospace applications
Renishaw – End user – optical sensor applications
Exxelis – Polymer development and fabrication
Stevenage Circuits – PCB manufacturers
Cadence – Design tools for PCBs
Rsoft Design – Modelling tools
Xaar – Print head technology
NPL – Waveguide/material characterisation

EPSRC I*e*MRC Support

	Grant
Heriot Watt	£269,960
Loughborough	£259,264
UCL	£270,604
Grant Total	£799,828
Industrial Total	£561,000
Grand Total	£1,360,828

XYRATEX OPTICAL RESEARCH AND DEVELOPMENT GROUP



Research Objectives

- Commercial development of optical backplane connection technology
  - Based on prototypes developed during DTI LINK project: “Storlite”
- System design and integration of OPCB technology

Progress to date

- Parallel optical transceiver developed and under characterisation
- Single stage optical backplane engagement mechanism developed
- Commercial form factor module designed and developed
- First mechanical prototype exhibited by Xyratex and Samtec at Electronica 2006 and DesignCon 2007
- C-PCI platform and line cards developed and under characterisation

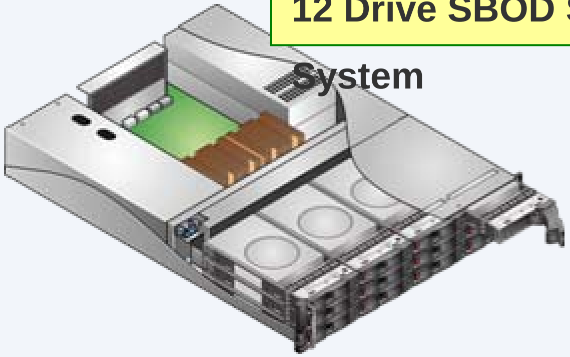
Storage System Roadmap

Storage Trends

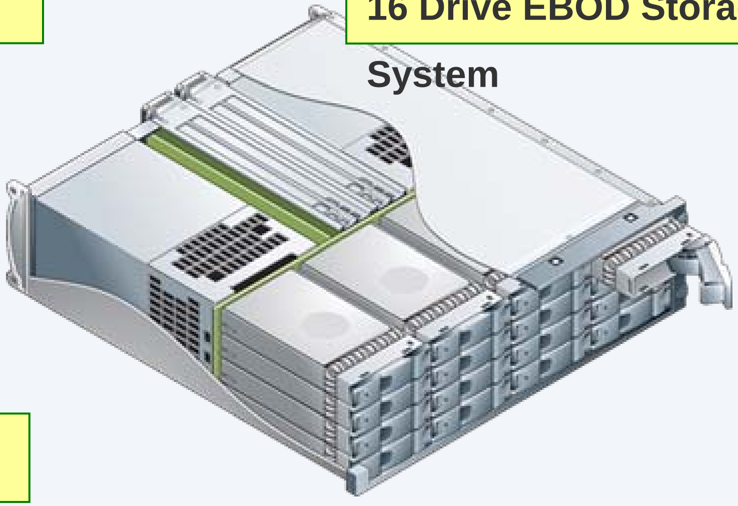
- Increasing data bandwidth
- Decreasing disk drive form factors
- Higher system integration

Eventual incorporation of OPCB technology into high bandwidth storage systems

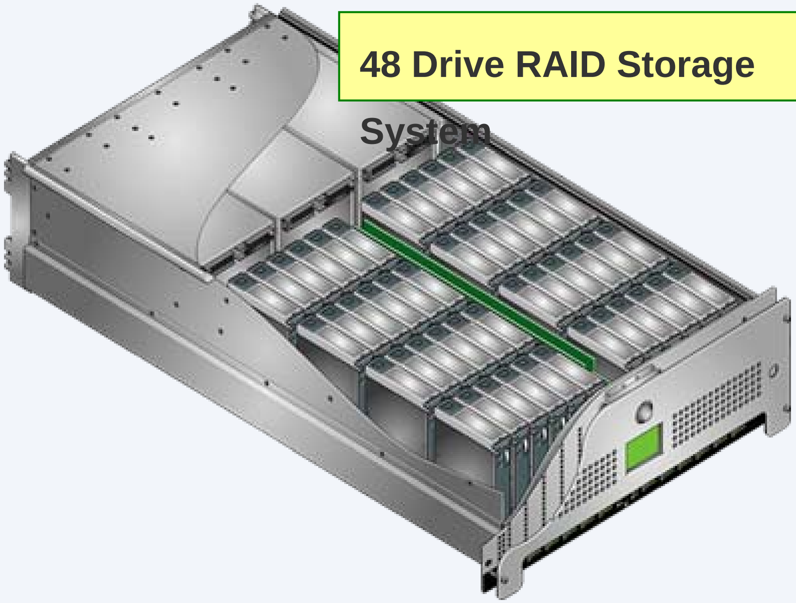
HIGH BANDWIDTH BACKPLANE ENVIRONMENTS



12 Drive SBOD Storage System



16 Drive EBOD Storage System



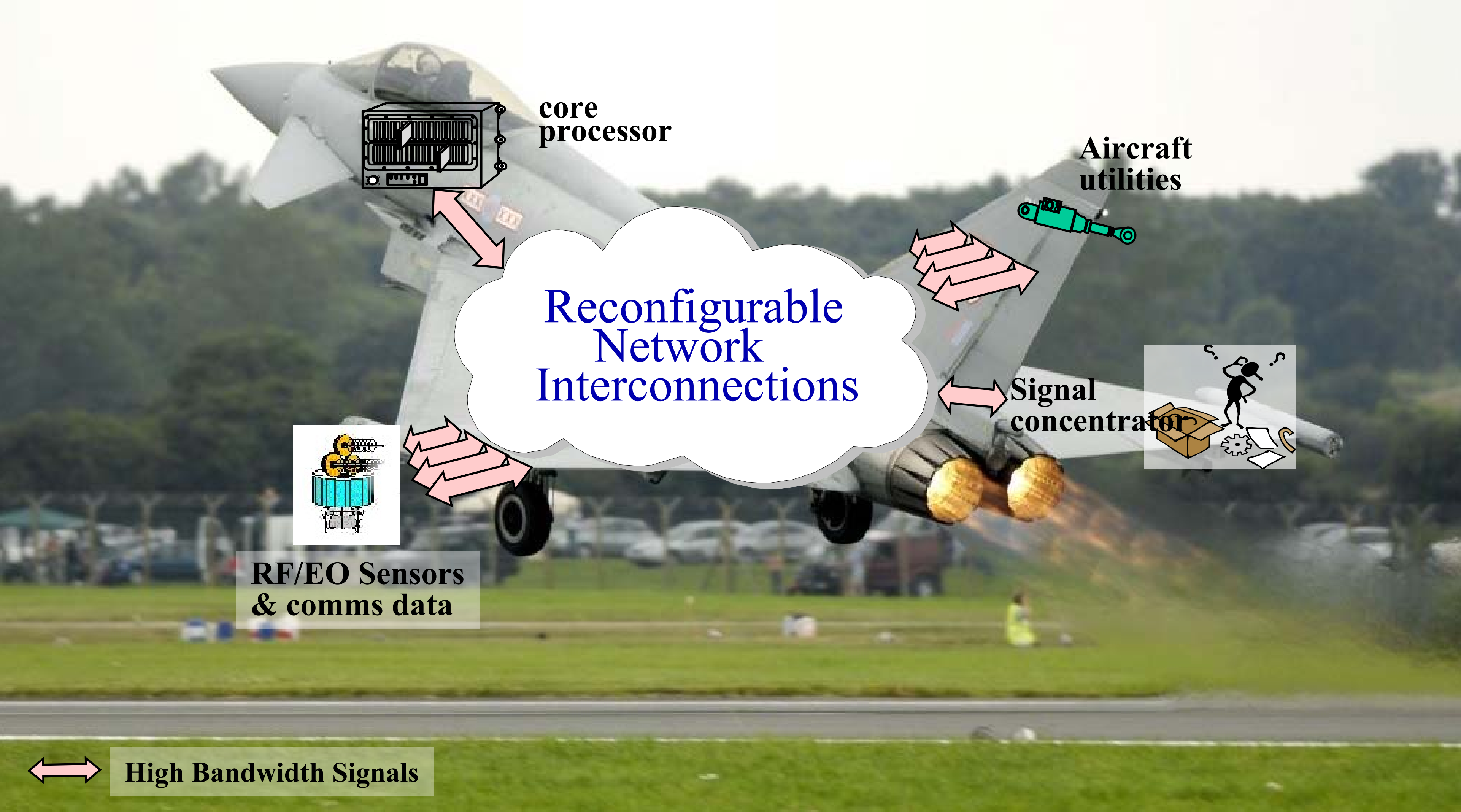
48 Drive RAID Storage System

Up to 48 TB storage, 4 Gb/s fibre-channel connectivity

Why do we need optical interconnects ?

- *Signal Integrity*
- *Electro-magnetic Emissions*
- *PCB Density*
- *Cooling*
- *Data Bandwidth*

On-board Platform Applications



core processor

Aircraft utilities

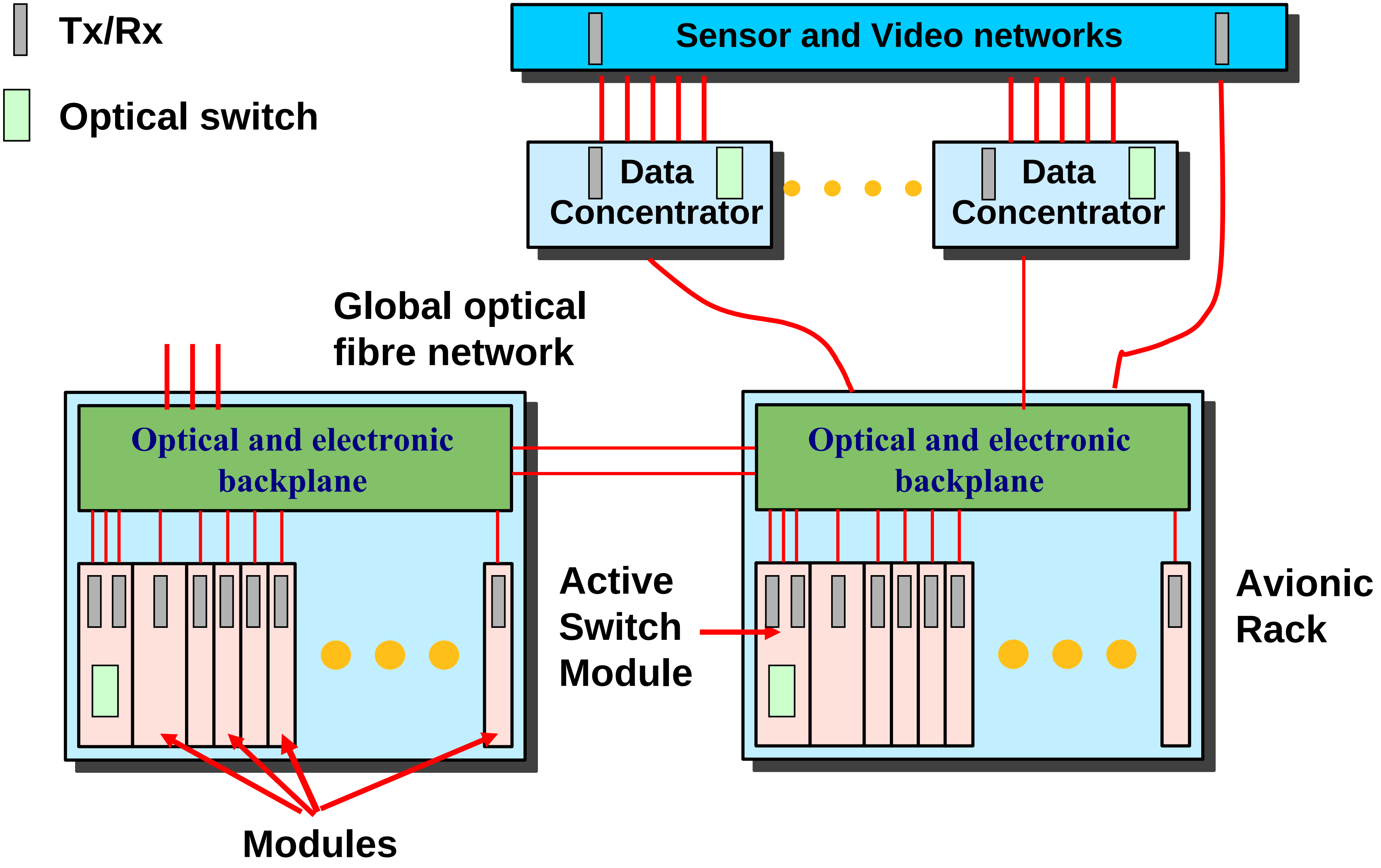
Reconfigurable Network Interconnections

Signal concentrator

RF/EO Sensors & comms data

⟺ High Bandwidth Signals

Simplified Modular Avionic Concept



▯ Tx/Rx

🟩 Optical switch

Sensor and Video networks

Data Concentrator

Data Concentrator

Global optical fibre network

Optical and electronic backplane

Optical and electronic backplane

Active Switch Module

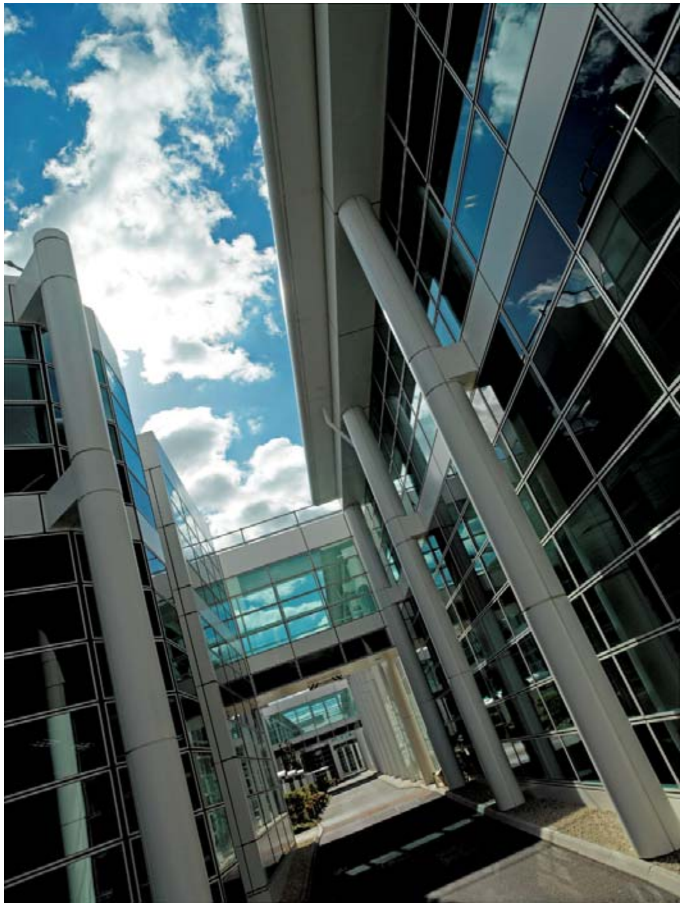
Avionic Rack

Modules

Stevenage Circuits

- Discussions held on PCB capability and alignment methods
- Waveguide test data has been printed into standard photoresist using 8000 DPI artwork
- SCL will process samples to allow solder bumps for flip chip bonding connections.
- Stevenage Circuits will laser ablate some spin coated samples from Loughborough.

NPL – Waveguide Characterisation



The Optical Technologies Group at NPL will

- characterise the optical properties of polymer planar waveguides, using proven techniques
- acquire data for modelling of prototype waveguides
- verify the capabilities of prototype waveguides

NPL has a unique range of facilities for

- measuring the properties of optical fibres and components
- characterising high speed opto-electronic components

This science is supported by direct access to the NPL National Standards.

NPL

Cadence Update

- Software installation at UCL completed
- Overview training at UCL session completed
- Further UCL support visits planned
- Cadence expectations
    - technical input to Cadence for enhancement of software layout tools
    - technology support

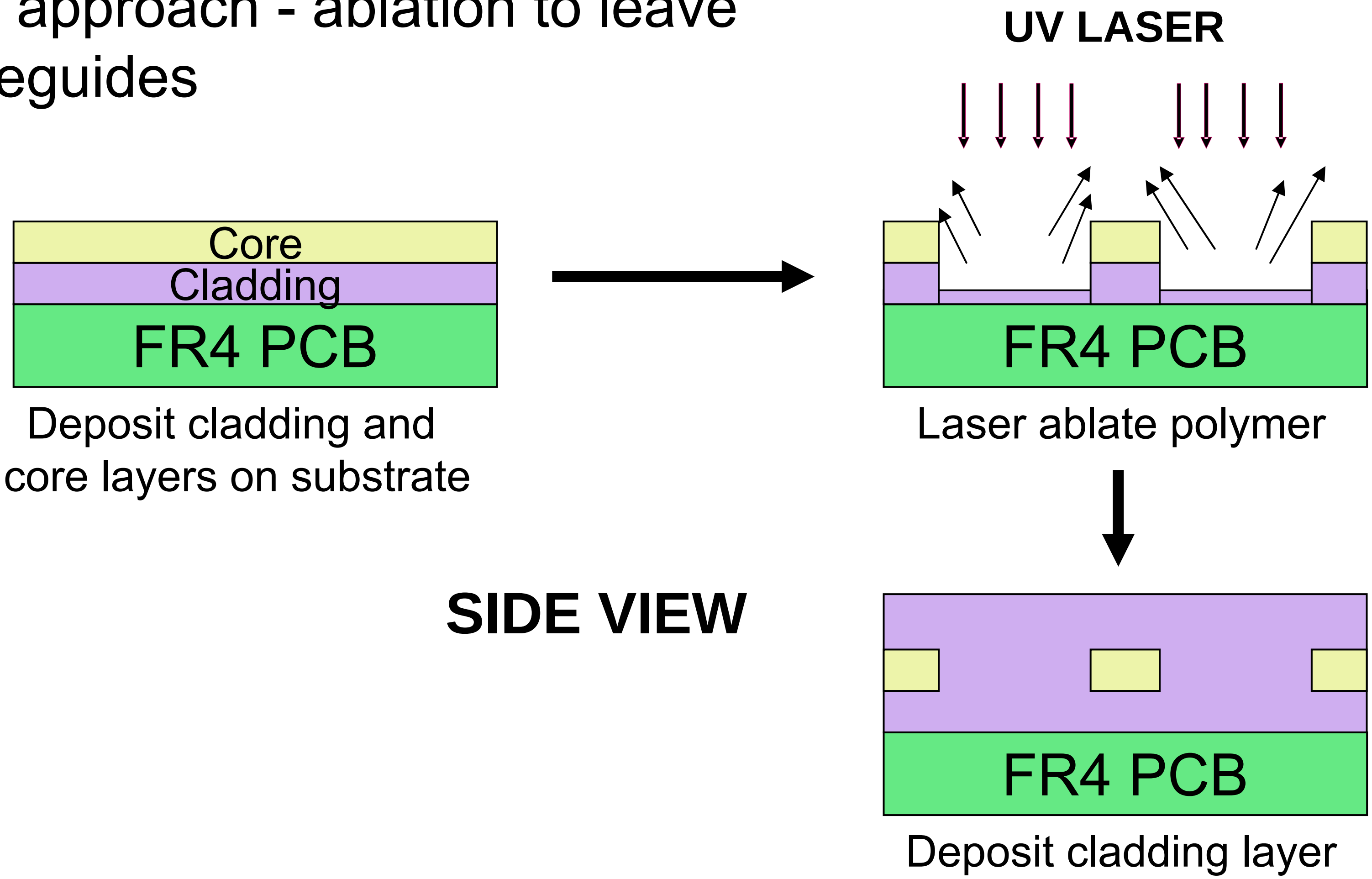
Loughborough University

- Investigators: David Hutt, Paul Conway, Karen Williams
- Researchers: Shefiu Zakariyah (PhD student)

  John Chappell (Research Associate)
- Waveguide fabrication
  - Laser ablation
  - Ink Jet printing
- Connector development
- Flip-chip interconnect
  - Self-alignment of lasers and photo detectors with waveguides

Excimer Laser Ablation of Waveguide Structures

- Scaleable to large areas
- One approach - ablation to leave waveguides



UV LASER

Core

Cladding

FR4 PCB

Deposit cladding and core layers on substrate

FR4 PCB

Laser ablate polymer

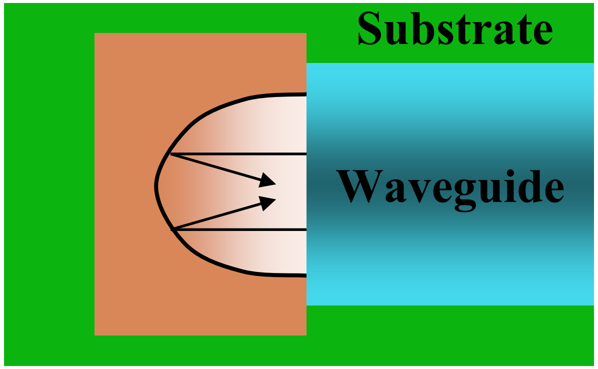
SIDE VIEW

FR4 PCB

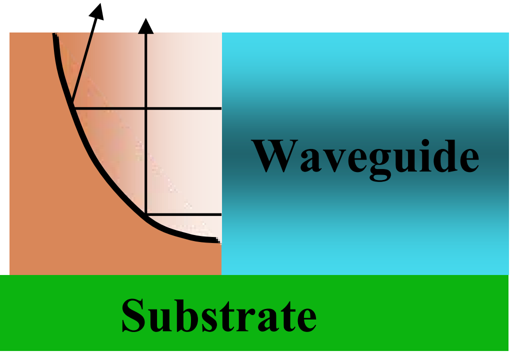
Deposit cladding layer

Waveguide Termination

- Investigating the formation of profiled mirrors to direct light
- More efficient light capture and transmission than traditional 45^{o} mirrors
- Careful characterisation of machining rates and design of beam delivery system required
- Metal coating to form mirror surfaces



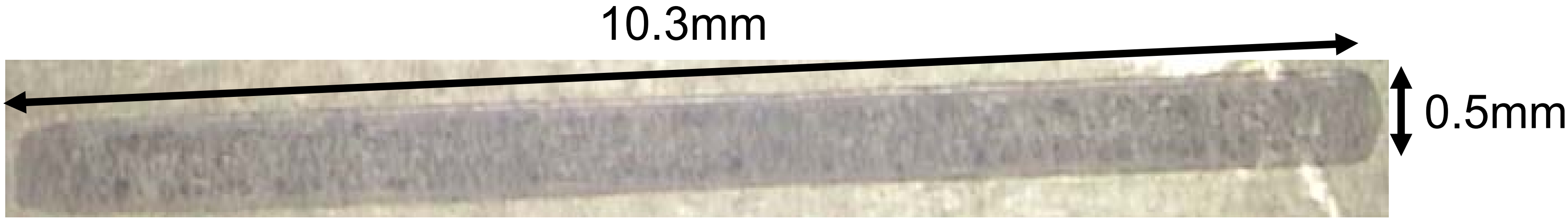
Plan View



Cross-section Side View

Preliminary Work

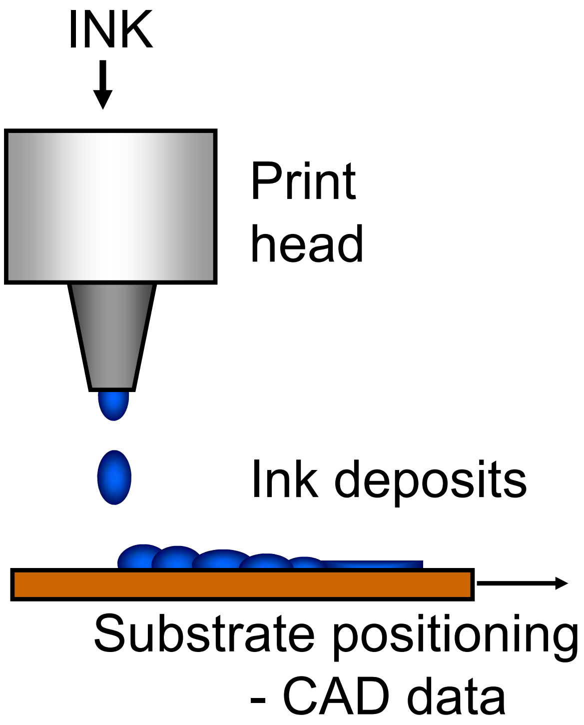
- Strong absorption of Excimer laser by polymer
  - Efficient ablation
  - Minimal heating
- Characterisation of laser machining parameters
  - Control ablation rate / depth
  - Minimisation of debris
  - Side wall roughness



Groove machined in acrylic – test structure

Ink Jet Deposition of Polymer Waveguides

- Localised deposition of cladding and / or core materials
  - More materials efficient
  - Active response to local features
- Materials
  - Solutions
    - e.g. PMMA in solvent
    - Limited deposition rate
  - Functional materials


INK

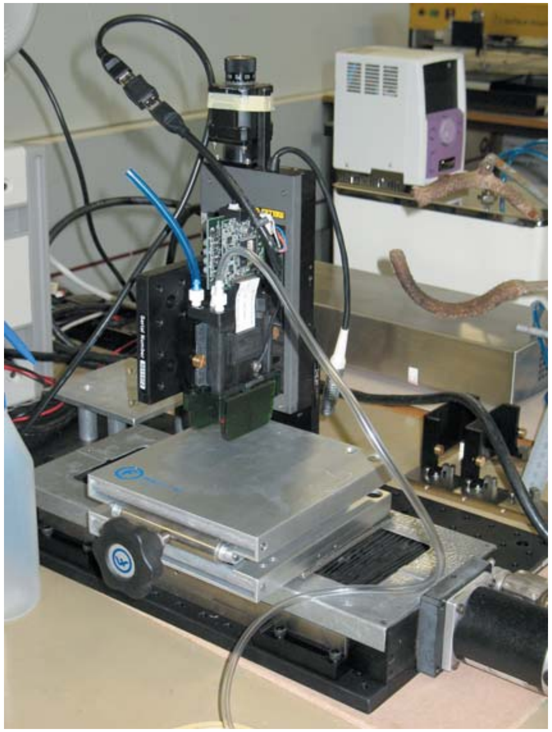
Print head

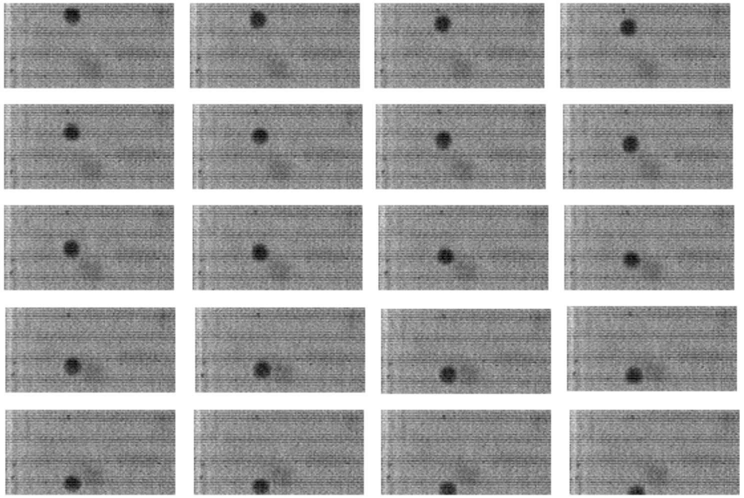
Ink deposits

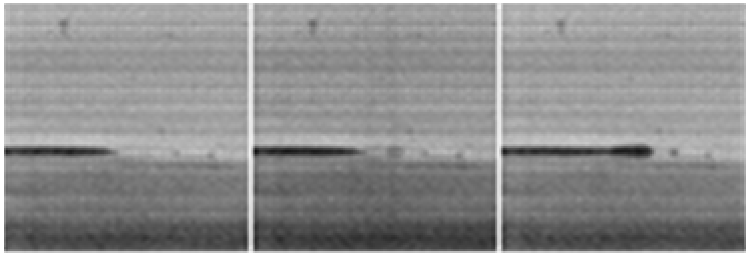
Substrate positioning - CAD data

Ink Jet System

- Ink Jet printing system established
- Head stationary, substrate moved
- High speed camera on loan from EPSRC – droplet imaging

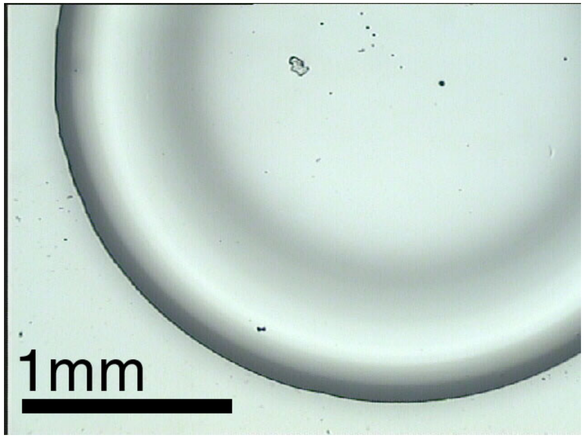




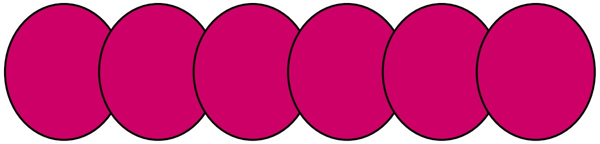


Ink Jet Challenges

- Ink formulation
  - Viscosity, surface tension
- Drying effects
  - Coffee stain
- Wall roughness caused by multiple droplets
- Wetting and droplet spread



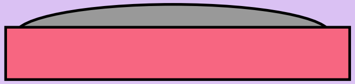
PMMA on glass.
Deposited by pipette.



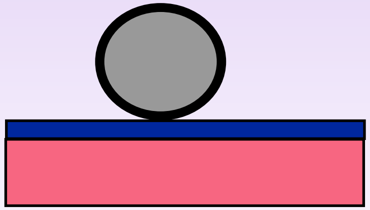
Droplet merging, effect on wall roughness

Control of Surface Wetting

- Need to control contact angle of polymer droplet on surface
  - Wetting angle determines waveguide cross-section and printing resolution
  - Control of surface chemistry (balance of wetting and adhesion)



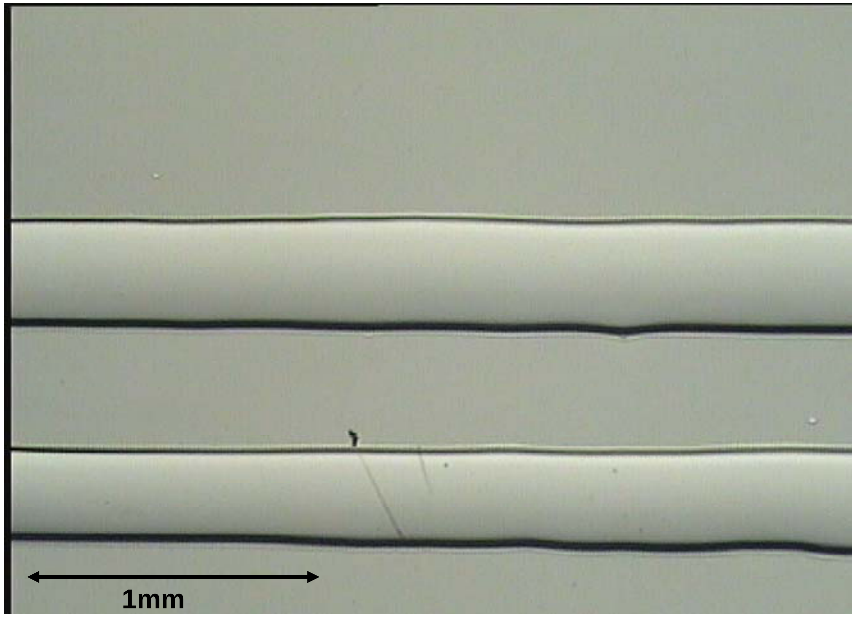
Wettable surface leads to broad droplet

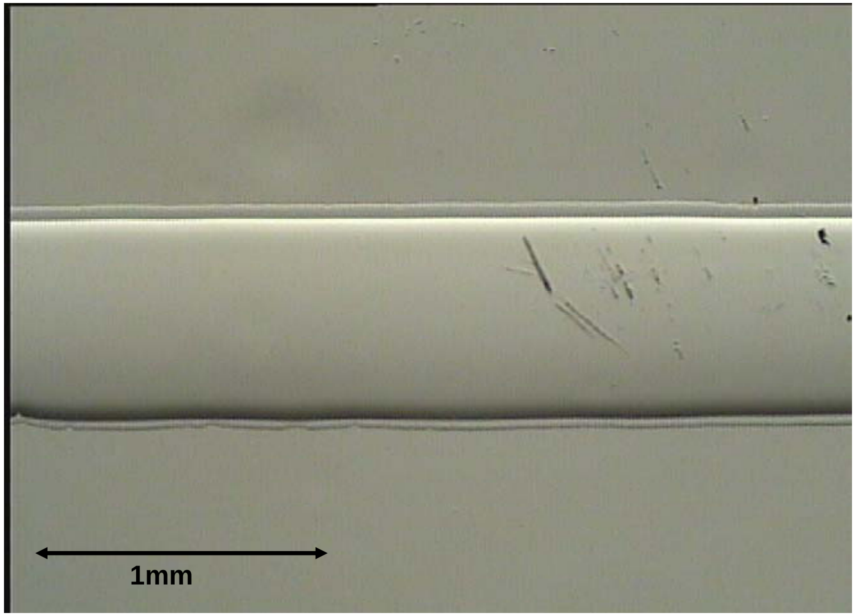


Non-wettable surface leads to high contact angle, but limited adhesion

Preliminary Results

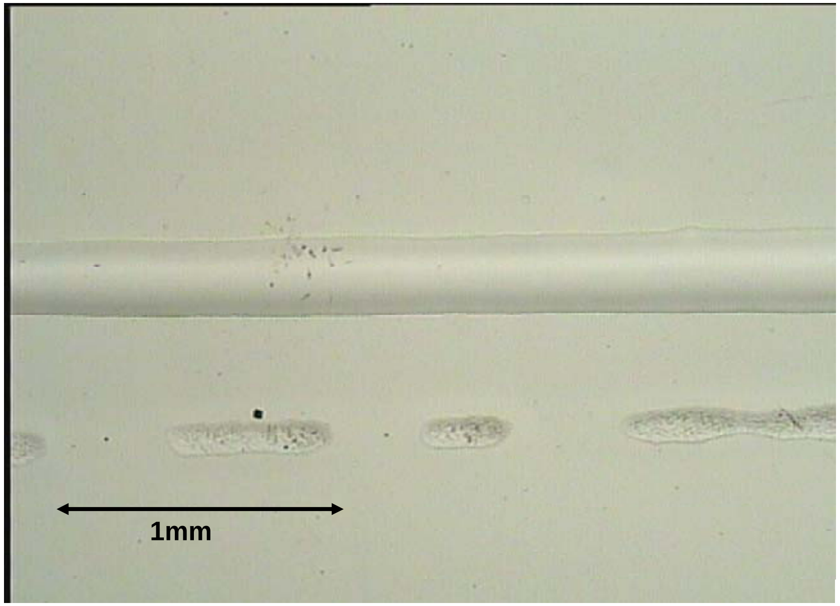
- Functional materials ink jetted
- Extensive spreading
- Further characterisation of process required

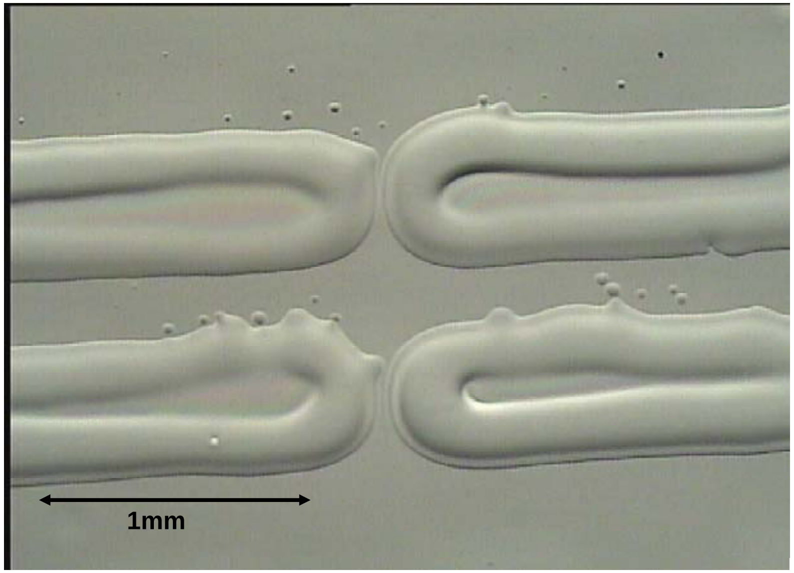




Preliminary Results

- Investigating process parameters to influence deposit size and spread
- Many defects to be understood





HWU Contribution to OPCB Project

Andy Walker, Aongus McCarthy, Himanshu Suyal

- **Direct Laser-writing of waveguides**
  - Increase writing speeds and manufacturability
- **Photo-polymer Formulation**
  - Optimise for faster writing; alternative polymer systems; possible dry formulation
- **Writing over large areas** (400 – 500 mm long)
  - Stationary "writing head" with board moved on long translation stage
- **Connectors**
  - Possible use of 45-deg out-of-plane mirrors
- **Advanced Optoelectronic Integration**

Custom Photopolymer

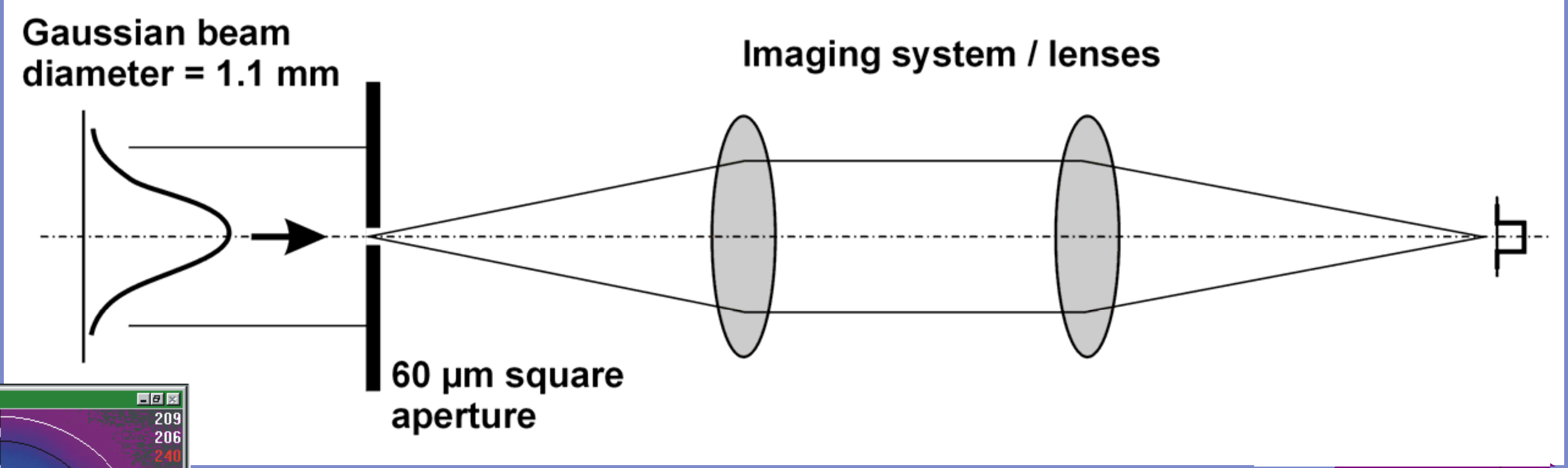
- Polymer recipe
  - Exxelis (Terahertz Photonics) formulation
  - Multifunctional acrylate polymer
  - Tunable refractive index & viscosity
  - High glass transition temperature

- Polymer application
  - Spinning
  - Doctor-blading

- Polymer curing
  - Photoinitiators: Irgacure 184 / 651 – UV-induce polymerisation
  - Direct UV laser-writing used for waveguide cores & bumps
  - Blanket curing of “large” areas using UV lamp

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

HERIOT WATT UNIVERSITY



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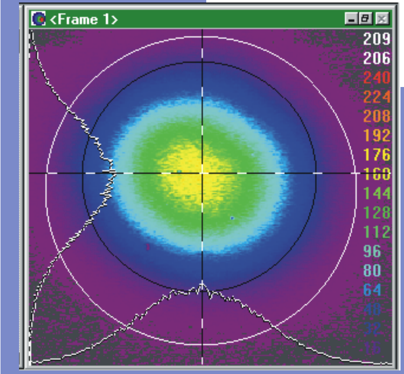
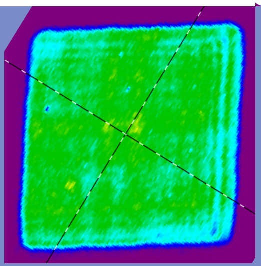
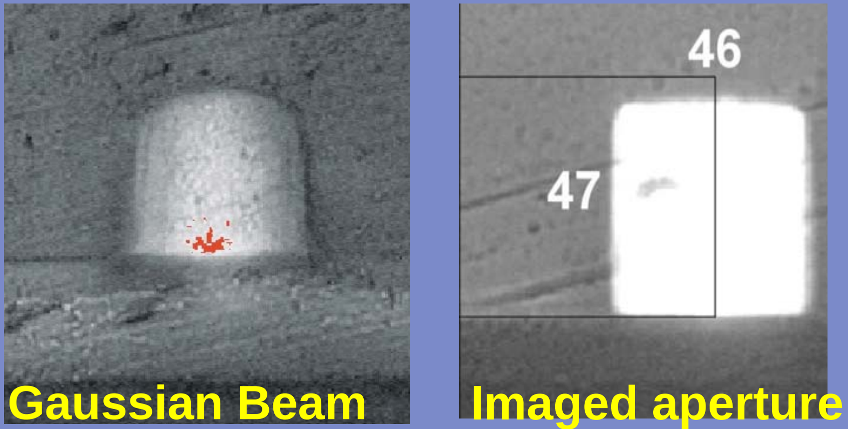






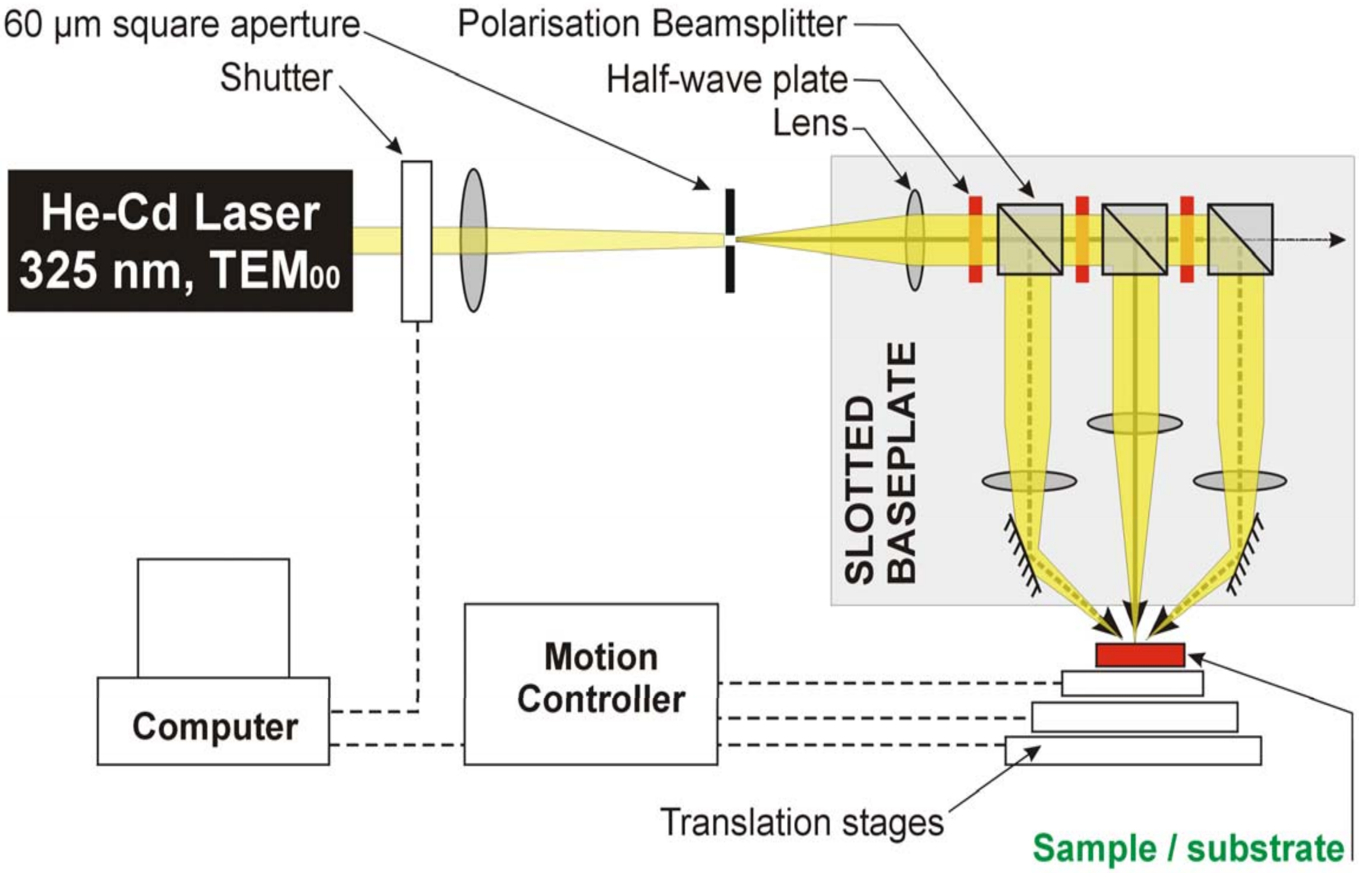
Gaussian Beam

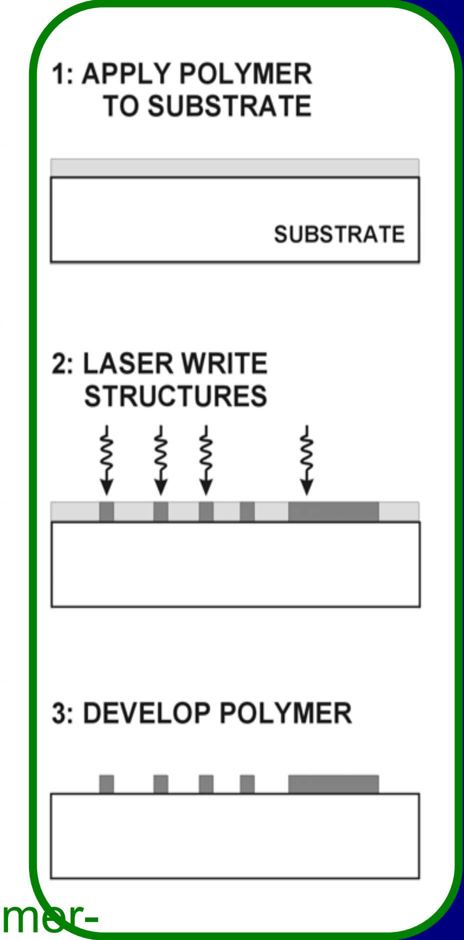
Imaged aperture

Images of resulting waveguide cores

OPCB

Direct Laser-writing Set-up




1: APPLY POLYMER TO SUBSTRATE

2: LASER WRITE STRUCTURES

3: DEVELOP POLYMER

- UV-illuminated square aperture (50 µm) imaged, 1-to-1, onto polymer-coated substrate, carried on computer-controlled x-y stage.
- Three beams available – to write: (a) vertically-walled features, or
  (b) plus/minus 45-deg structures.

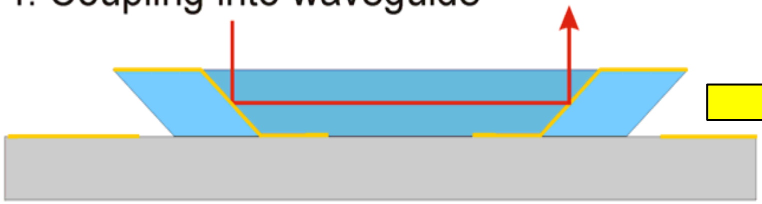
45º Turning Mirrors

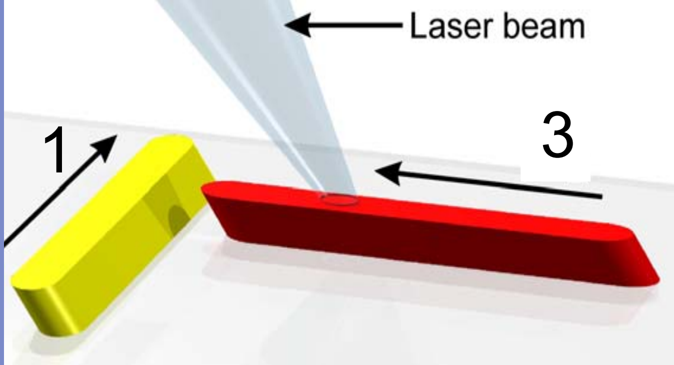
1. Direct laser writing of 45º structures

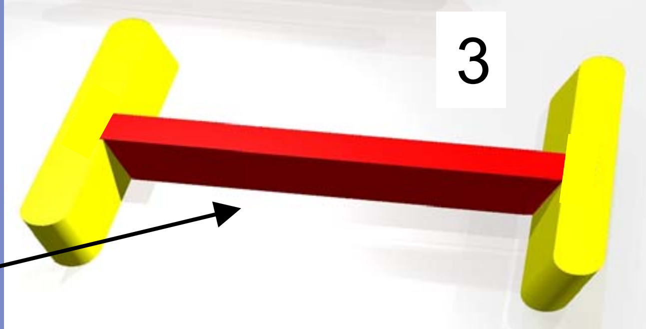
2. Patterned evaporation of gold

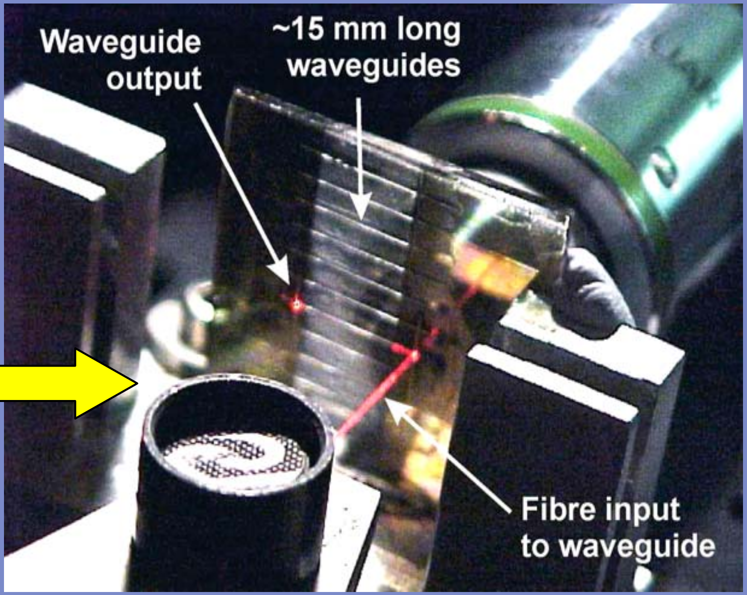
3. Direct laser writing of “link” waveguide

4. Coupling into waveguide



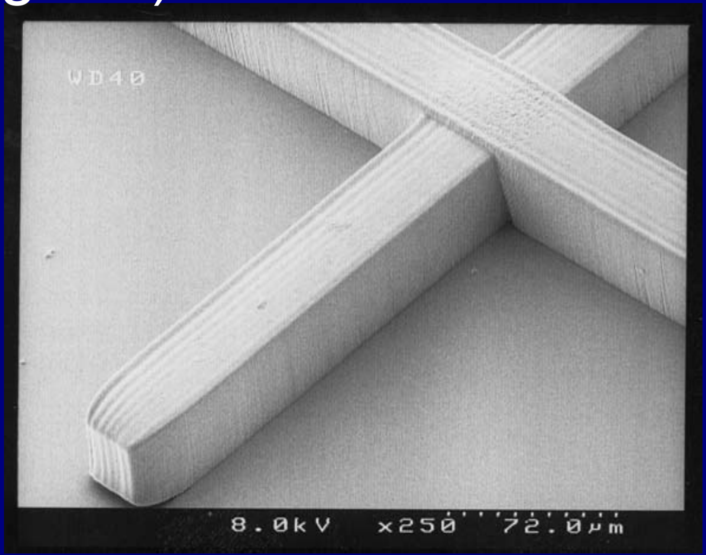


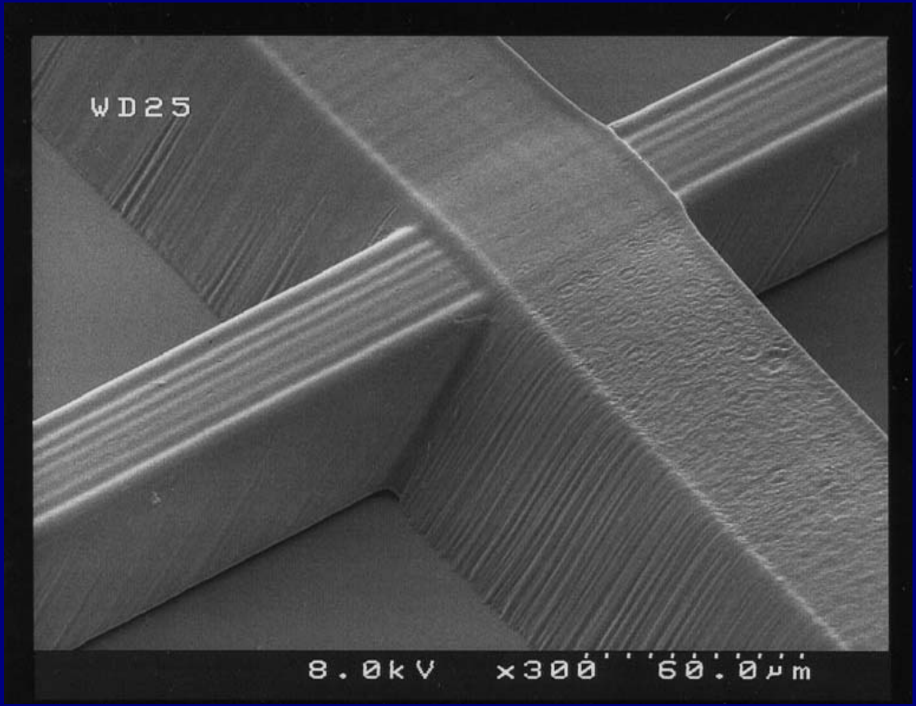




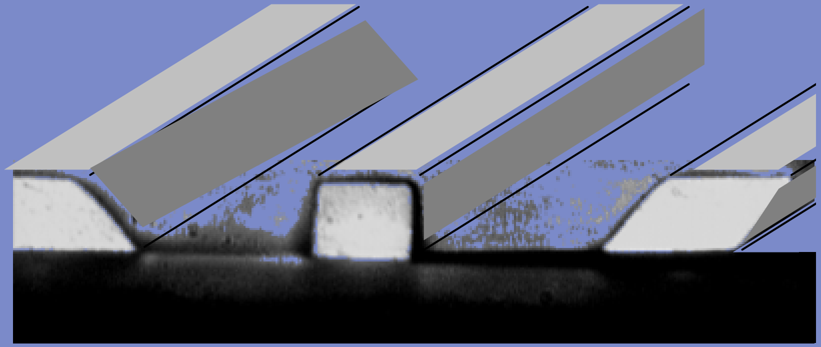
Laser written polymer structures

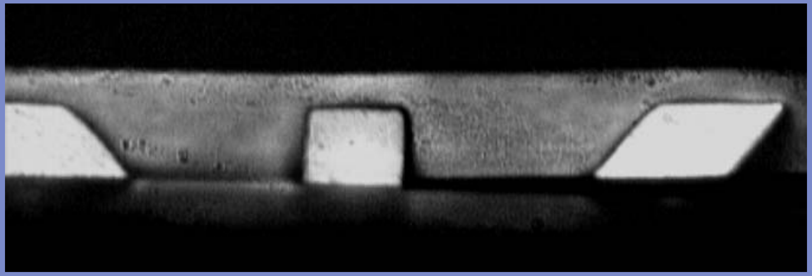
SEM images of polymer structures written using imaged 50 µm square aperture (chrome on glass)





Laser written polymer structures



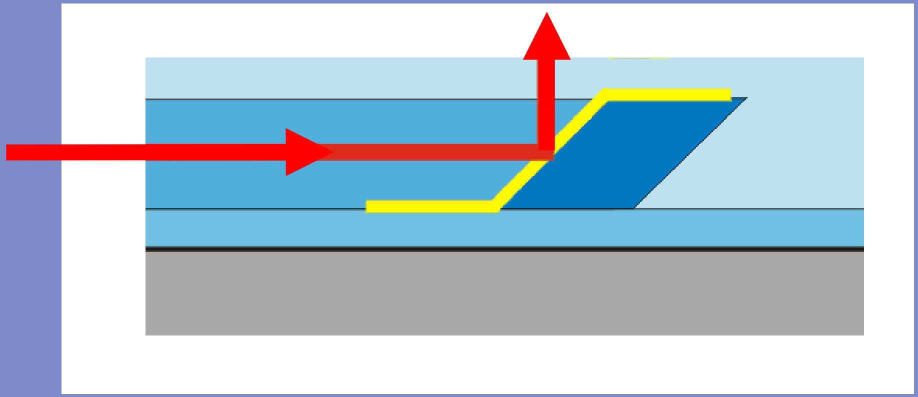


Optical microscope image showing end on view of vertical and 45º surfaces

Cladding spun over waveguide cores (and other features): same polymer Δn ~ 1%, blanket cured under UV lamp (N_2 atmos.)

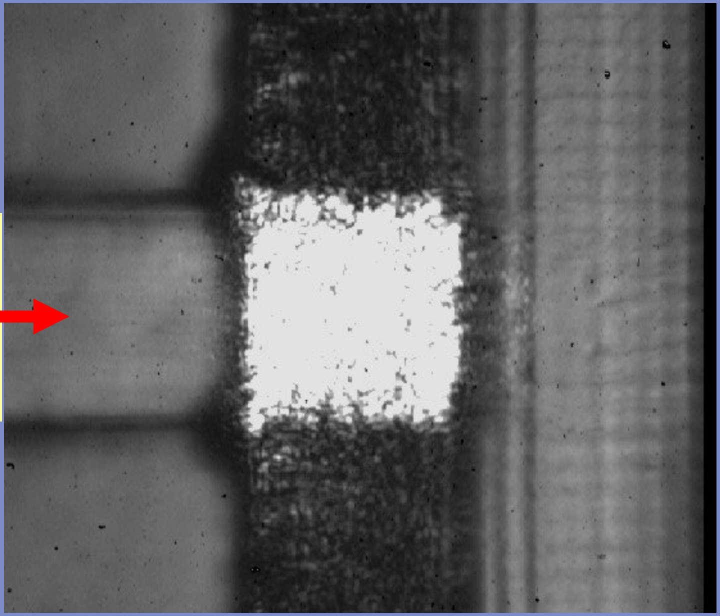
Waveguide terminated with 45-deg mirror

Out-of-plane coupling,
using 45-deg mirror
(silver)



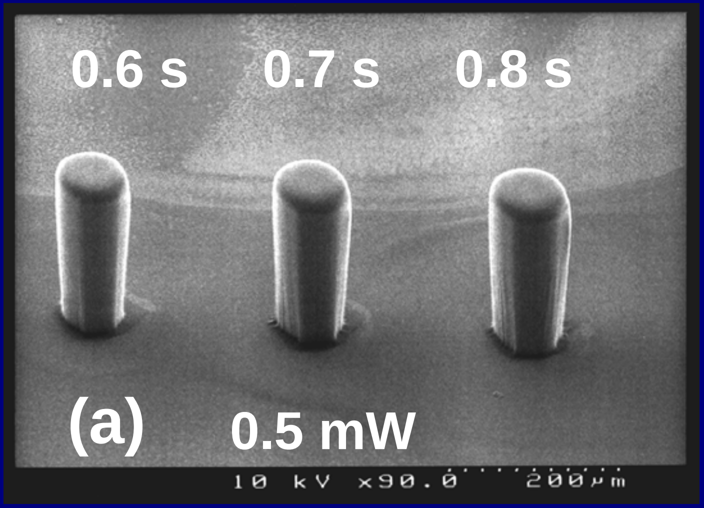
Microscope image looking
down on mirror
coupling light towards camera

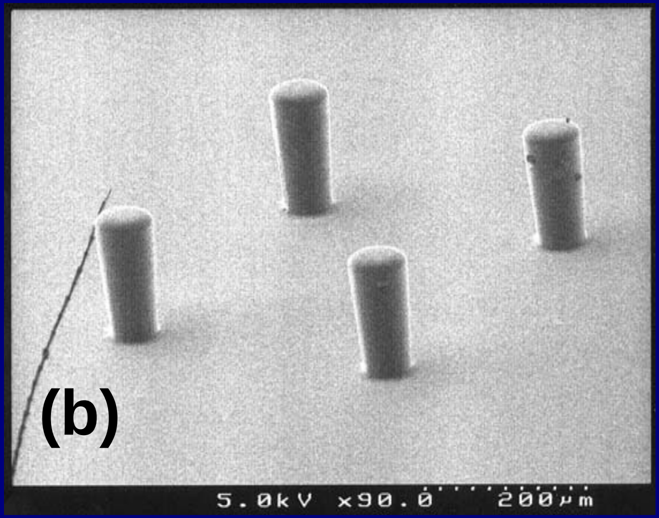
OPTICAL INPUT



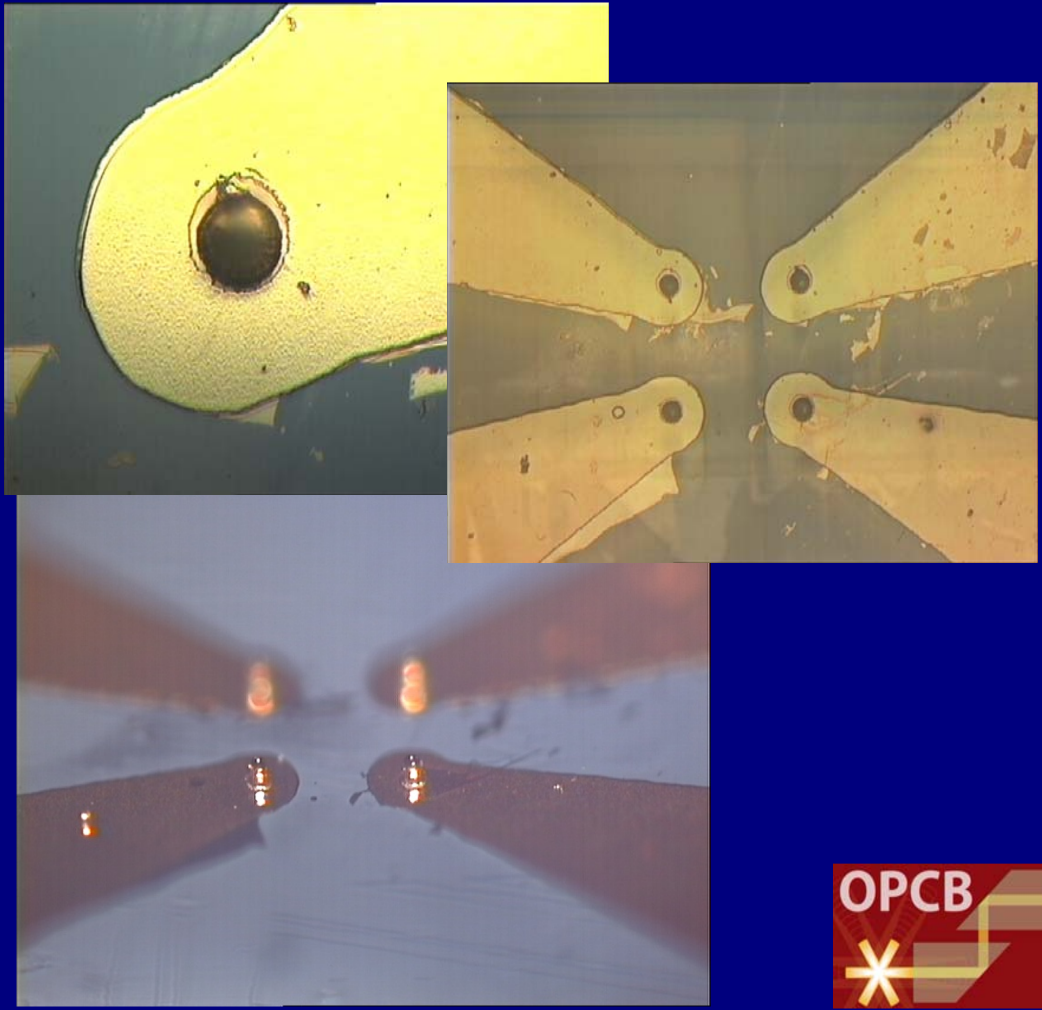
Compliant Polymer Bumps

Direct laser writing of polymer bumps

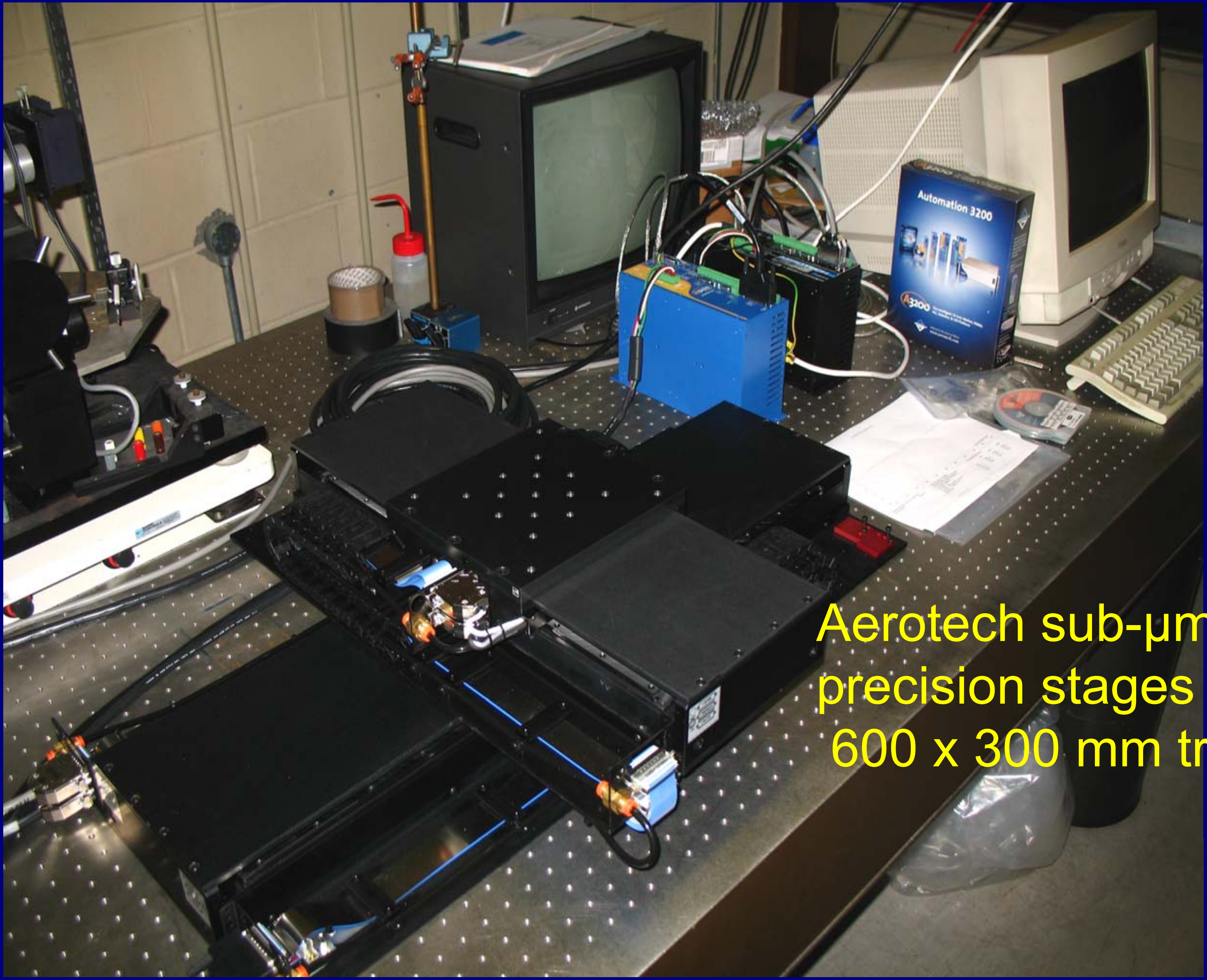




Metal coated bumps and patterned metallisation of substrate



Large area writing



Aerotech sub-μm precision stages
600 x 300 mm travel

Latest Results

Laser-writing Parameters:

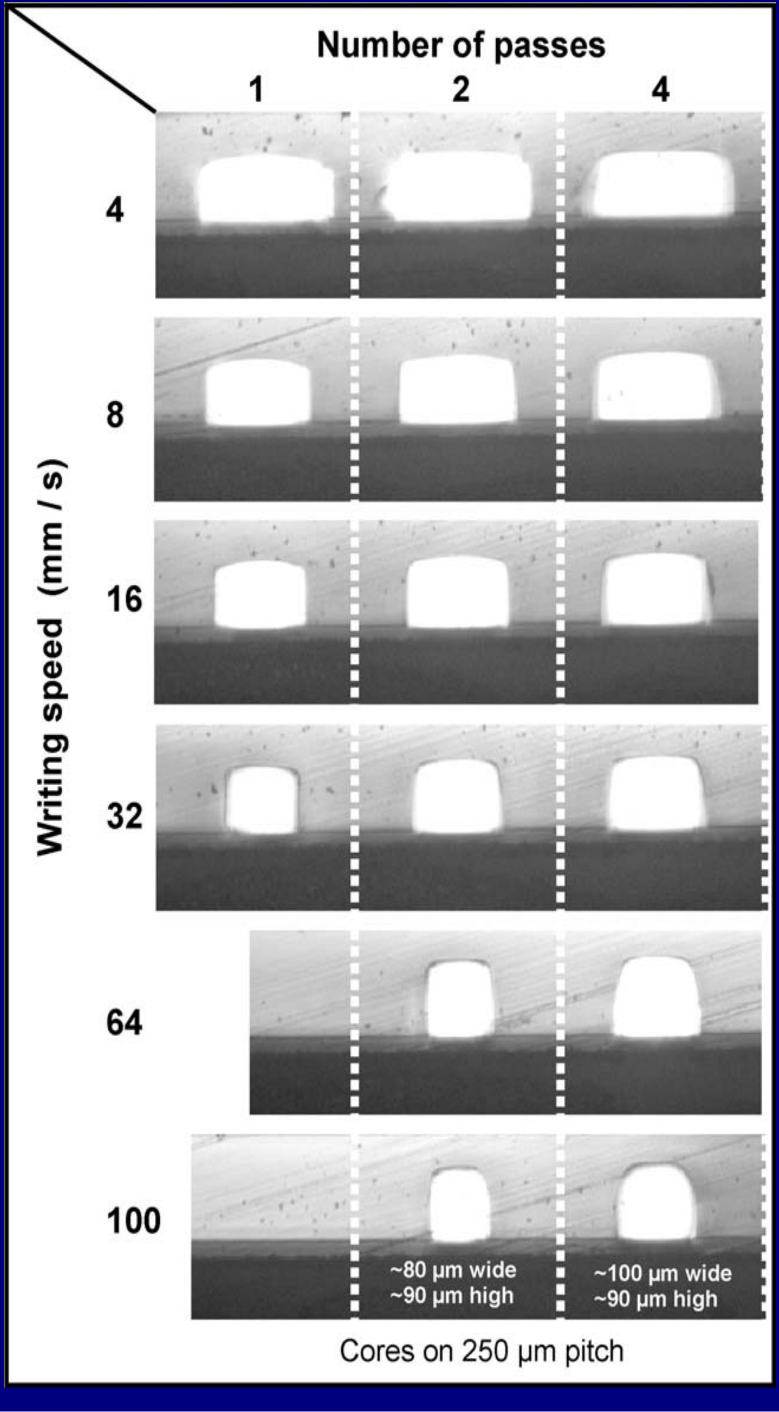
- Intensity profile: Gaussian
- Optical power: ~8 mW
- Oil immersion

Polymer

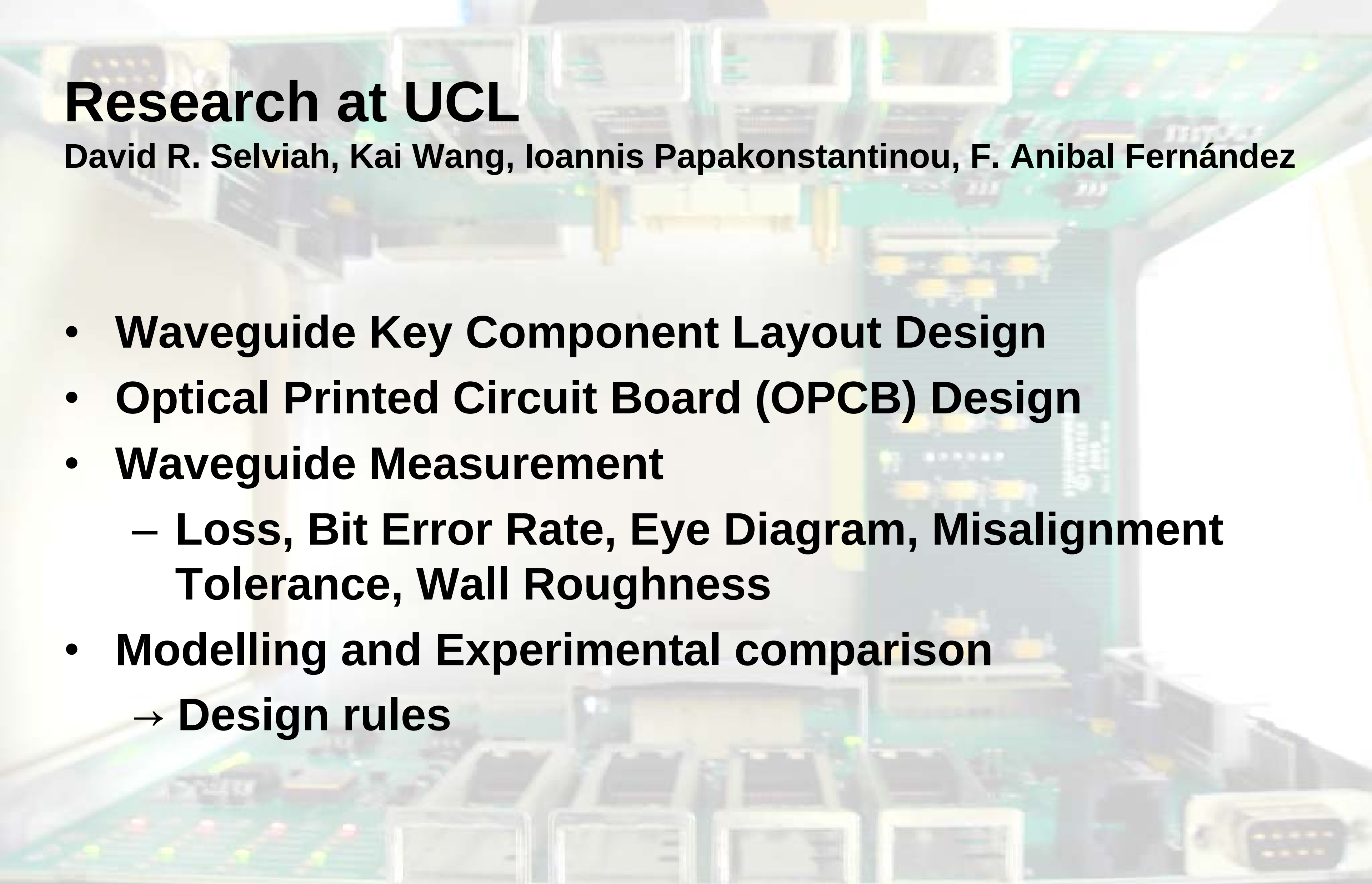
- Multifunctional acrylate
- Photoinitiator: Irgacure 184

Substrate

- FR4, with polymer undercladding



Cores on 250 µm pitch

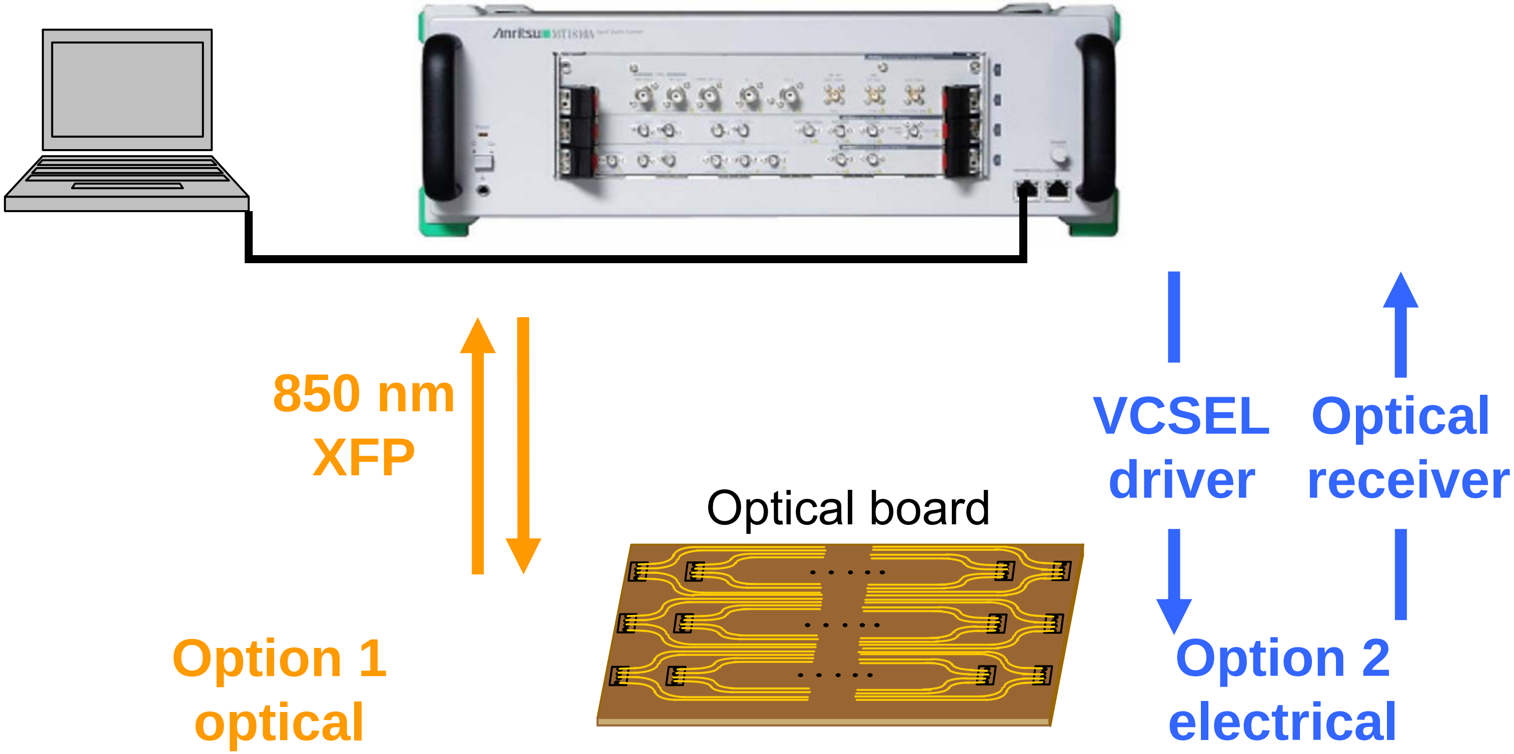


Research at UCL

David R. Selviah, Kai Wang, Ioannis Papakonstantinou, F. Anibal Fernández

- **Waveguide Key Component Layout Design**
- **Optical Printed Circuit Board (OPCB) Design**
- **Waveguide Measurement**
  - **Loss, Bit Error Rate, Eye Diagram, Misalignment Tolerance, Wall Roughness**
- **Modelling and Experimental comparison**
  - **→ Design rules**

Measurement system for 10 Gbit/s device



850 nm
XFP

Optical board

VCSEL driver

Optical receiver

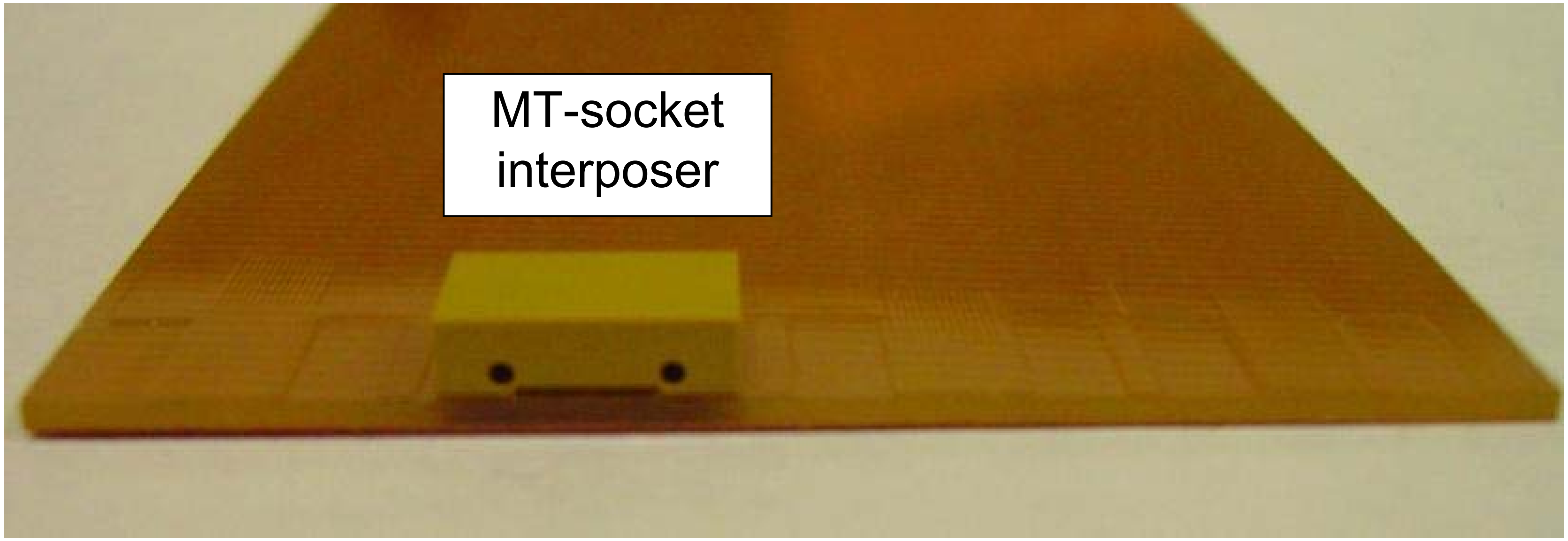
Option 1
optical

Option 2
electrical

- Operating bit rate 9.95 to 11.10 Gbit/s
- Power -4.0 dBm to -1.08 dBm
- Wavelength range 840 nm to 860 nm

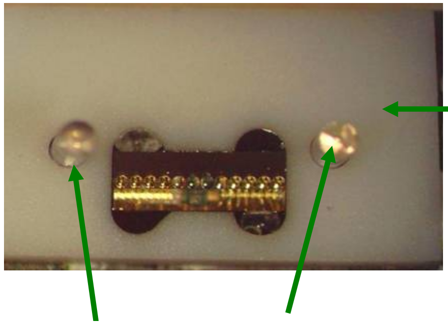
OPCB with MT - socket interposer

(a)



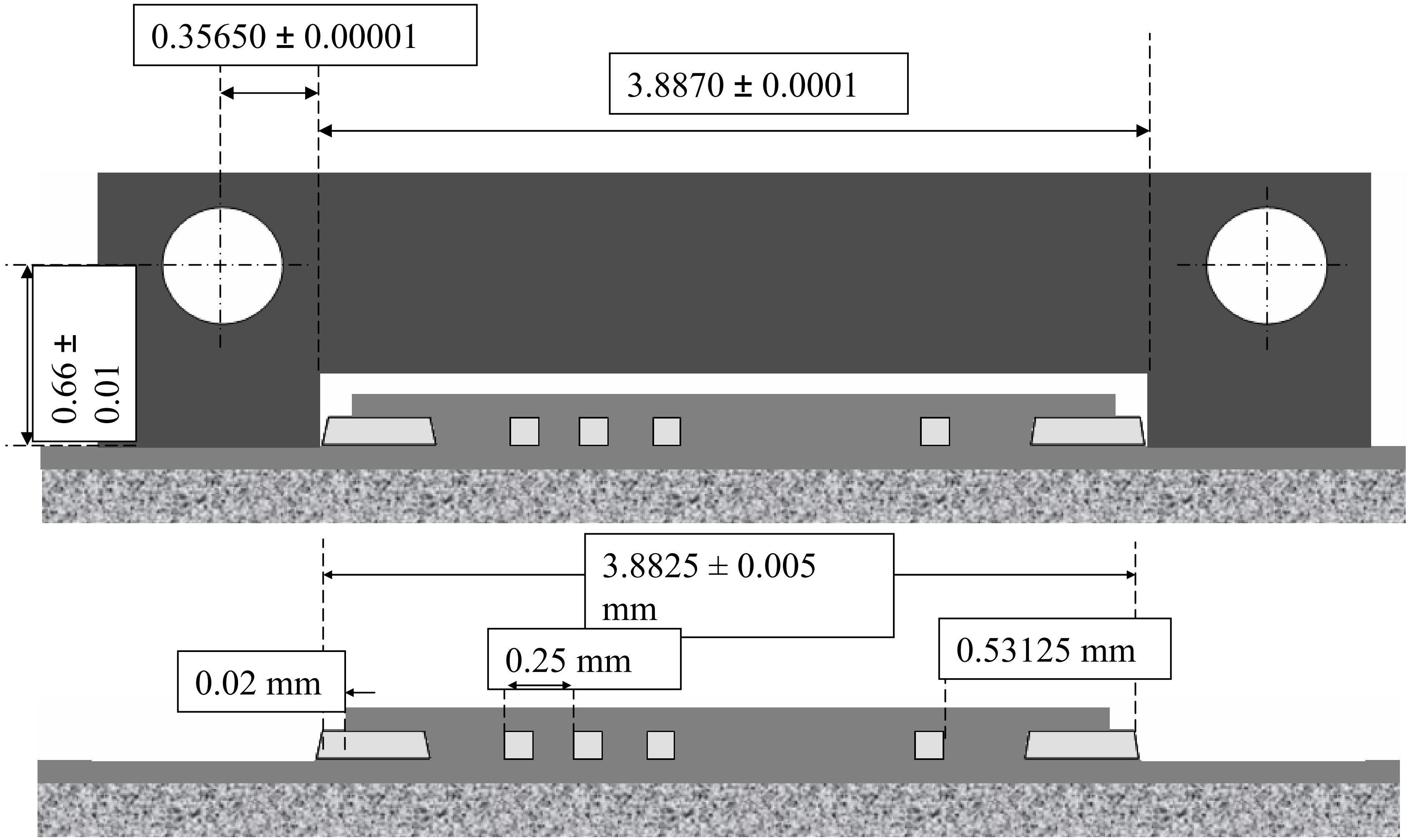
(b)

MT-plug

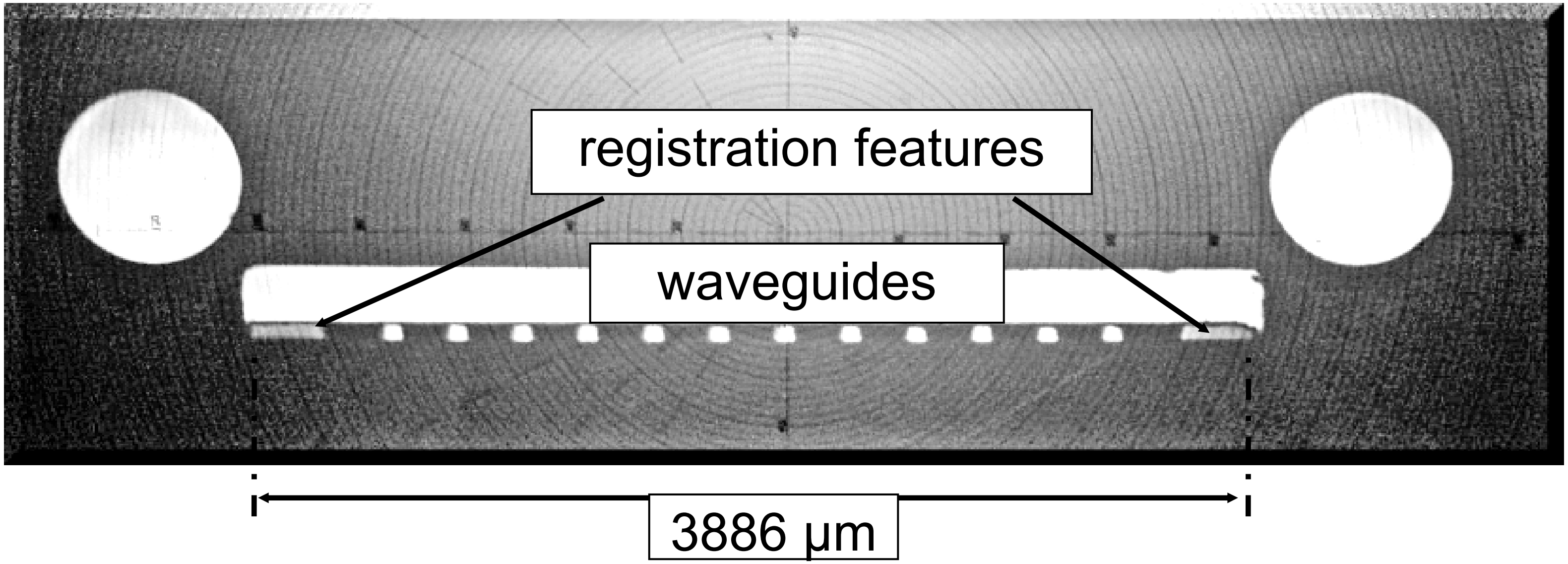


Alignment Precision
x: ± 3 μm
y: ± 4 μm
z: ± 10 μm

MT - Socket interposer on the top of backplane



Actual alignment of the component

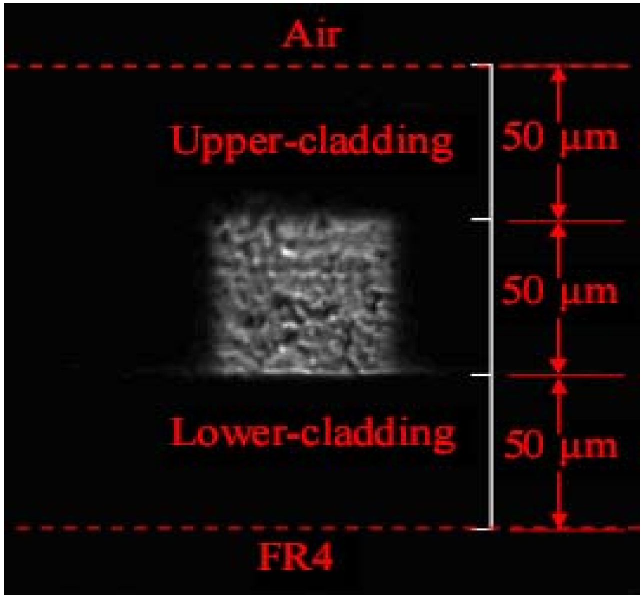


registration features

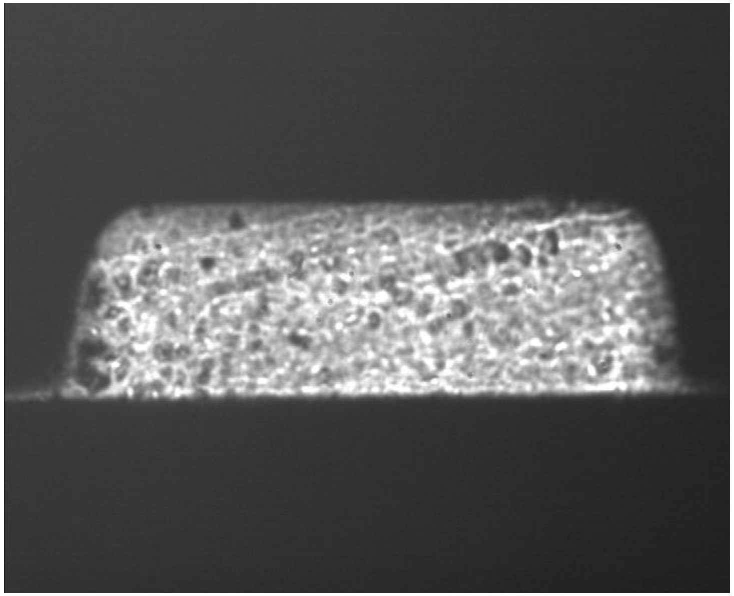
waveguides

3886 µm

Waveguide photographs



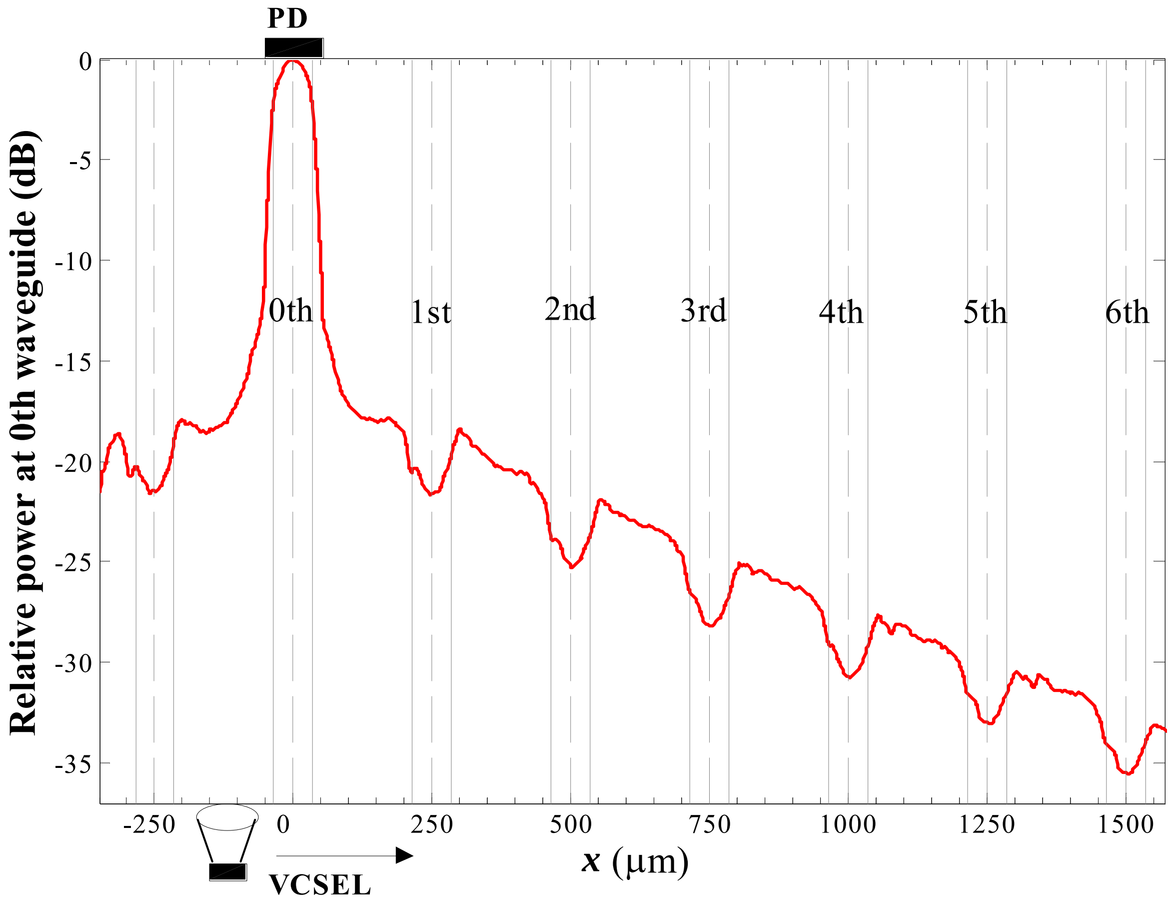
50 µm × 50 µm Waveguide



140 µm × 140 µm Waveguide

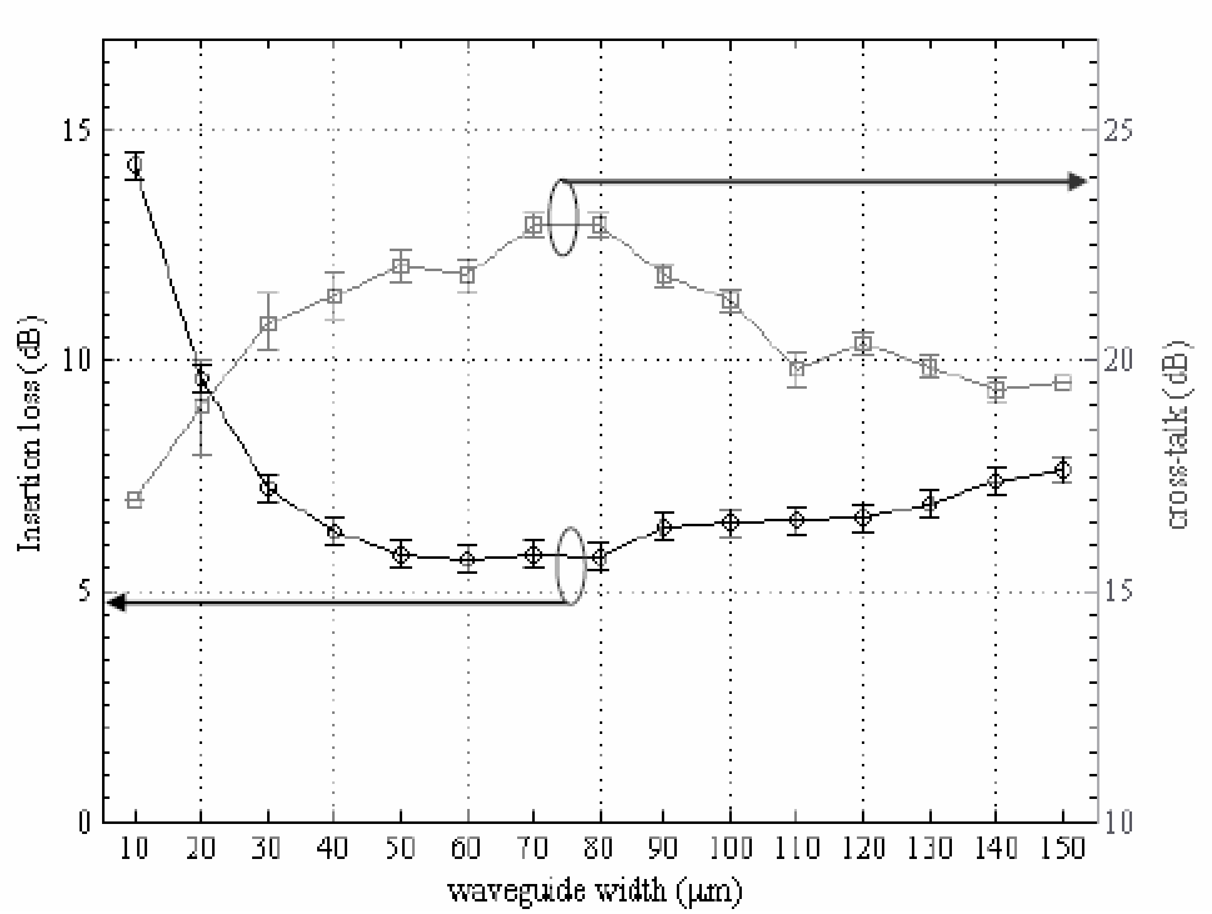
- Photolithographicly fabricated by Exxelis
- Cut with a dicing saw, unpolished
- VCSEL illuminated

Crosstalk measurement 1



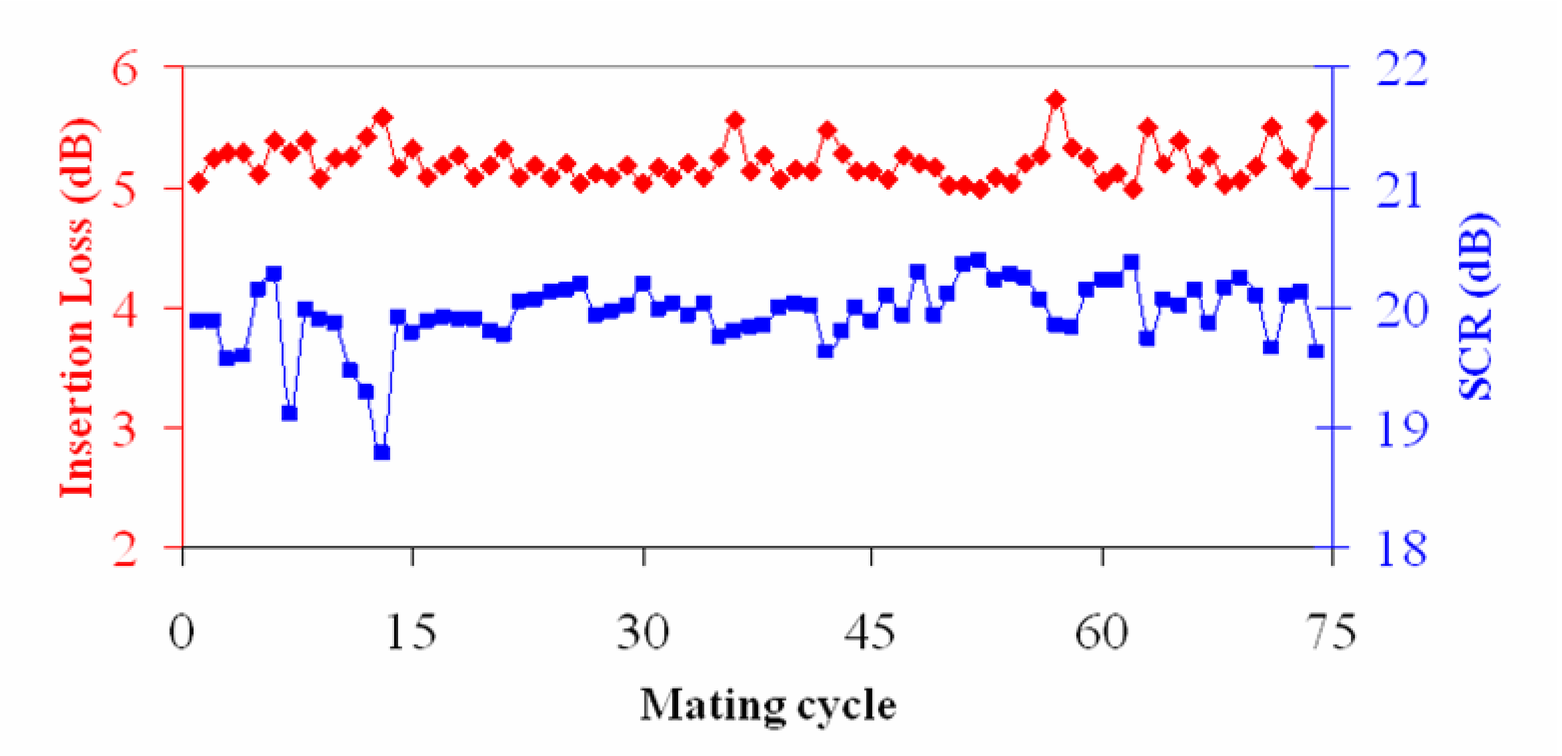
Power received at the end of 0th waveguide as a function of the lateral distance of the VCSEL from its center. The boundaries and the centers of the waveguides on the backplane are marked. In the cladding power drops at a rate of 0.011 dB/μm

Insertion Loss and cross-talk



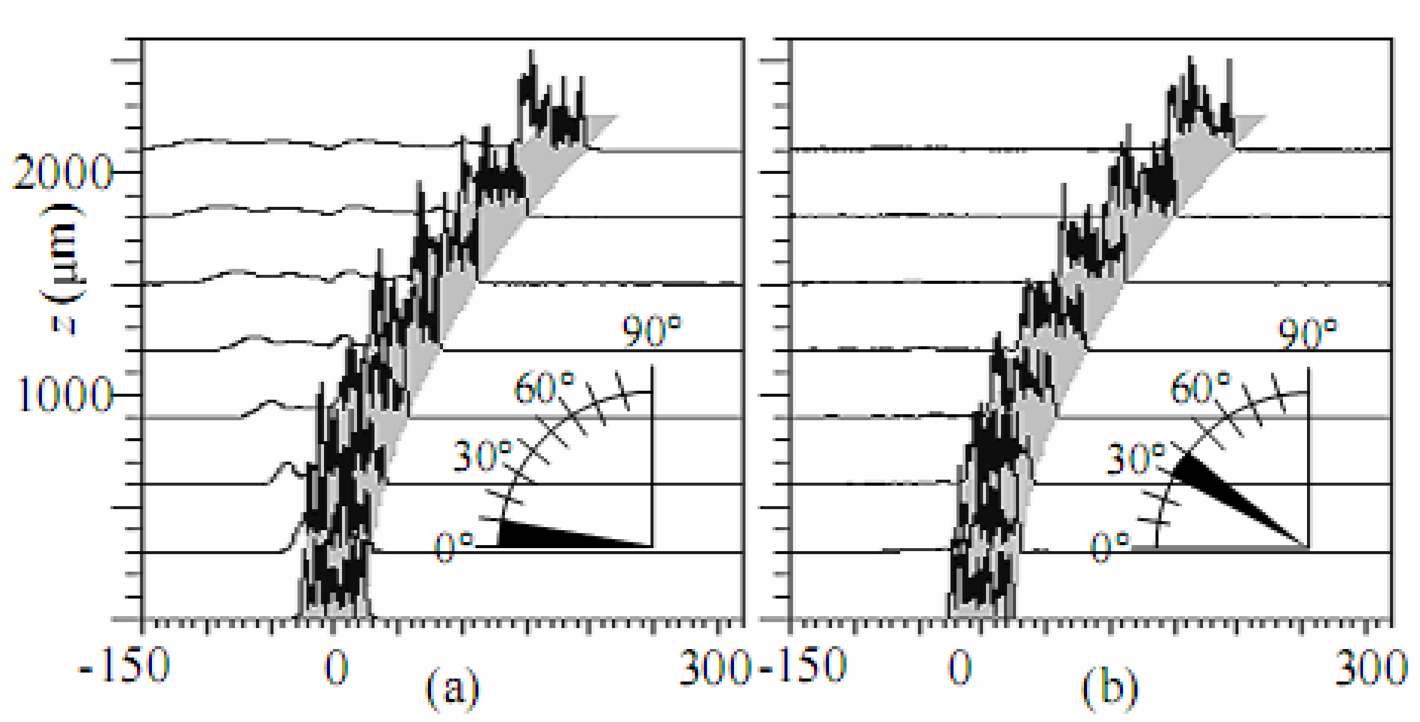
6~7dB for a 70 μm width waveguide

Stability testing of the MT – socket interposer 1



Insertion loss and signal to cross-talk (SCR) as a function of mating cycle for 75 engagements.

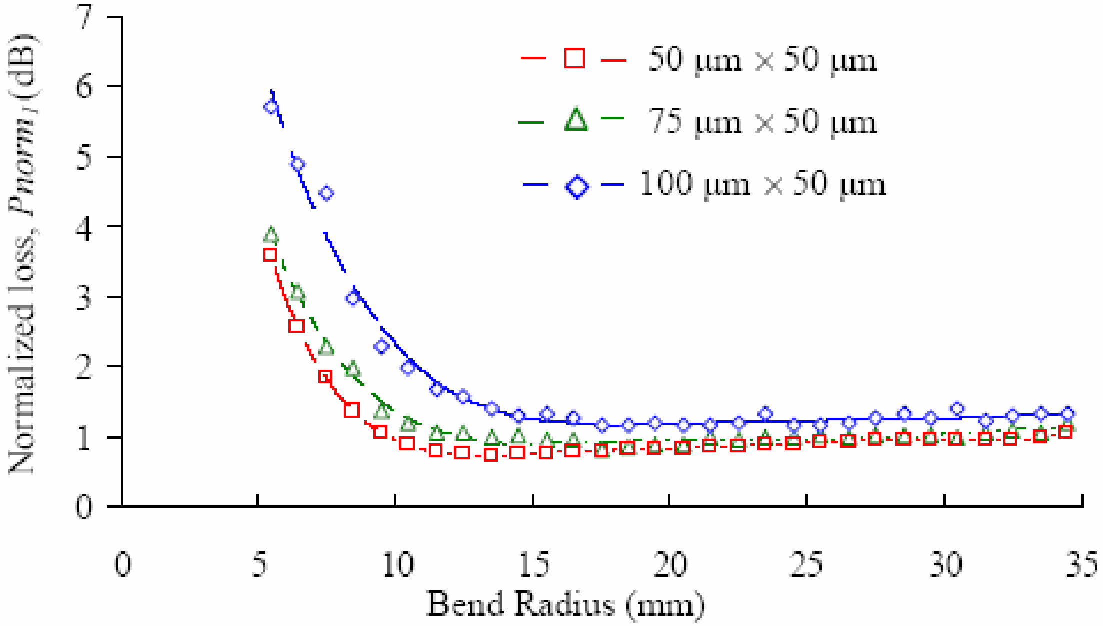
Beam Propagation Method (BPM) modelling



Computer simulations of the optical field in a 90º waveguide bend

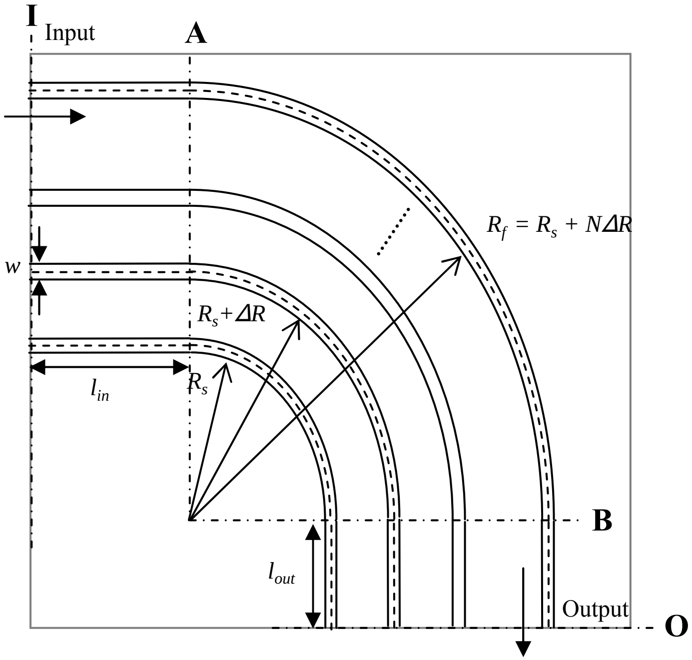
- left: at the start of the bend after a straight input waveguide
- right: a third of the distance along the bend.

Loss of waveguide bends as a function of bend radius

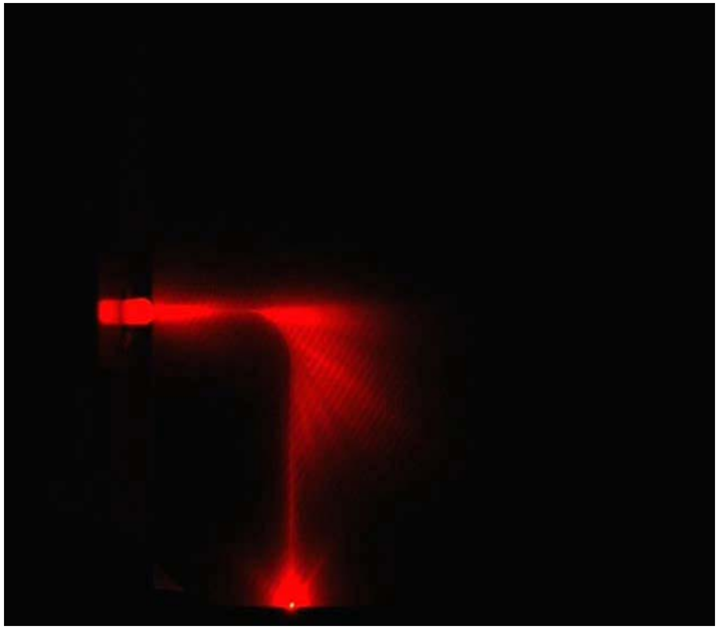


Width (μm)	Radius (mm)	Minimum Loss (dB)
50	13.5	0.74
75	15.3	0.91
100	17.7	1.18

Transition loss



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

Conclusions

- 11 months into the 3 year project
- Range of waveguide fabrication processes
  - High and low risk
- Strong Industrial Lead, Participation and Management
- Full Supply chain established
  - Modelling, Design Rules, Layout software, Fabrication Development, Transfer to PCB manufacturer, High bit rate measurements, end user company requirements
- Collaboration Agreement signed by partners
- IP already raised
- Secure Web Portal on-line