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
On-board Platform Applications

Reconfigurable Network Interconnections

RF/EO Sensors & comms data

Aircraft utilities

Signal concentrator

High Bandwidth Signals
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
**Direct Laser-writing Setup: Schematic**

- **Slotted baseplate** mounted vertically over translation, rotation & vertical stages; components held in place with magnets
- By using two opposing 45° beams we minimise the amount of substrate rotation needed
Writing sharply defined features
– flat-top, rectangular laser spot

Gaussian beam diameter = 1.1 mm

TEM_00

60 μm square aperture

Imaging system / lenses

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 45° 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

- 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
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

Deposit cladding and core layers on substrate
UV LASER
Laser ablate polymer
Deposit cladding layer
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

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

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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, 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

\[ w = 50 \, \mu m, \quad R = 13 \, mm \]

(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

- 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

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

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**(+)-Direction**

**(-)-Direction**

- **Power at the receiver (dBm)**
  - **BER**
  - **R = 9.5 mm**
  - **R = 13.5 mm**
  - **R = 20.5 mm**
  - **Straight**
  - **No wvg.**

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Contour map of VCSEL and PD misalignment

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

- 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 $x = 0$, $y = 0$, $z = 0$.

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

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Coupling Loss for VCSEL and PD for misalignments along optic axis

- VCSEL
- Photo Detector

axial distance $z$ (μm)

Insertion Loss (dB)
**Parallel optical transceiver circuit**
- Small form factor quad parallel optical transceiver
- Microcontroller supporting I²C 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
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
Hybrid Electro-Optical Printed Circuit Board

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- EPSRC and all partner companies for funding

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* Assembly and Reliability

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## Program

### System Design

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<td>Welcome&lt;br&gt;Henning Schröder&lt;br&gt;Fraunhofer IZM Berlin, Germany</td>
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<td>09:40-10:10</td>
<td>Optical Interconnect Applications for Multimode Siloxane Components&lt;br&gt;Ian H. White&lt;br&gt;University of Cambridge, Cambridge, UK</td>
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<tr>
<td>10:10-10:40</td>
<td>Design Rules for Polymer Waveguides and Measurement Mechaniques&lt;br&gt;Kai Wang&lt;br&gt;University College London, London, UK</td>
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<td>10:40-11:10</td>
<td>CAD of Board-Level Optical Interconnects&lt;br&gt;Jürgen Schrage&lt;br&gt;Siemens C-Lab, Faderbom, Germany</td>
</tr>
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<td>10:40-11:10</td>
<td>Coupling Light to and from Optical Boards&lt;br&gt;Peter van Daele&lt;br&gt;University of Gent, Gent, Belgium</td>
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<td>Lunch break</td>
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### Components

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<td>240 Gbit/s Parallel Optical Transmission Using Double Layer Waveguides in Thin Glass Sheets&lt;br&gt;Henning Schröder&lt;br&gt;Fraunhofer IZM Berlin, Germany</td>
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<tr>
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<td>Flexible Optical Interconnects&lt;br&gt;Geert van Steenberge&lt;br&gt;University of Gent, Gent, Belgium</td>
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<td>01:30-02:00</td>
<td>Refractive Index Profiling of Polymer Planar Optical Waveguides Using Optical Coherence Tomography&lt;br&gt;David Ives&lt;br&gt;National Physical Laboratory, Middlesex, UK</td>
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<td>02:00-02:30</td>
<td>Ink Jet Printing of Optical Waveguide Material&lt;br&gt;John Chappell and David Hutt&lt;br&gt;Loughborough University Loughborough, UK</td>
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<td>Coffee break</td>
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### Integration Technologies

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<td>Transfer of Polymer Waveguide Fabrication Processes to a Commercial PCB Foundry&lt;br&gt;Dougall Stewart&lt;br&gt;Stevenson Circuits Limited, Stewana, UK</td>
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<tr>
<td>03:50-04:20</td>
<td>Board-Level Optical Interconnects for Computing Applications&lt;br&gt;Bert Offreins&lt;br&gt;IBM Research Labs, Röschlikon, Switzerland</td>
</tr>
<tr>
<td>04:20-04:50</td>
<td>Pluggable Interconnect Technology for Electro-Optical PCBs&lt;br&gt;Richard Pitwon&lt;br&gt;Ynixtas, Hampshire, UK</td>
</tr>
<tr>
<td>04:50-05:20</td>
<td>Optoelectronic Printed Circuit Board Realised by Two Photon Absorption Structuring&lt;br&gt;Gregor Langer&lt;br&gt;AT&amp;S AG, Leoben, Austria</td>
</tr>
<tr>
<td>05:20-05:30</td>
<td>Final Remarks&lt;br&gt;Henning Schröder&lt;br&gt;Fraunhofer IZM Berlin, Germany</td>
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