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
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

Imaging system / lenses

TEM$_{00}$

60 µm square aperture

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

- 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 \(~1.4\,\text{m}\). 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

**Diagram:**
- Deposit cladding and core layers on substrate
- 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
Challenges of Inkjet Deposition

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

![Graph showing viscosity vs. temperature](image1)

![Image of inkjet printed drops and cross-section of dried droplet](image2)
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

- 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

\( w = 50 \, \mu m, \ R = 13 \, mm \)

(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

![Graph showing BER vs. Power at the receiver (dBm) for (+) and (-) Direction. The graph includes lines for different R values: 9.5 mm, 13.5 mm, and 20.5 mm. The graph also shows different markers for Straight and No wvg. configurations.]
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 \( \Delta x = \Delta y = 1 \, \mu m \).
Coupling Loss for VCSEL and PD for misalignments along optic axis

- VCSEL
- Photo Detector

(axial distance $z \ (\mu m)$)

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**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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Polymer optical waveguides on optical layer

Optical connector site

Compact PCI slot for single board computer

Compact PCI slots for line cards
Acknowledgments

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2. International Symposium on Photonic Packaging
Electrical Optical Circuit Board and Optical Backplane

At the International Symposium on Photonic Packaging international experts from Germany and abroad will present the current state-of-the-art in this field and discuss technological aspects as well as market launch.

The event is open to developers and decision makers from the realms of data communication, telecommunication, medical engineering, sensor technology, and automotives.

**Topics**
* Roadmaps and System Requirements
* Design and Components
* System Integration and PCB Technology
* Assembly and Reliability

[Program (.pdf/48KB)]

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**Time:** November 13, 2008, 9:30 am - 5:30 pm  
**Venue:** Messe München, Hall A1, Conference Room A12  
**Conference language:** English

**Conference fees (including conference proceedings):**  
**Speaker fee:** EUR 195,-  
**Early bird:** EUR 275,- (until September 30, 2008)  
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# 2. International Symposium on Photonic Packaging

**Electrical Optical Circuit Board and Optical Backplane**

organized by Fraunhofer IZM, co-organized by VDI/VDE-IT, IEEE-CMPT, IEEE-LEOS

November 13, 2008, Electronica, Messe München | Hall A1 Conference Room A12, 9:30 am – 5:30 pm

## Program

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<th>Components</th>
<th>Integration Technologies</th>
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<td><strong>09:30-09:40</strong> Welcome Henning Schröder Fraunhofer IZM Berlin, Germany</td>
<td><strong>12:30-01:00</strong> 240 Gbit/s Parallel Optical Transmission Using Double Layer Waveguides in Thin Glass Sheets Henning Schröder Fraunhofer IZM Berlin, Germany</td>
<td><strong>03:20-03:50</strong> Transfer of Polymer Waveguide Fabrication Processes to a Commercial PCB Foundry Dougal Stewart Stevenage Circuits Limited, Stevenage, UK</td>
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<td><strong>09:40-10:10</strong> Optical Interconnect Applications for Multimode Siloxane Components Ian H. White University of Cambridge, Cambridge, UK</td>
<td><strong>01:00-01:30</strong> Flexible Optical Interconnects Geert van Steenberge University of Gent, Gent, Belgium</td>
<td><strong>03:50-04:20</strong> Board-Level Optical Interconnects for Computing Applications Bert Offreins IBM Research Labs, Röschlikon, Switzerland</td>
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<td><strong>10:10-10:40</strong> Design Rules for Polymer Waveguides and Measurement Techniques Kai Wang University College London, London, UK</td>
<td><strong>01:30-02:00</strong> Refractive Index Profiling of Polymer Planar Optical Waveguides Using Optical Coherence Tomography David Ives National Physical Laboratory, Middlesex, UK</td>
<td><strong>04:20-04:50</strong> Pluggable Interconnect Technology for Electro-Optical PCBs Richard Pitwon Xyratex, Hampshire, UK</td>
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<td><strong>10:40-11:10</strong> CAD of Board-Level Optical Interconnects Jürgen Schrage Siemens C-Lab, Faderbom, Germany</td>
<td><strong>02:00-02:30</strong> InkJet Printing of Optical Waveguide Material John Chappell and David Hutt Loughborough University Loughborough, UK</td>
<td><strong>04:50-05:20</strong> Optoelectronic Printed Circuit Board Realised by Two Photon Absorption Structuring Gregor Langer AT&amp;S AG, Leoben, Austria</td>
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<td><strong>10:40-11:10</strong> Coupling Light to and from Optical Boards Peter van Daele University of Gent, Gent, Belgium</td>
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<td><strong>05:20-05:30</strong> Final Remarks Henning Schröder Fraunhofer IZM Berlin, Germany</td>
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<td><strong>11:40-12:30</strong> Lunch break</td>
<td><strong>02:30-03:20</strong> Coffee break</td>
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