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Micro-optical Modules for Board and Chip Level interconnects

C. Debaes, M. Vervaeke, Y. Isshii, B. Volckaerts, J. Van Erps, L. Desmet, H. Ottevaere, P. Vynck , V. Gomez, A. Hermanne, H. Thienpont

Lab for Applied Physics and Photonics

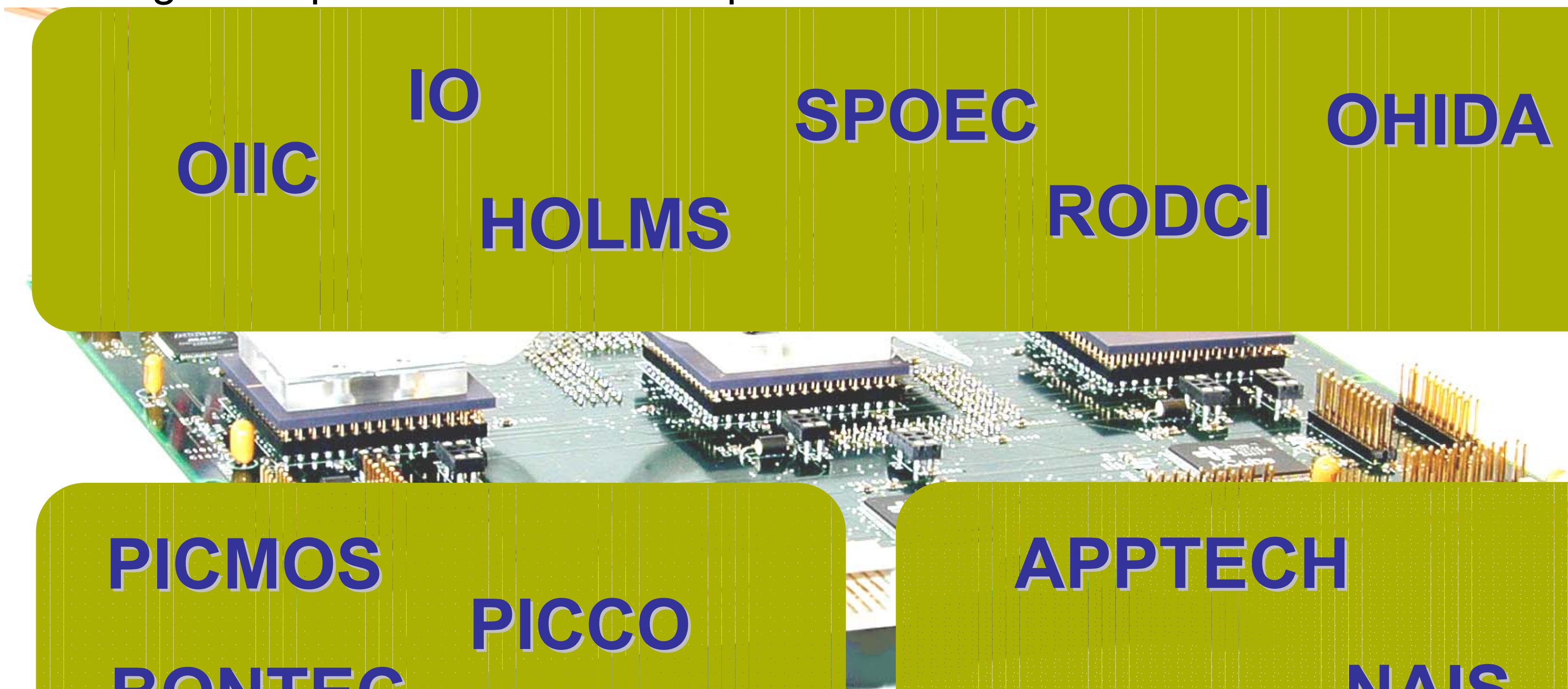
Vrije Universiteit Brussel

Optical Interconnect Lenghts

Bhanu Jaiswal
University at Buffalo

Past and present European projects

Large European Consortia on Optical Interconnect Demonstrators



IO

SPOEC

OHIDA

OIIC

HOLMS

RODCI

PICMOS

PICCO

BONTEC

MONOLITH

Photonic Integrated Circuits

APPTECH

NAIS

GIANT

FTTx, Passive Optical Networks

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Past and present European projects

- European consortia have demonstrated highly advanced demonstrators
- Optical interconnect technologies are maturing:
  - Optoelectronic device technology
    - low threshold VCSEL, modulators, efficient detectors
  - Hybridization techniques
  - Many alternative waveguide fabrication technologies

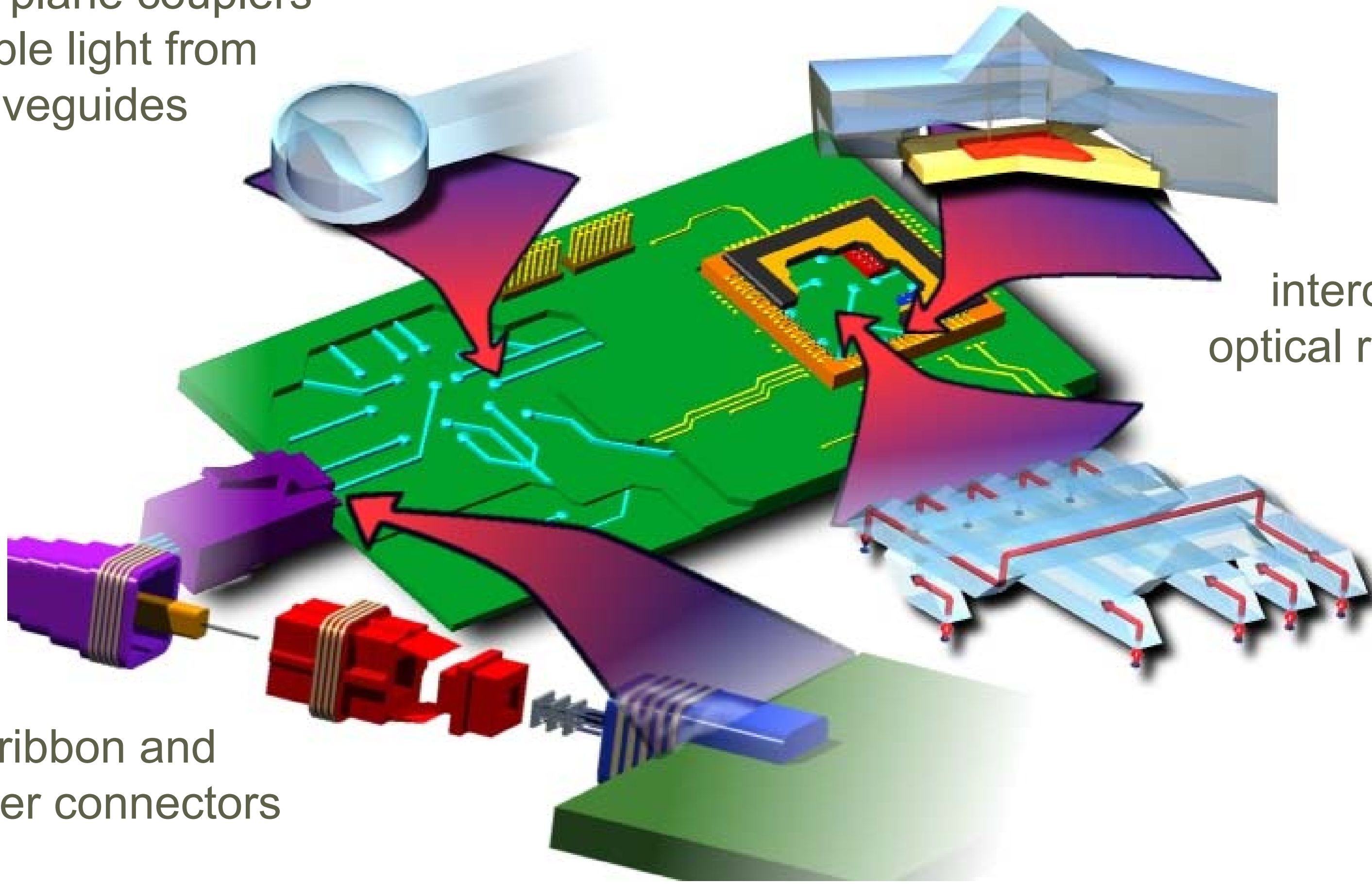
We believe that one of the largest remaining challenges is to develop **Optical Interconnect Modules** that efficiently couple and reliably package with optoelectronic chips

Microfabrication of reliable components in polymers

Vrije Universiteit Brussel

Out-of-plane couplers to couple light from the waveguides

Intra-MCM interconnections, optical redistribution layers



Fiber ribbon and 2D fiber connectors

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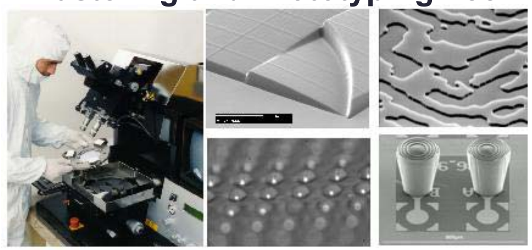
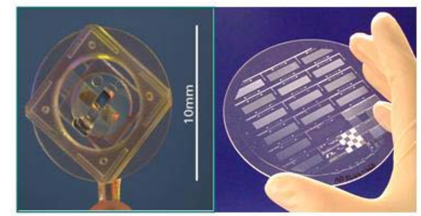
Network of Excellence of Micro-Optics (NEMO)

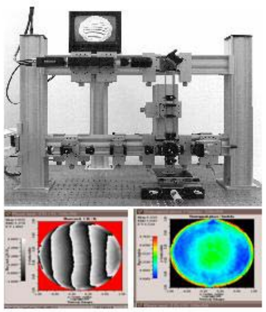
Network of Excellence on Micro-Optics

Mastering and Prototyping Technologies

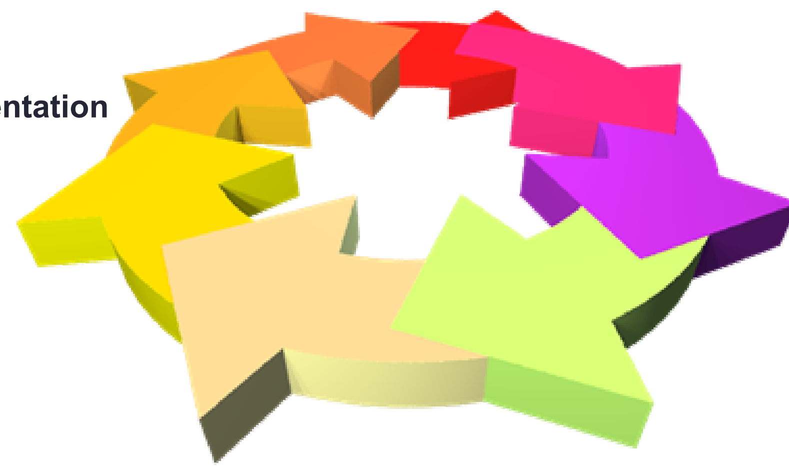


Low-Cost Replication

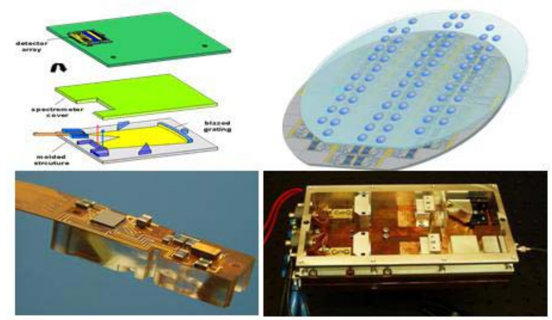


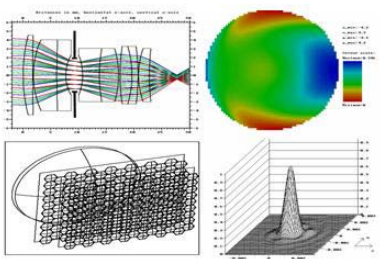


Measurement and Instrumentation

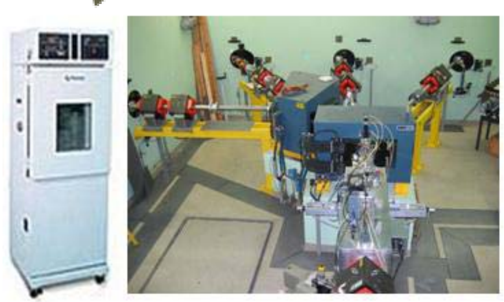


Assembly, Integration and Packaging





Modelling and Design



Reliability

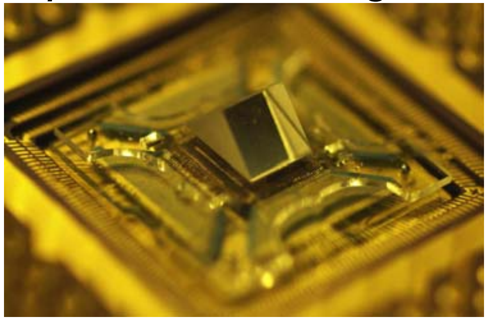
NEMO Workpackage 9: Optical Interconnects

Ghent University
(TFCG)

Laser Ablation

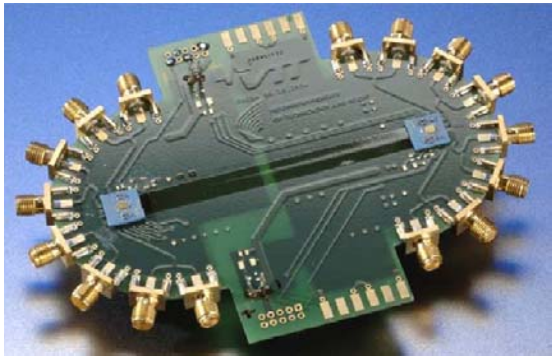
Vrije Universiteit Brussel
(TONA)

Deep Proton Writing, DPW



VTT

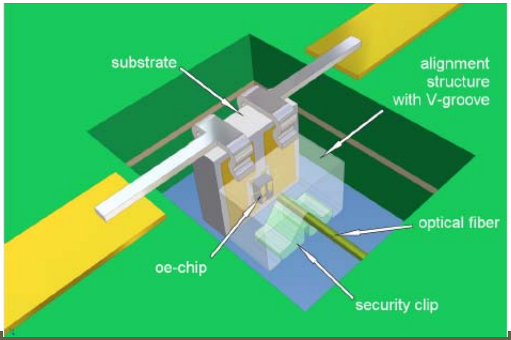
Packaging and integration



CNRS-TSI

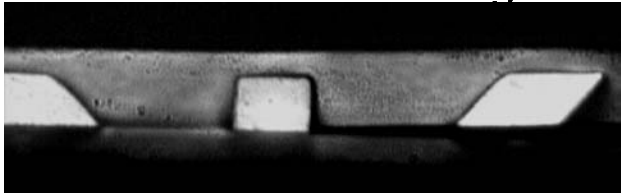
Solgel waveguides
And grating couplers

FZK
Forschungszentrum Karlsruhe
Embedded fibers in PWB



Herriot Watt Univeristy

Direct Laser Writing



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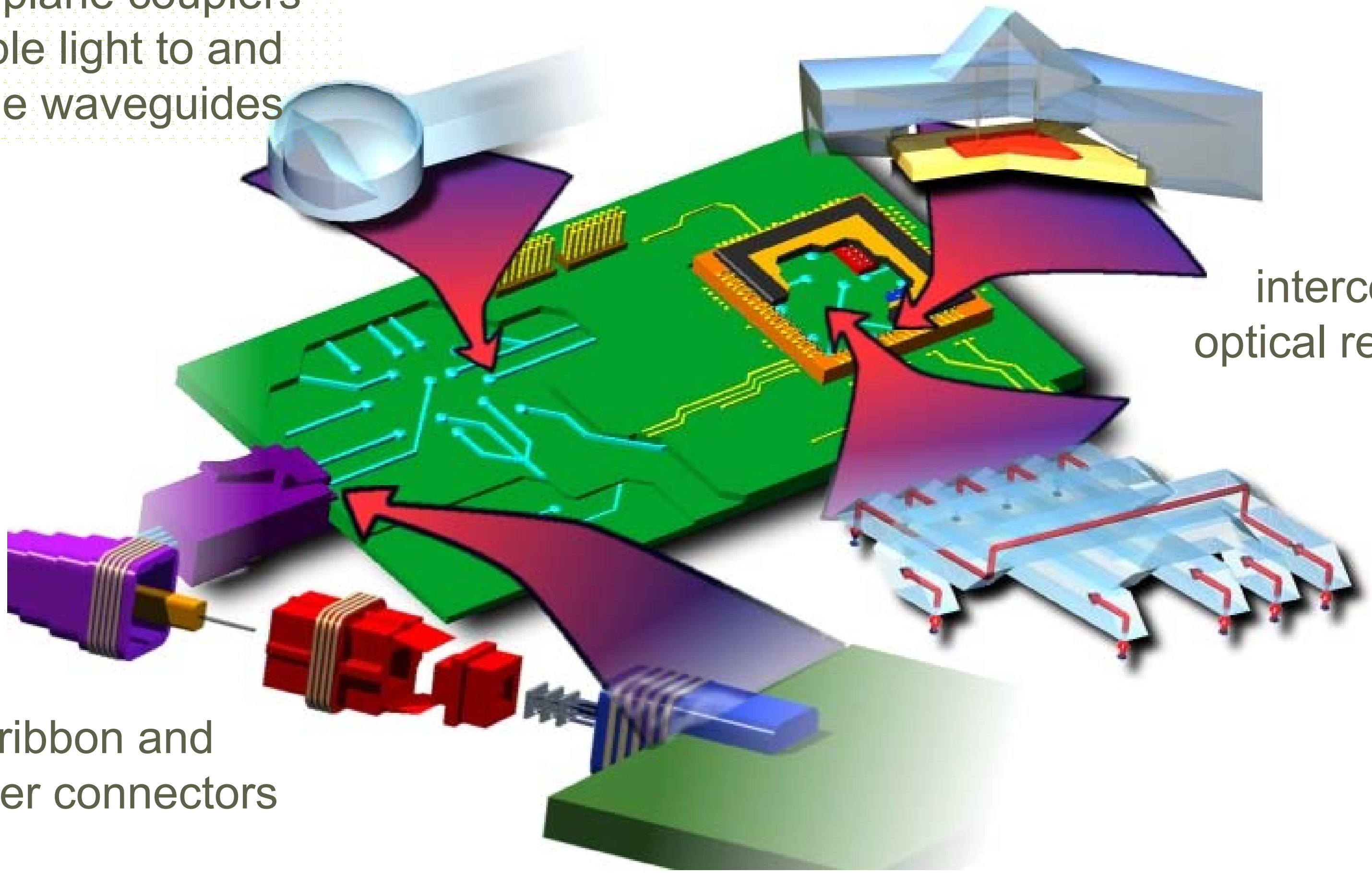
Microfabrication of reliable components in polymers

Out-of-plane couplers to couple light to and from the waveguides



Intra-MCM interconnections, optical redistribution layers

Fiber ribbon and 2D fiber connectors

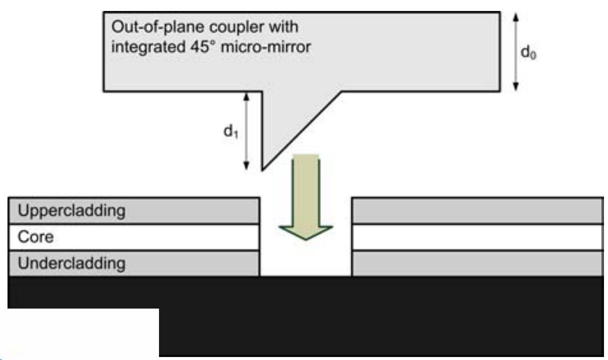
Vrije Universiteit Brussel

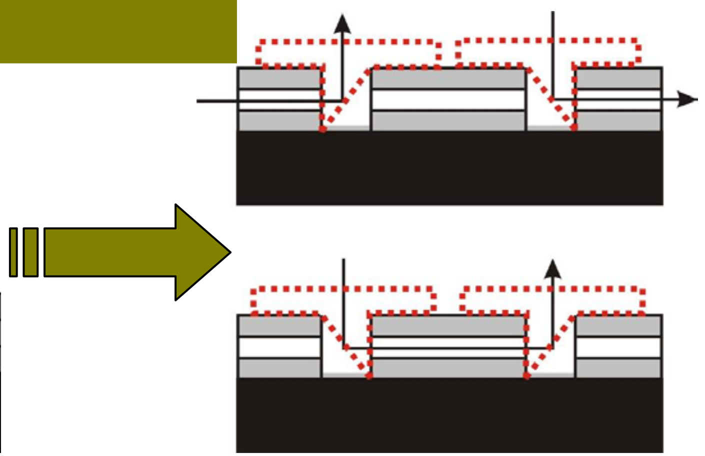
Pluggable out-of-plane coupler for multimode waveguides

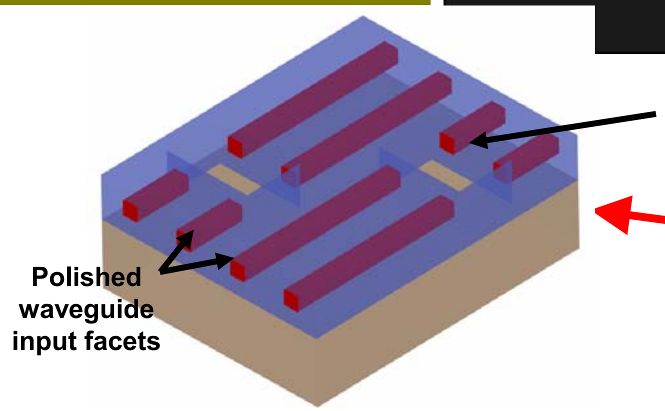
- ➔ 90° out-of-plane optical deflection important for use in optical paths between waveguides and optoelectronic devices (LDs, PDs)
- ➔ Mostly realised by using 45° micro-mirrors

Drawbacks of Diamond blade cutting, RIE and Laser ablation:

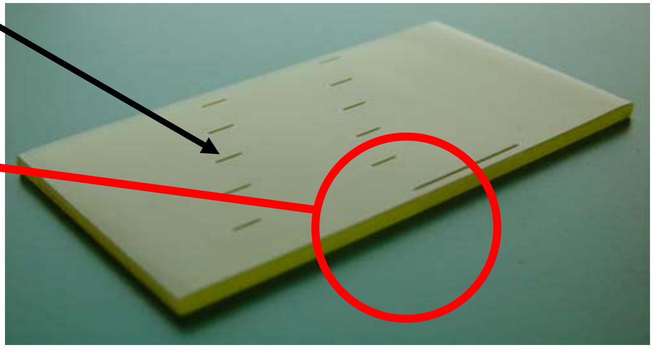
- ➔ Relatively high surface roughness
- ➔ Limited flexibility:
  - Micro-mirror formed in the waveguide itself
  - Sometimes impossible to cut individual waveguides





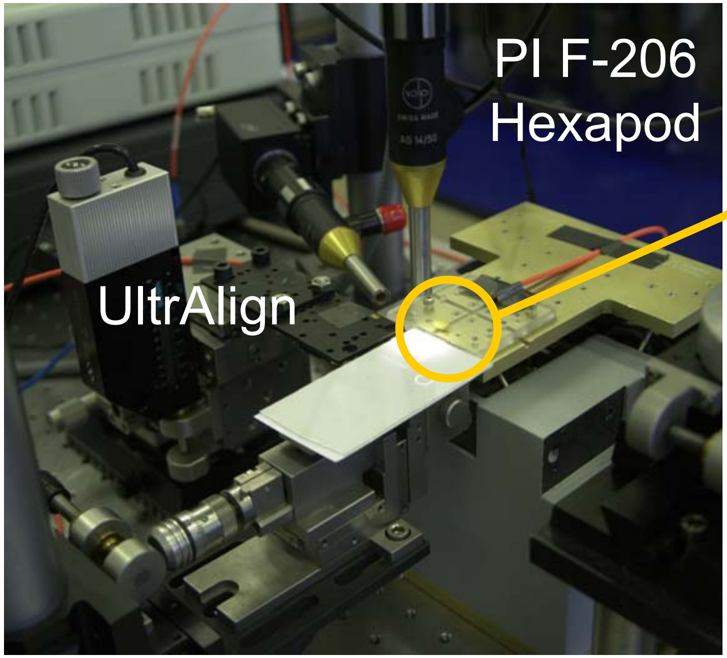


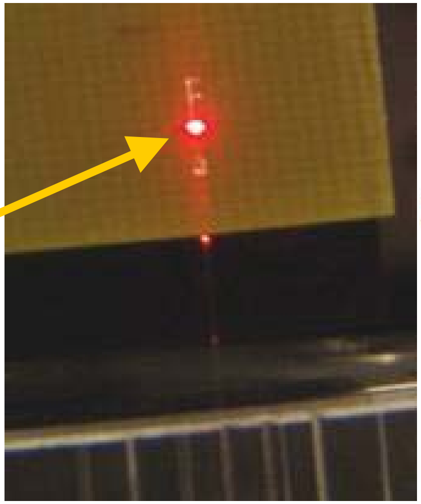
Laser ablated cavities

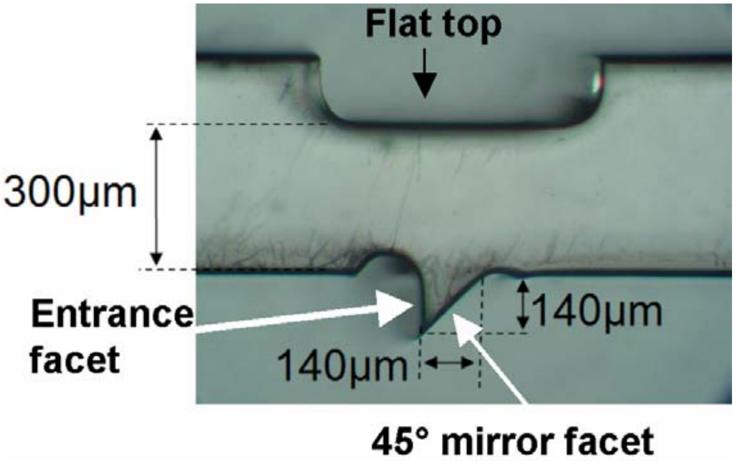


The realized out-of-plane coupler

- **Deep Proton Writing** allows us to make versatile, pluggable components with very high quality 45° micro-mirrors







UltraAlign: XYZ + tip/tilt
Hexapod: 6 DOF, 300nm repeatability
Source: MMF, λ=850nm
Detector: MMF ∅50µm core NA 0.22

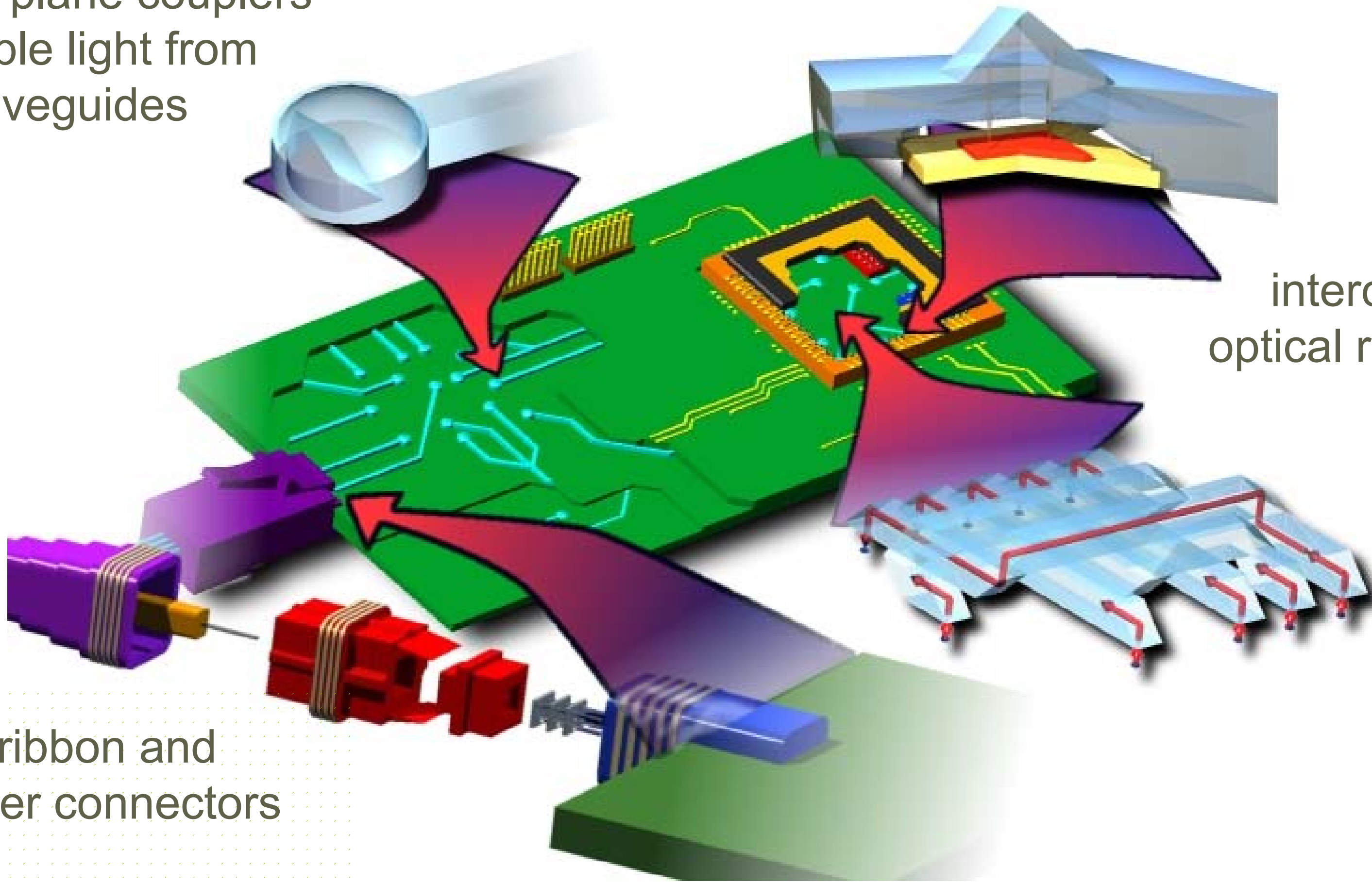
Measured	Simulations
47.5% (-3.25dB)	63.4% (-1.98dB)

Increases to **56.5% (-2.49dB)** when using index matching gel at the entrance facet of the out-of-plane coupling component

Microfabrication of reliable components in polymers

Vrije Universiteit Brussel

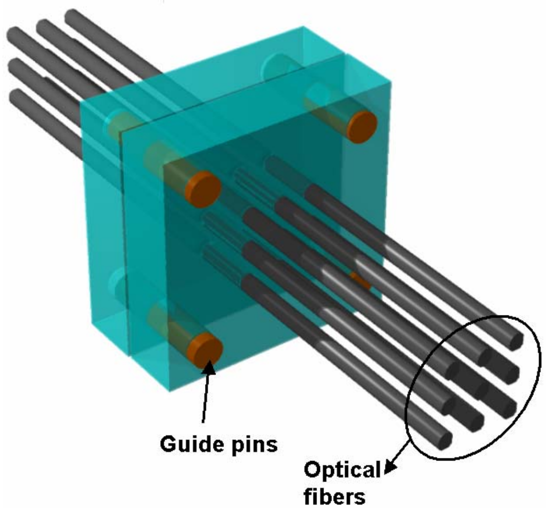
Out-of-plane couplers to couple light from the waveguides

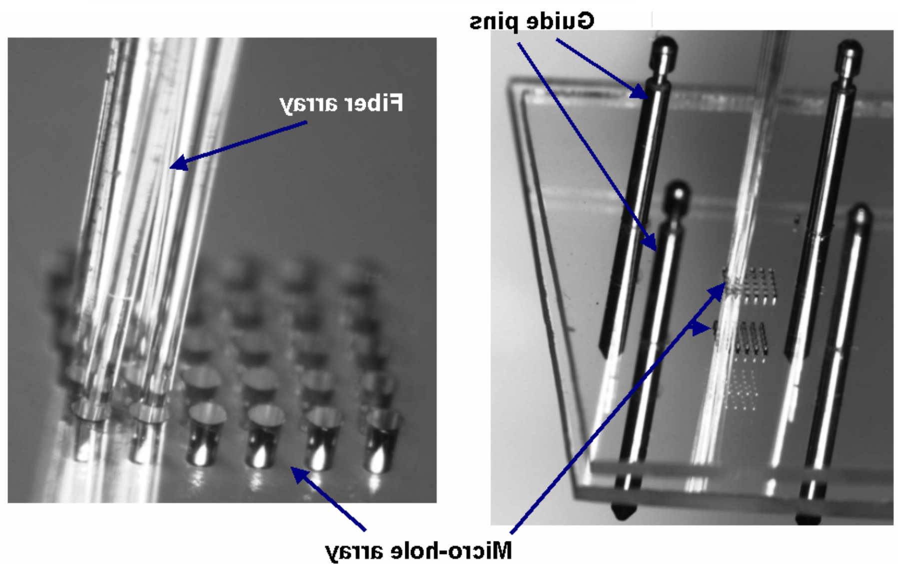


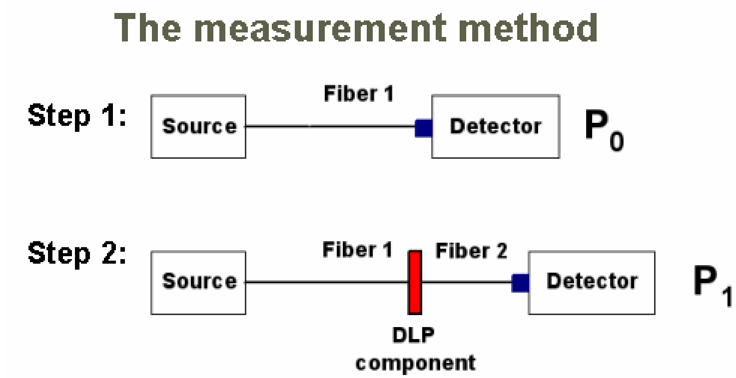
Intra-MCM interconnections, optical redistribution layers

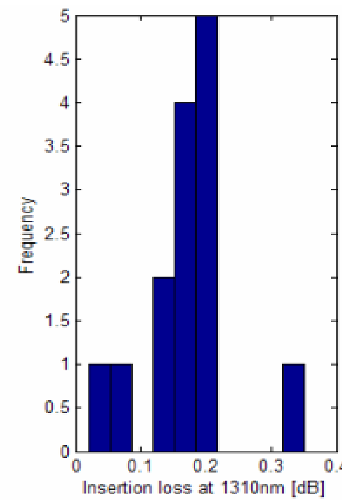
Fiber ribbon and 2D fiber connectors

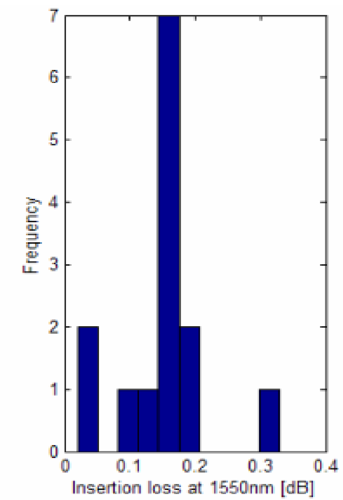
Large low-loss 2D fiber connectors







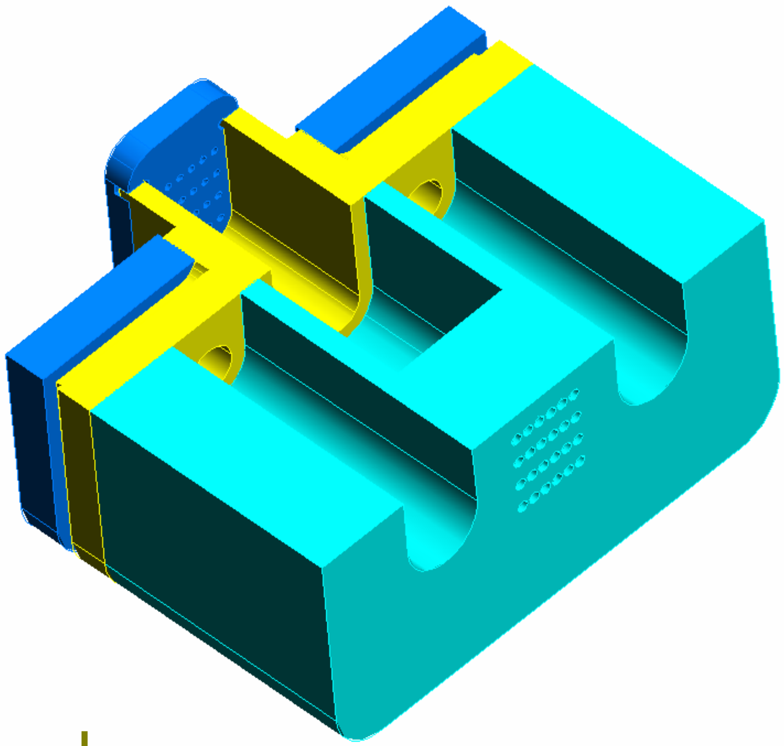


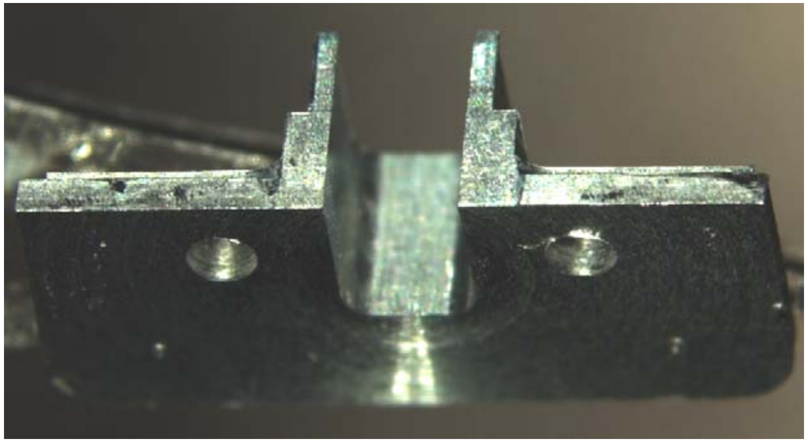


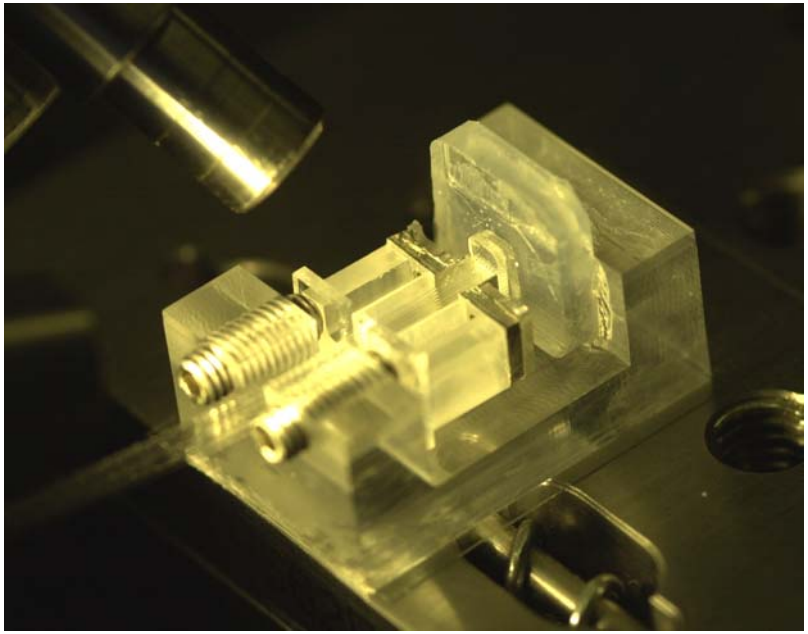
Aver. loss = 0.17dB
St.dev. loss = 0.07dB

Aver. loss = 0.15dB
St.dev. loss = 0.07dB

Fiber connector system for inter-chip interconnects

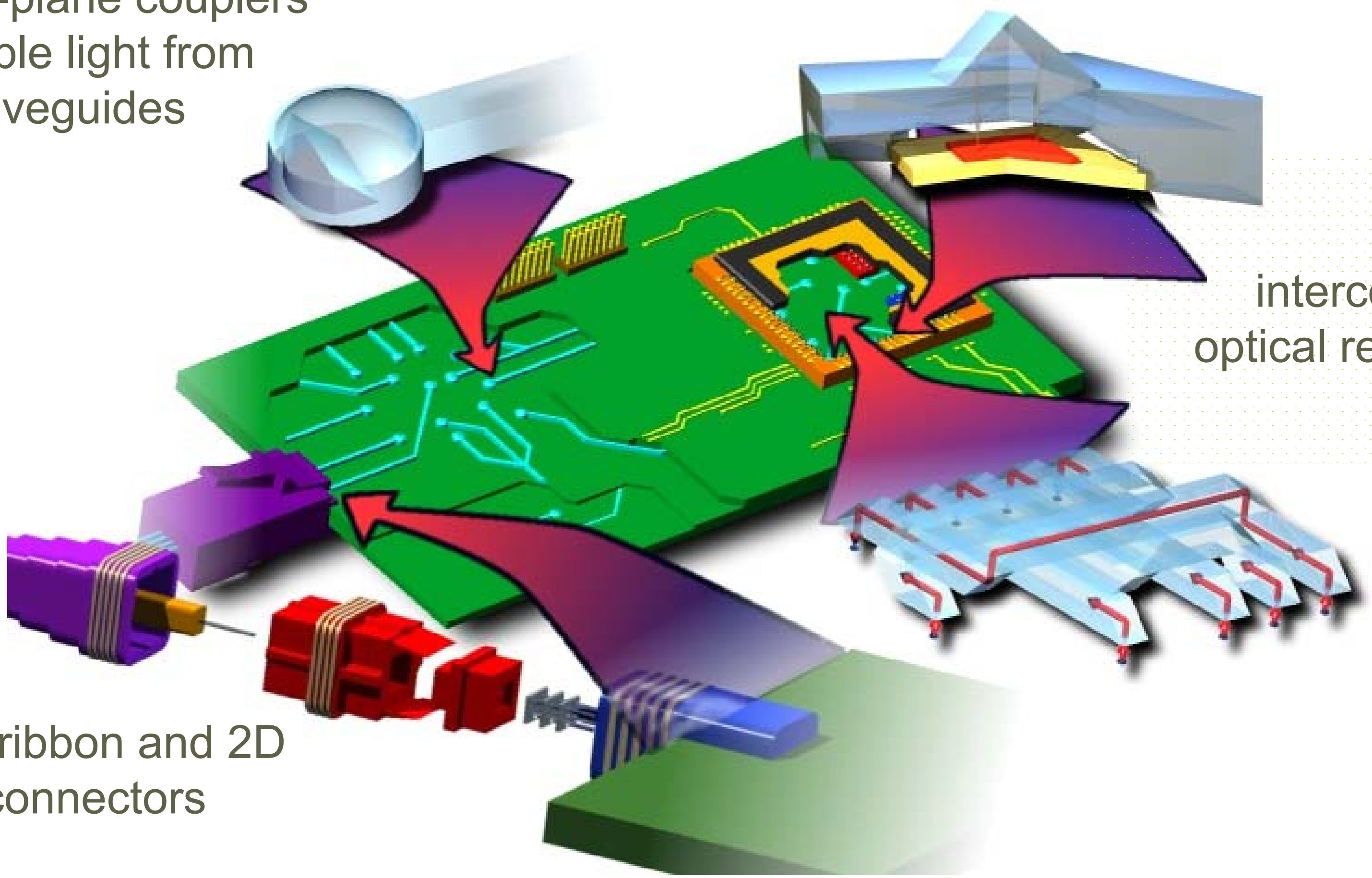






Multimode 6x4 fiber connector by integration of micro-milled structures and micro-holes fabricated with Deep Proton Writing

Microfabrication of low-cost components in polymers



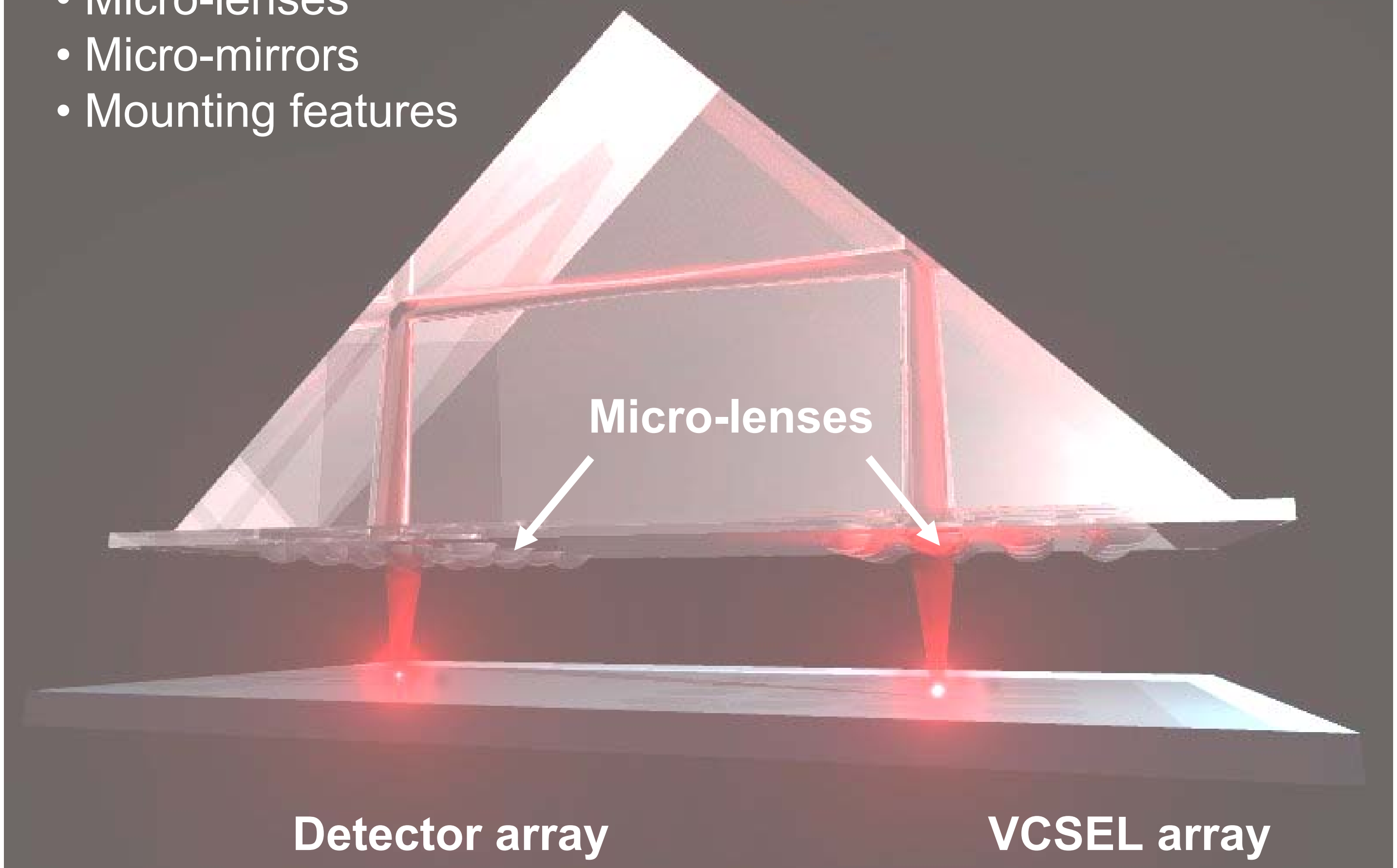
Out-of-plane couplers to couple light from the waveguides

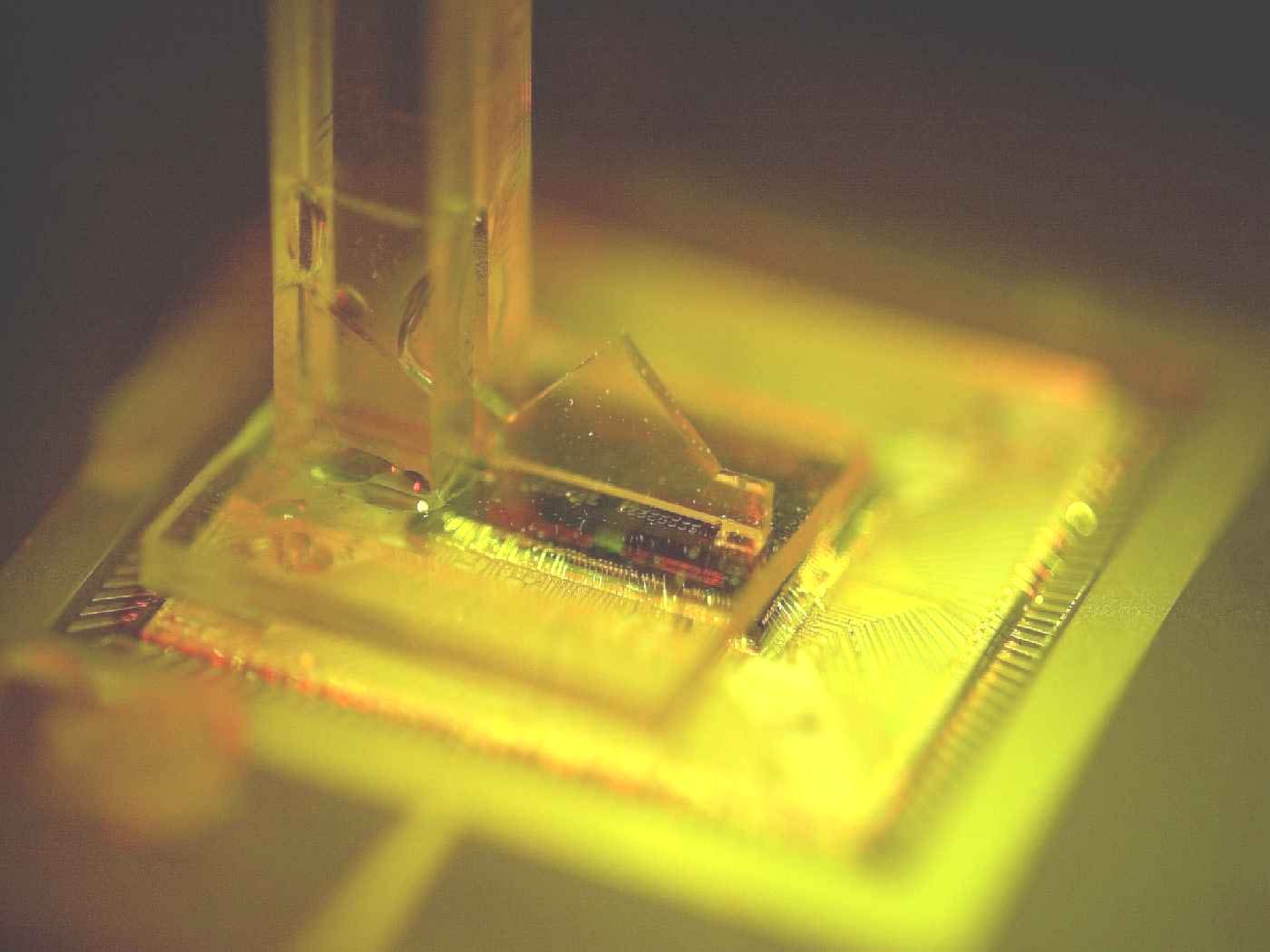
Intra-MCM interconnections, optical redistribution layers

Fiber ribbon and 2D fiber connectors

Intra-MCM interconnection modules

Combination
- Micro-lenses
- Micro-mirrors
- Mounting features



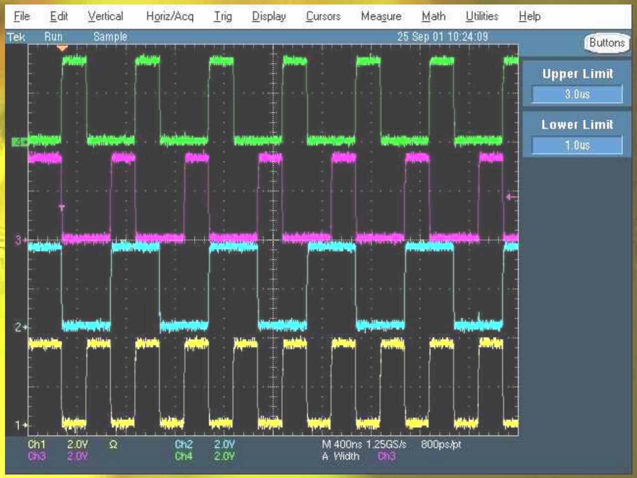


OIIC: First Demonstration of intra-chip Optical links

Micro-optical Module Featuring:
- a micro-prism (500 µm thick)
- a baseplate with 2 times 2x8 micro-lens arrays

Manual Alignment with precision stages

4 Channel intra-chip links
Crosstalk -22dB
10Mb/s



Opto-electronic FPGA (OE-FPGA), Featuring:
- **CMOS chip, non-aggressive 0.6µm technology**
- **flipchipped 2D VCSEL array, emitting at 980nm**
- **flipchipped 2D photodetector array**

(Fabricated in the framework of the OIIC-project)

C. Debaes, et all, "Low-cost micro-optical modules for MCM level optical Interconnections", IEEE J. of Sel. Topics in Quantum Electronics, Vol 9, No. 2, pp. 518- 530, 2003

Towards demonstration of a manufacturable DPW OI scheme

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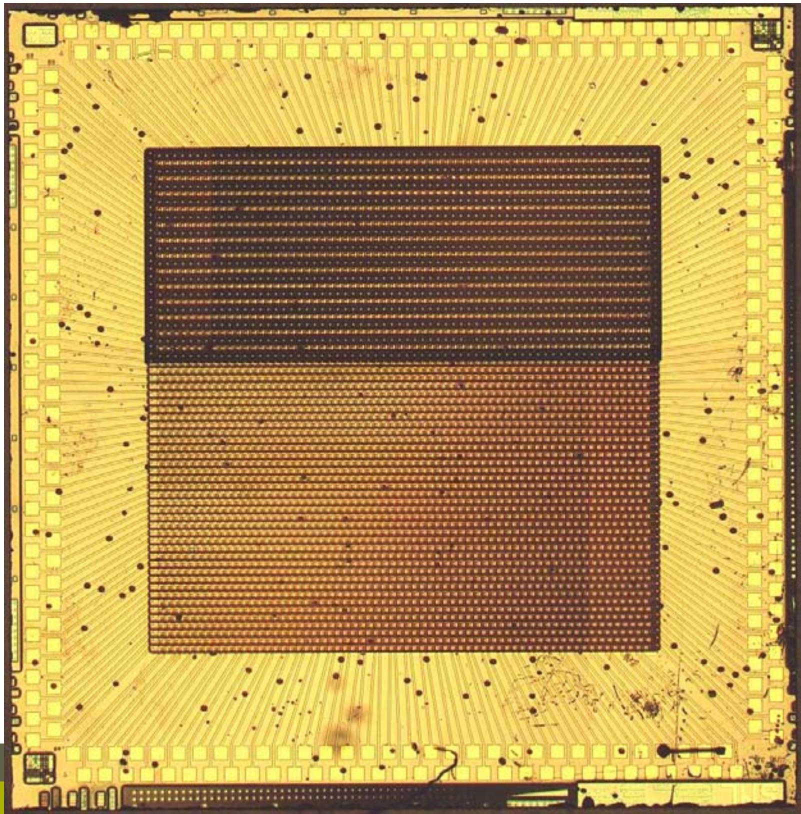
Main objectives of the demonstrator

- High-density intra-chip interconnects
  - **Small channel pitches**: from 220 µm down to 55 µm
  - **Large channel density**:
    64x64 interleaved VCSEL/RCPD Array on 55 µm pitch
    matrix addressable
  - **Plug-and-play** principle of optical pathway block
  - **Experimental verification** of design rules
- Off-chip coupling
  - For **inter-chip** applications
  - For **LAN** applications
- Testbed for **reconfigurable interconnects**
- Testbed for aspherical optics
- **First complete DPW integration with FSOI's**

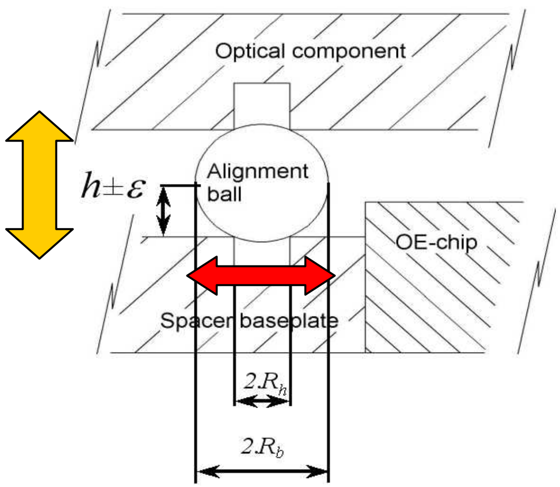


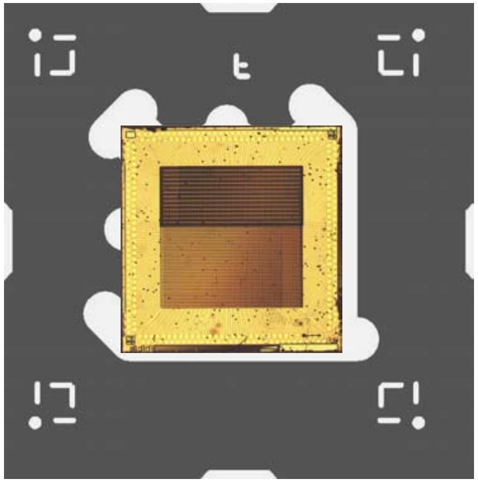
K.M. Geib, K.D. Choquette, D.K. Serkland, A.A. Allerman, T.W. Hargett, "Fabrication and performance of large (64x64) arrays of integrated VCSELs and detectors", SPIE Photonics West, 4649, 2002.

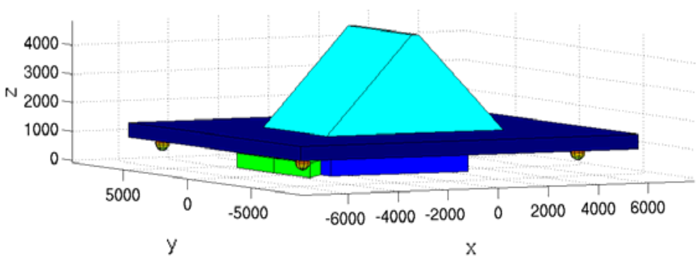
System Concept and tools

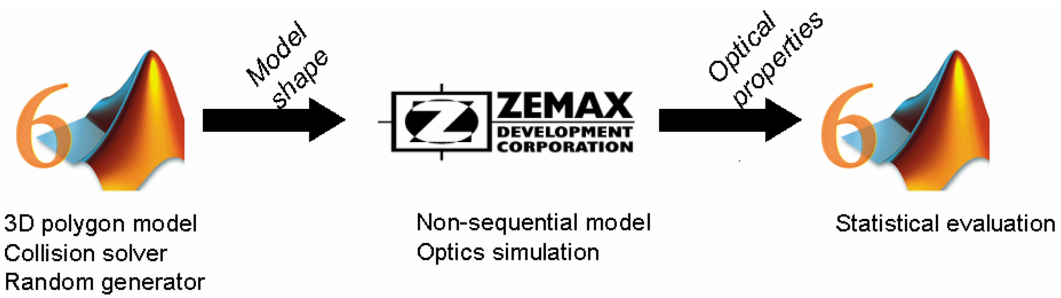
- Mating structures mates with chip circumference
- Microspheres fit into precise microholes

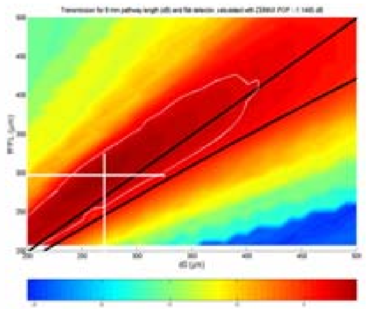
} Written in one DPW process step





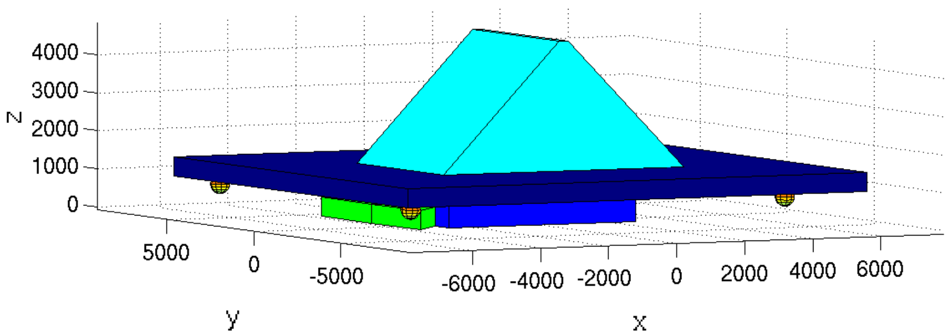


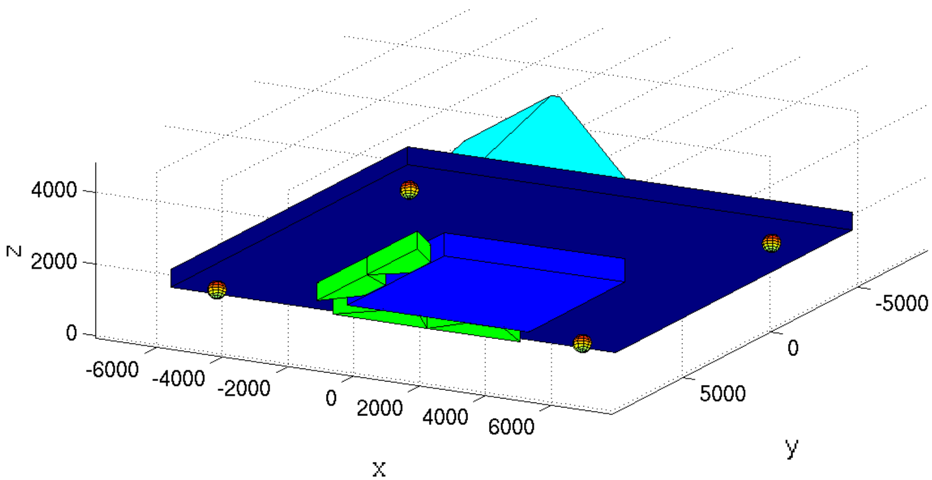




Obtained Tolerances with the Deep Proton Writing

Parameter	Accuracy
Proton Writing Process	
Surface Roughness R_a	32 nm (over 50×50µm area)
Flatness	±1µm (over 3.75mm)
Position Error	±0.5µm
Hole Diameter	±1.18µm
Lens focal length	±0.31µm
Total System	
Total working distance variation	±0.6µm
Baseplate tilt	$\pm 6.4 \cdot 10^{-3}$ °
Rotational Error	$\pm 2.6 \cdot 10^{-3}$ °





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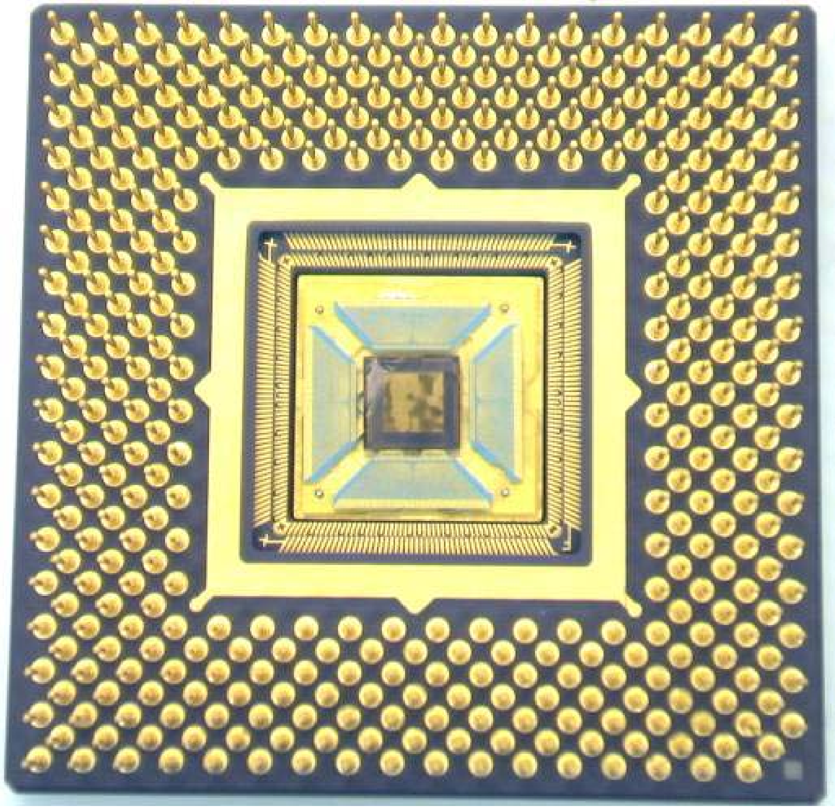
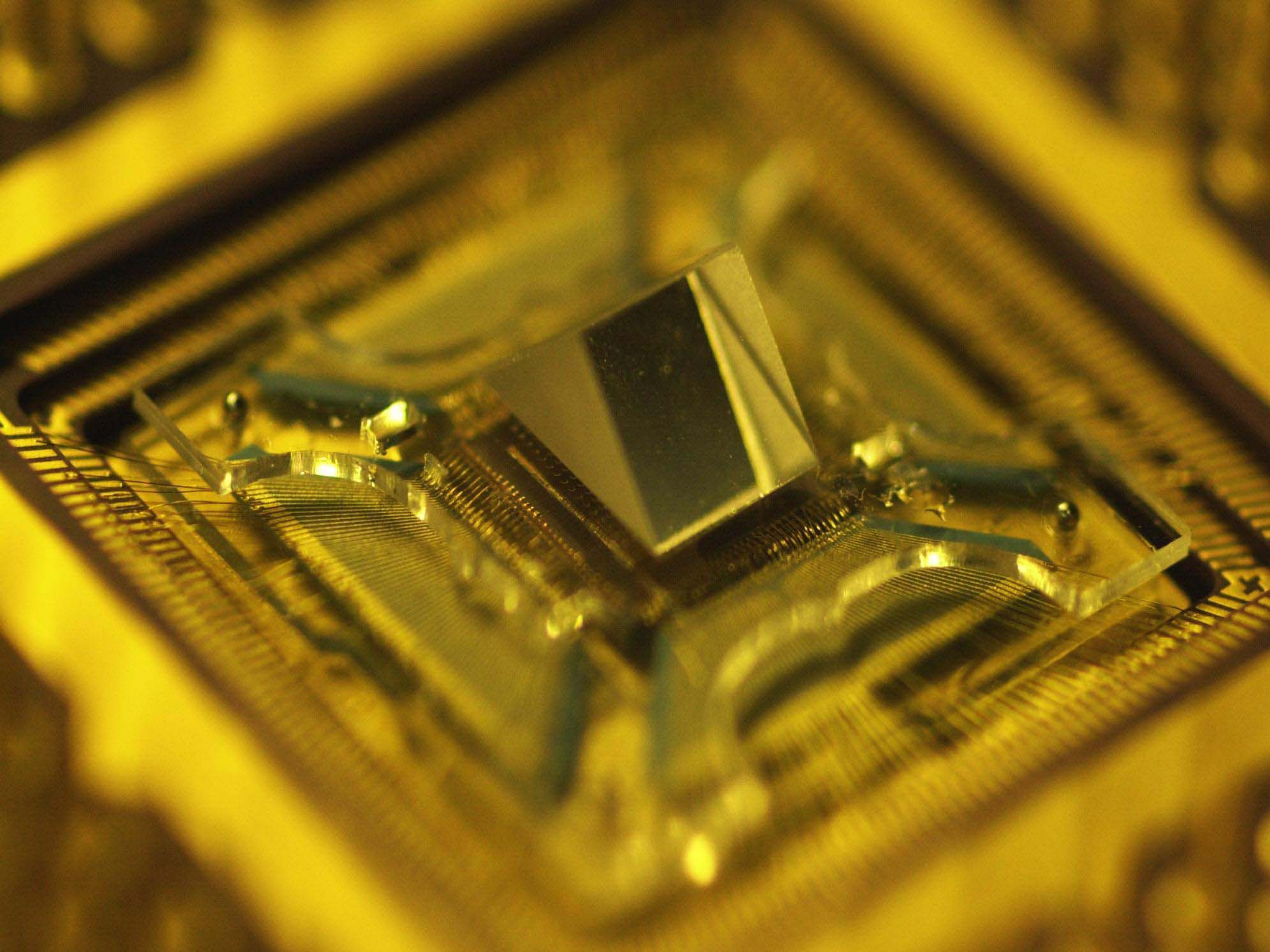
Packaging: Low Temperature Co-fired Ceramic

- Wire carrier
  - Low Temperature Co-fired Ceramic wire carrier (130 µm thickness) bonded onto DPW alignment structure
  - Provides the clearance needed for the optical components
  - Eases bonding of small pitch device
- Adhesive bonding of spacer and chip
  - Using standard silver epoxy/UV-curable adhesive
  - Handling and flatness control is important
- Bonding
  - 62.5 µm gold wires
  - Chippad to wire carrier in short loops
  - Wire carrier to package pads are standard

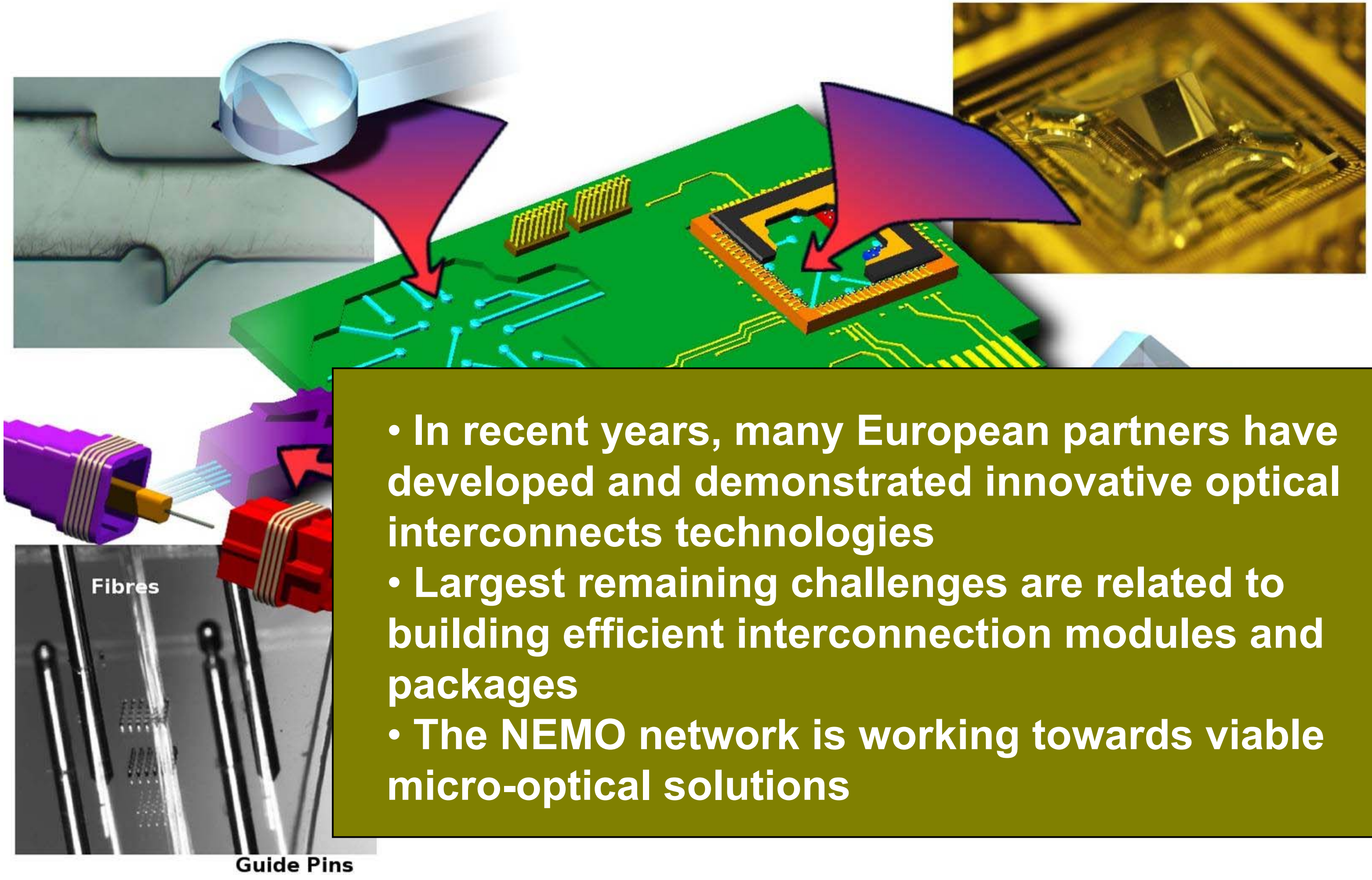


NEMo Network of Excellence on Micro-Optics

Collaboration with VTT Elektroniikka (Oulu, Fin.)



Conclusion



- In recent years, many European partners have developed and demonstrated innovative optical interconnects technologies
- Largest remaining challenges are related to building efficient interconnection modules and packages
- The NEMO network is working towards viable micro-optical solutions

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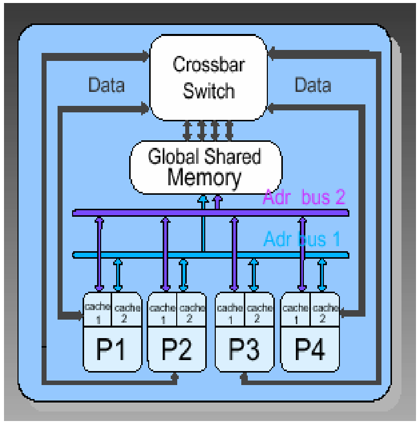
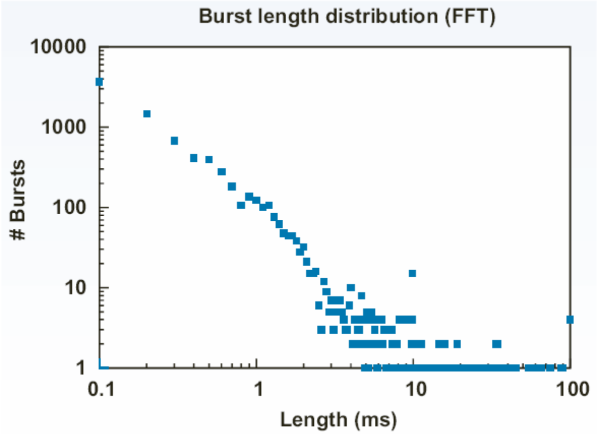
Strategic research with Future Valorisation Potential: Reconfigurable Optical Interconnects

Architectural Simulator

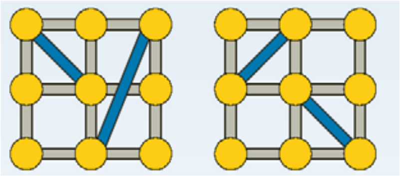


Identified Traffic Patterns



Target System

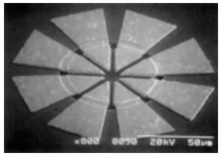
SunFire, 16 processors connected through a torus network and extra **reconfigurable** links



System Simulations

Measured performance increase ranging from 1%-40% depending on

- **Benchmark** application
- Reconfiguration **interval**
- **Fanout** and number of extra links



Practical Implementation

WDM inspired systems with wavelength **tunable VCSELS** and micro-optical elements