Planar-Integrated Free-Space Optics as Interconnection Technology - Principle and Demonstration

M. Jarczynski, J. Jahns

Optische Nachrichtentechnik (ONT)
FernUniversität in Hagen
Deutschland

phone / fax: +49 2331 987-1123 / -352
manfred.jarczynski@fernuni-hagen.de
www.fernuni-hagen.de/ONT/LGONThome.html

Round Table Meeting on: Optical Interconnects for High Throughput On Board Processors

9th February 2006

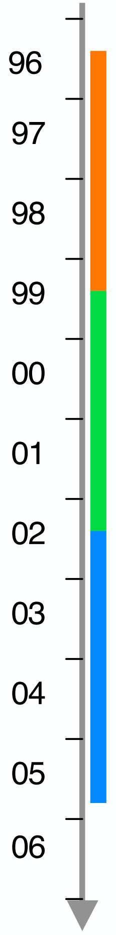
outline

- ONT-group at the University of Hagen and its focus of research
- concept of planar-integrated free-space optics (PIFSO)
- demonstrations on:
  - binary associative memory
  - massive parallel interconnects
  - integration technology
- issues

The ONT-Group

staff:	around 10 scientific and technical co-workers or student assistants
research:	microoptics, diffractive optics, microoptics integration, optical interconnects, signal processing
equipment:	clean room with conventional optical lithography, RIE, thin film evaporation, etc. and optical labs
teaching:	optical information technology, high-frequency engineering, MSc-extension course „Photonics“

previous research at Hagen



binary associative storage
(VW-project in co-operation with FSU Jena and IPHT Jena):
complete system with integrated modulator chip in GaAs („SEED“)
free-space optical chip-to-chip interconnect

…

„planar-optical system technology“
(DFG-project in co-operation with University of Karlsruhe):
multiprocessor system
free-space optical chip-to-chip interconnect
fibre-optical interface

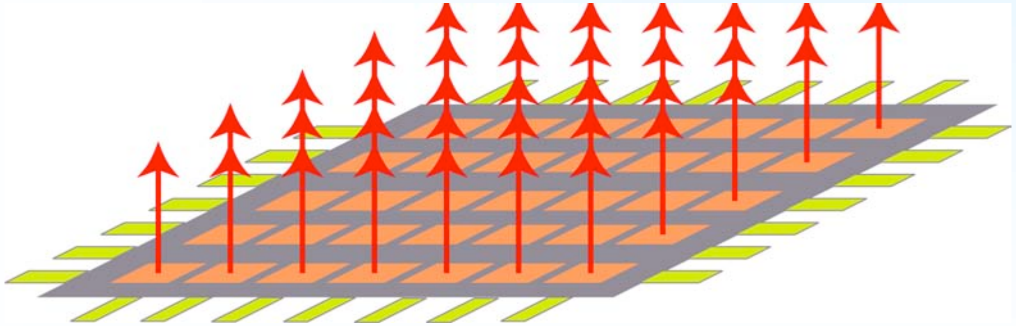
…

„High-speed optoelectronic memory system“
(EU-project in co-operation with
Siemens, Thales, ILFA, ETH-Zürich, Uni Paderborn, Supelec, Heriot-Watt Univ.)
multiprocessor system
fibre-optical interface for board-to-board-interconnects
PCB-embedded waveguide for on-board-interconnects
free-space optical chip-to-Board and chip-to-fibre interface

Optical vs. electrical interconnection

Advantages of optics:

- large bandwidth (temporal, spatial)
- RF immunity
- reduced power consumption at high data rates
- scaling properties

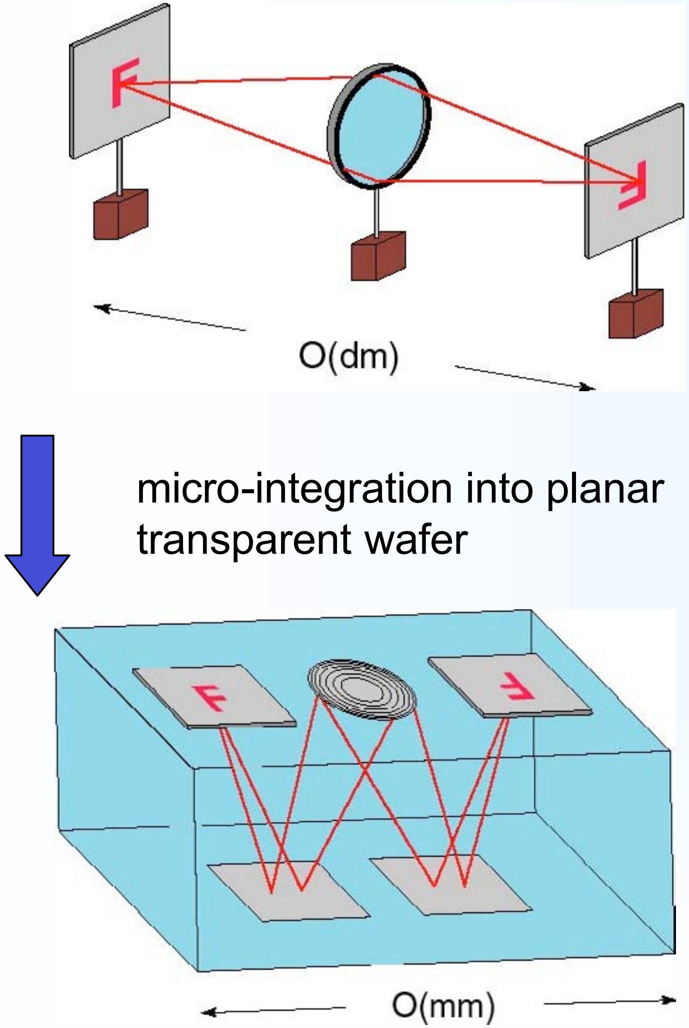


Scaling:

No. of devices: A
2-D connections: $A^{1/2}$
3-D connections: A

A - chip area

PIFSO principle



micro-integration into planar transparent wafer

J. Jahns, A. Huang, **Appl. Opt.** 28 (1989) 1602

characteristic features:

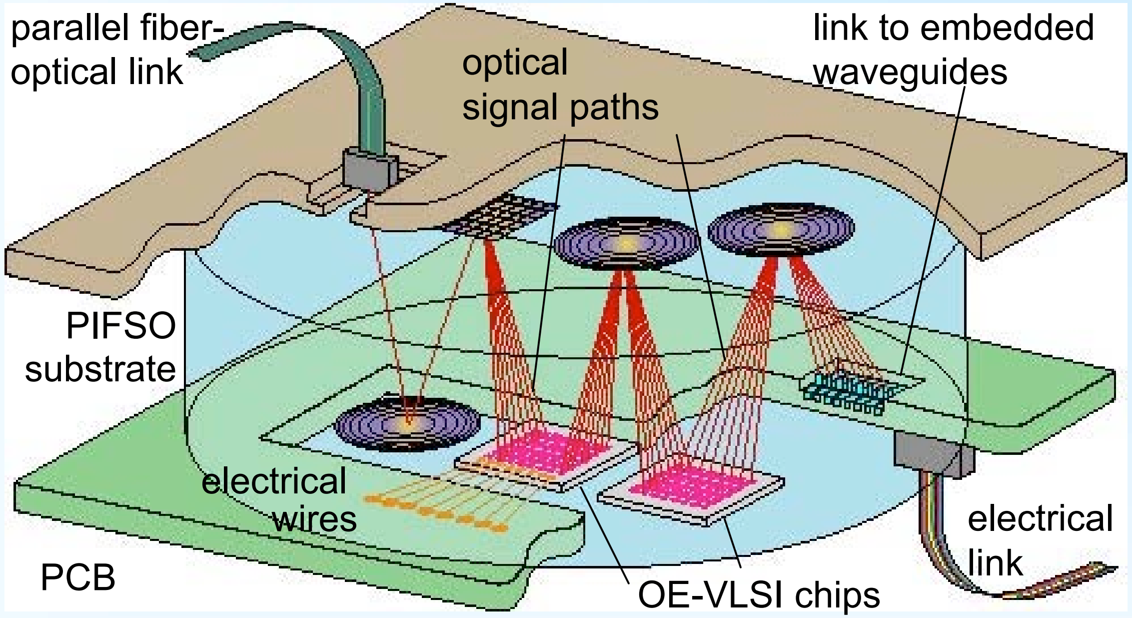
- optical components at surfaces
- folded signal paths
- system-level design and fabrication
- compatibility with planar lithography-based methods
- 3-D topology with 2-D complexity
- suitable integration platform for opto-electronic components
- reliable monolithic micro-system for passive optical elements
- hybrid integration for active optical elements

PIFSO for optical interconnects ?

requirements:

- support parallelism
- VLSI compatibility
- compatibility to waveguiding optics
- interfacing technologies

fully satisfied by PIFSO



- supports dense channel packaging > 1000 / mm^2

  S. Sinzinger, J. Jahns, “Integrated micro-optical imaging system with a high interconnection capacity fabricated in planar optics “, Appl. Opt. **36,** p. 4729, 1997

- complex interconnection schemes (involving large fan-out and fan-in, 10x)

  D. Fey, W. Erhard, M. Gruber, J. Jahns, H. Bartelt, G. Grimm, L. Hoppe, S. Sinzinger, "Optical interconnects for neural and reconfigurable VLSI Architectures”, Proc. IEEE, 88, p. 838, 2000

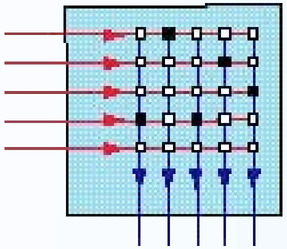
- interfacing and packaging for OE-MCMs, fibre-optics and PCB waveguides

  P. Lukowicz, et al., ”Optoelectronic Interconnection Technology in the HOLMS System”, IEEE JSTQE, 8, p. 624, 2000

project: binary associative storage

interconnect topology

vector-matrix-multiplication



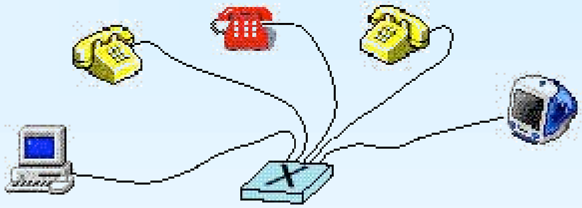
input-
vector

matrix

output-vector

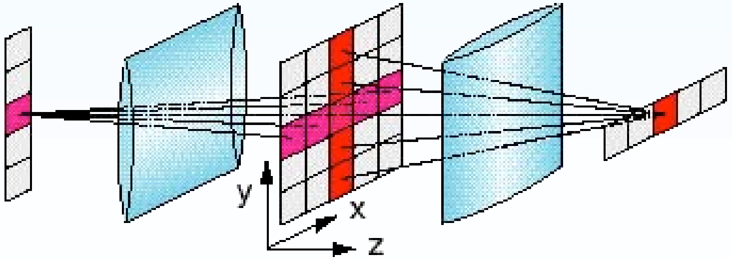
motivation

general relevance for
- parallel optical computing
- crossconnect switches



principal optical implementation

2D modulator array



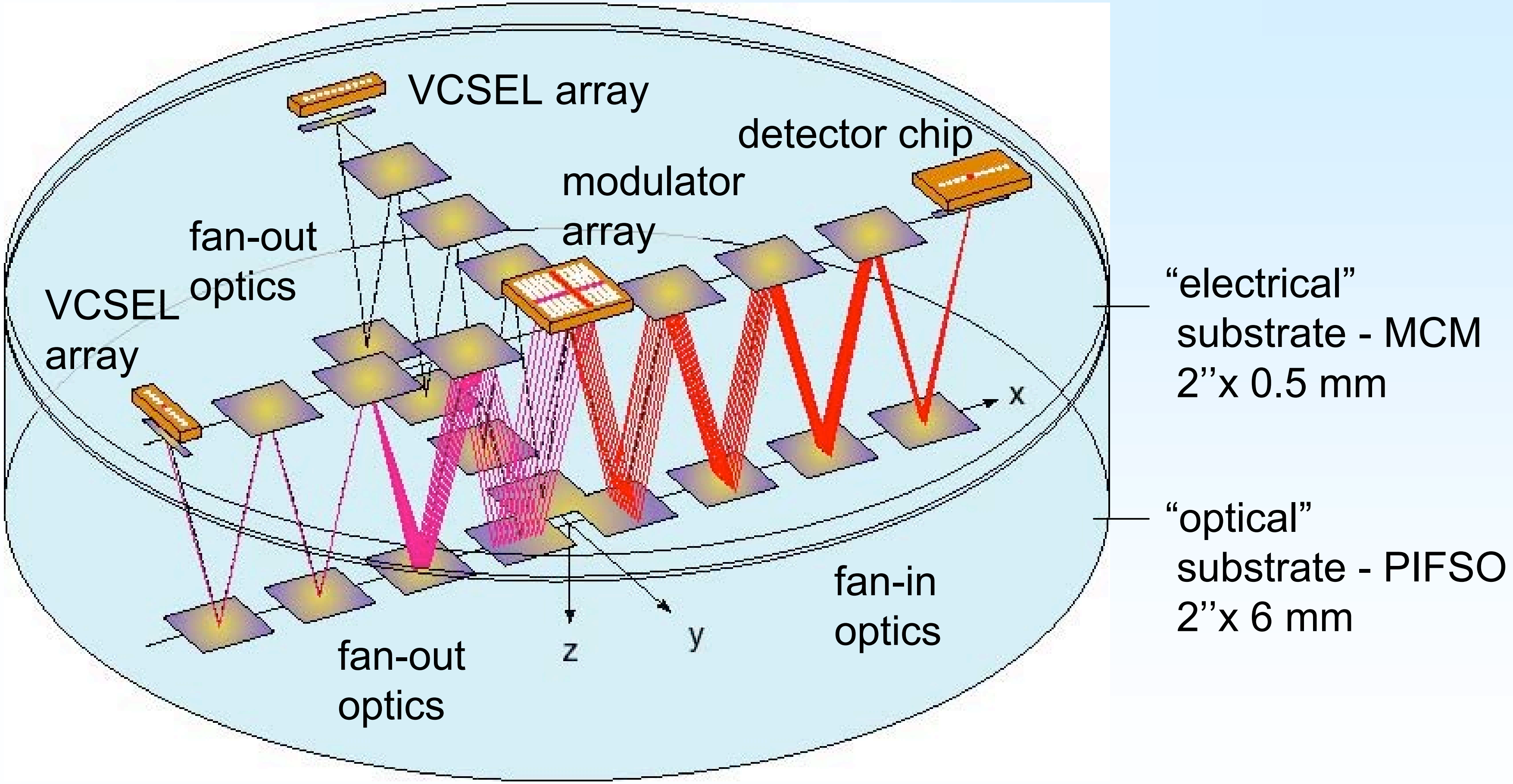
1D-emitter-
array

fan-out

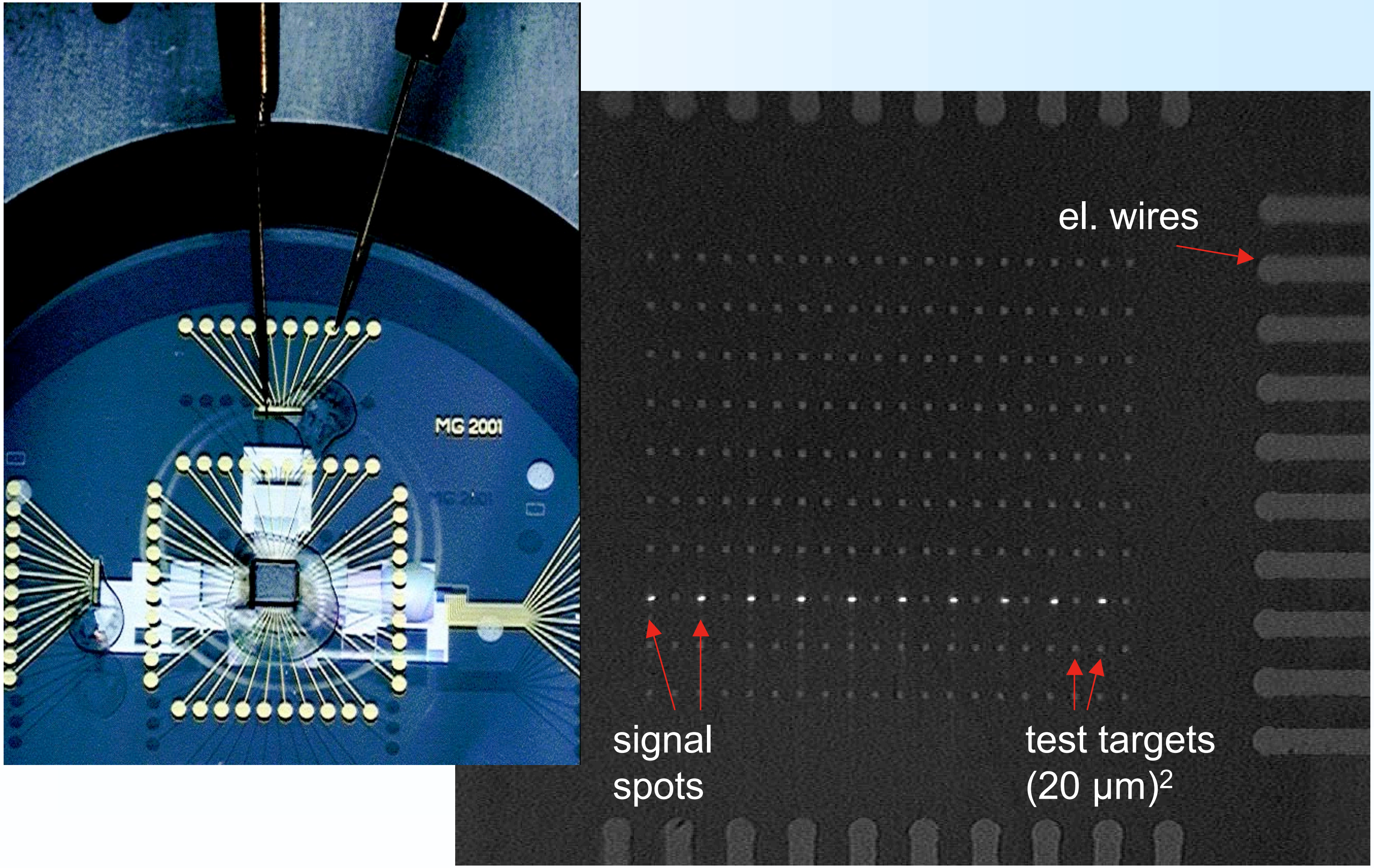
fan-in

1D-receiver-
array

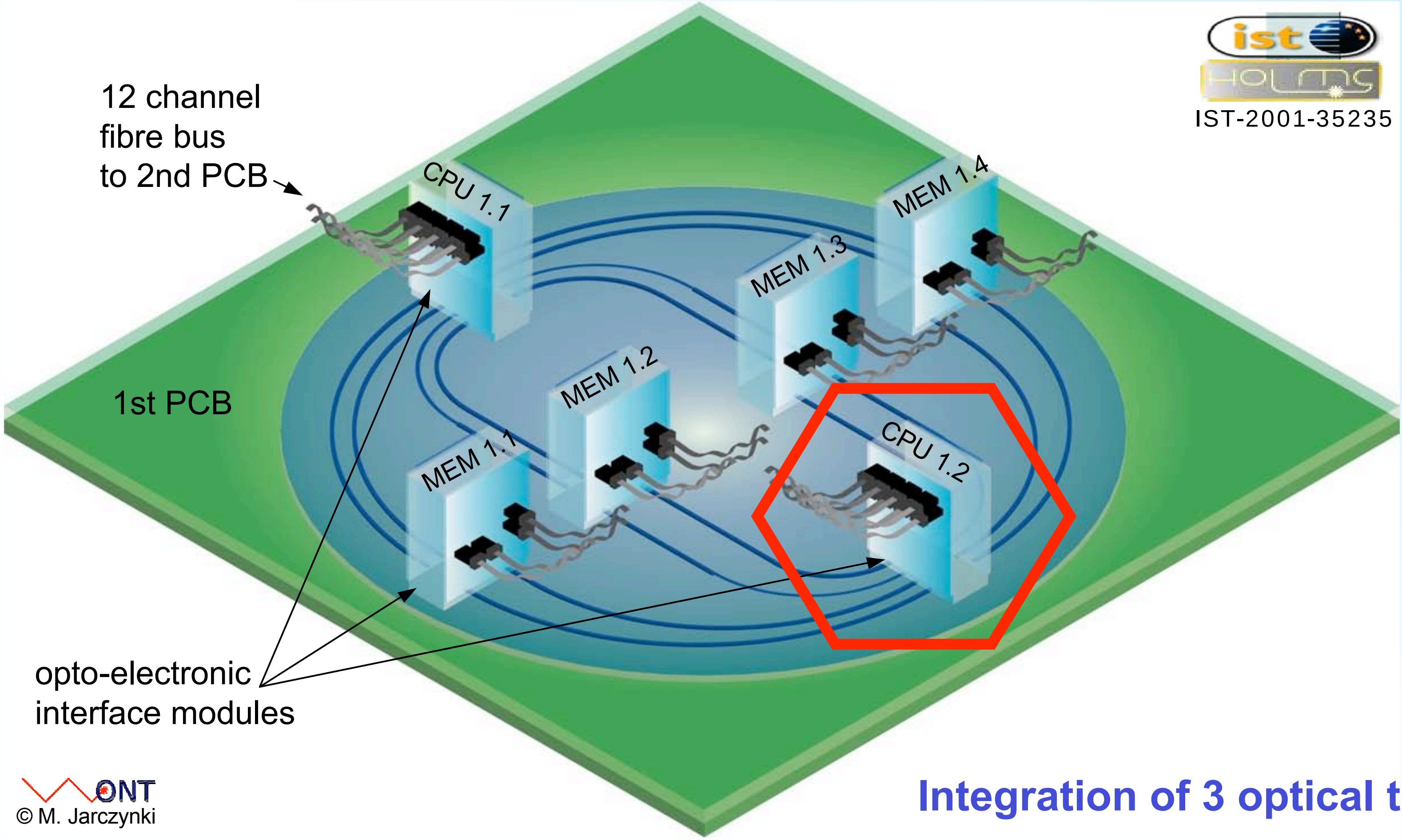
PIFSO-type electro-optical multi chip module



demonstrator and optical fan-out



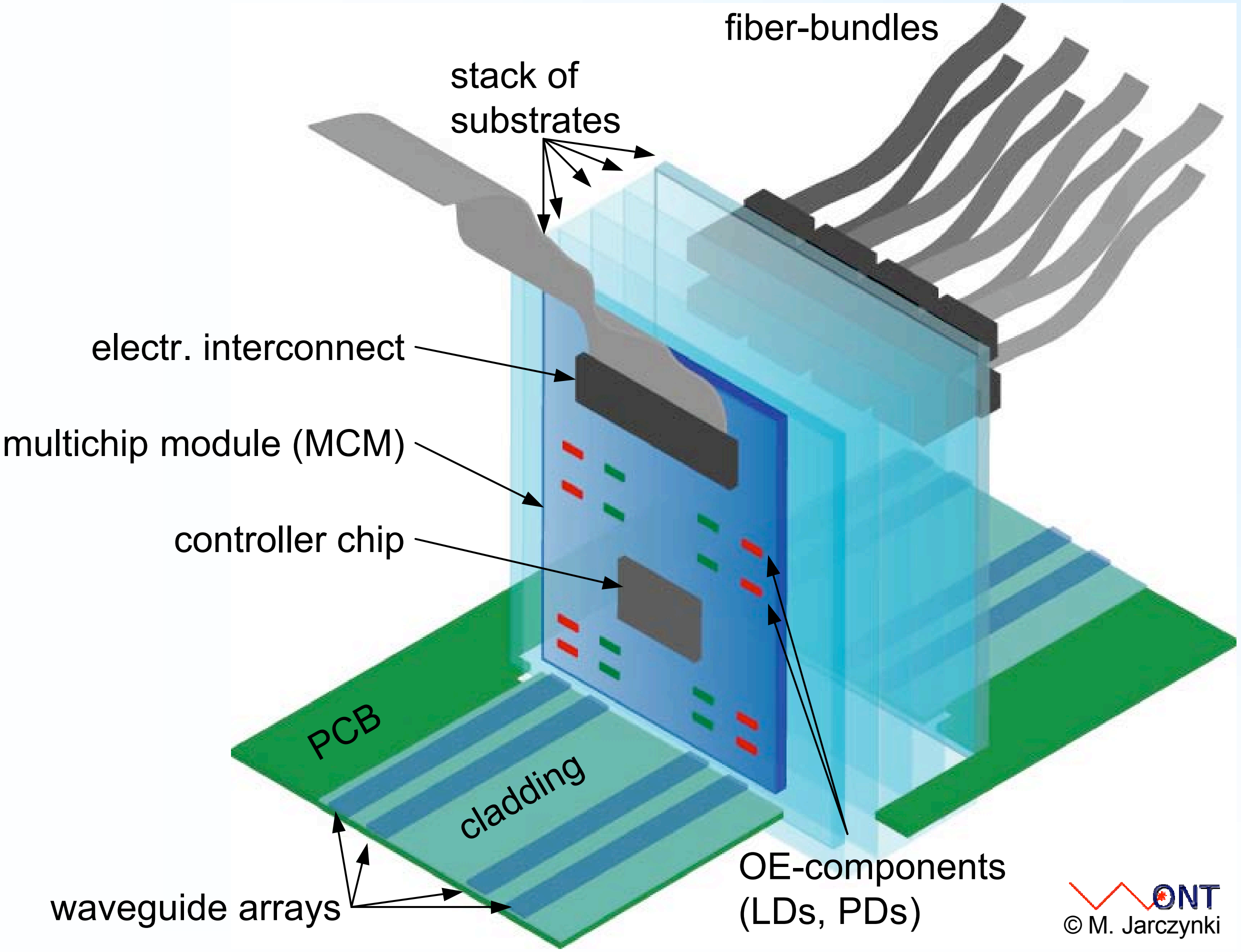
project: high-speed opto-electronic memory systems



Integration of 3 optical technologies

- ☞ **fibre-optics**
- ☞ **embedded waveguide-optics**
- ☞ **free-space optics**

details of packaging (3D free-space optical multilayer)



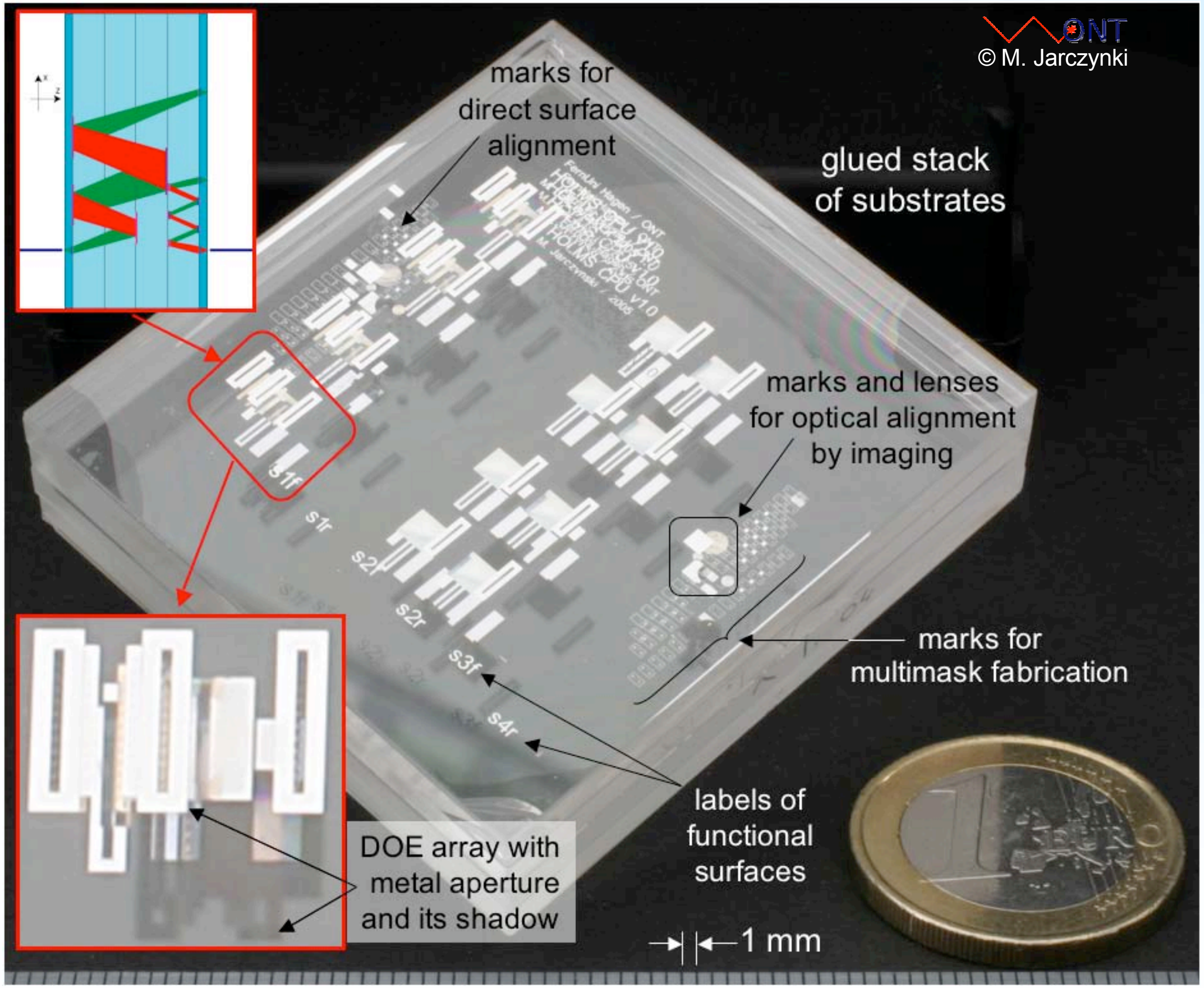
task and coupling of free-space optics:

- ☞signal distribution
- ☞co-planar opto-electronic interfacing
- ☞ fibre-coupling
- ☞ waveguide coupling (vertical slot-concept)

special packaging of PIFSO:

- ☞ stack of several substrates
- ☞ internal functional surfaces
- ☞ increase of design freedom

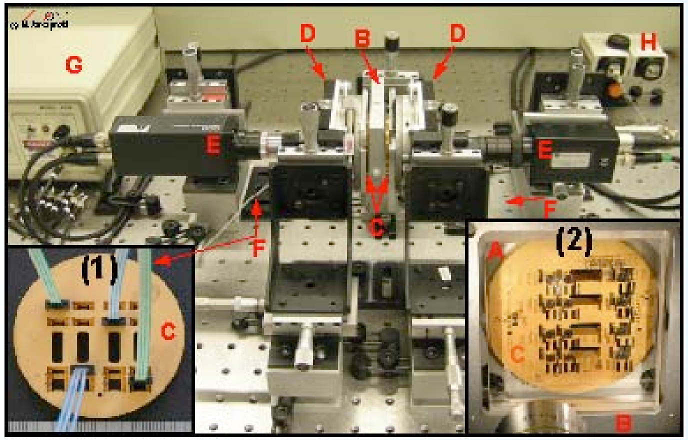
PIFSO-multilayer



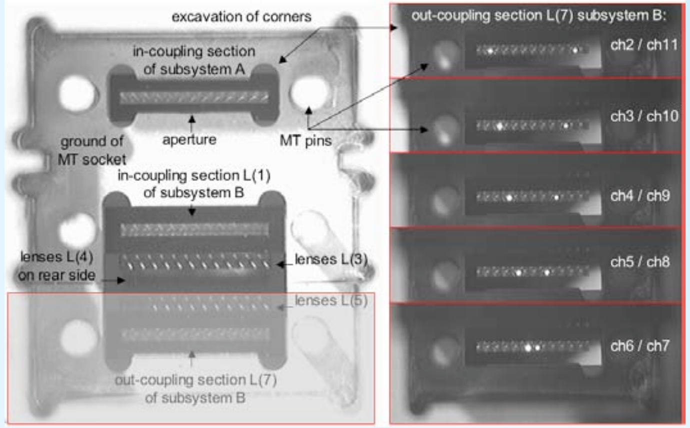
- ✓ 192 interconnects
- ✓ 6 functional surfaces
- ✓ 6 stacked substrates

experimental specification

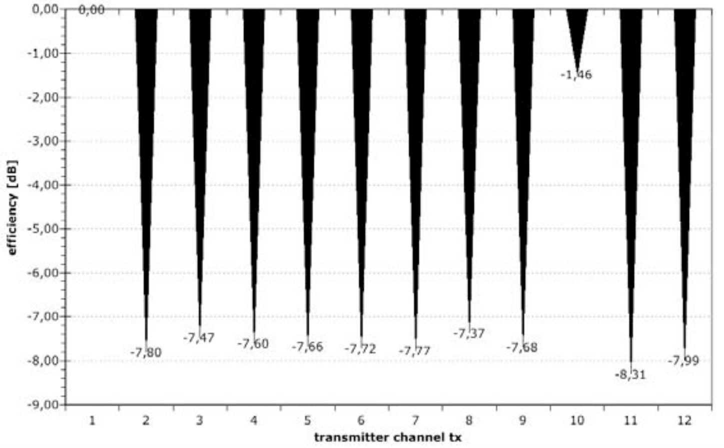
laboratory setup with metal interface plates (MIP)



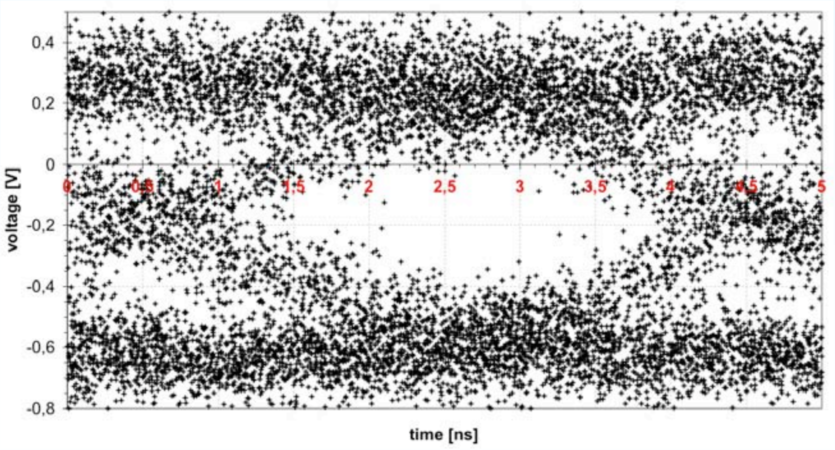
check of the interconnection



efficiency of hybrid imaging system



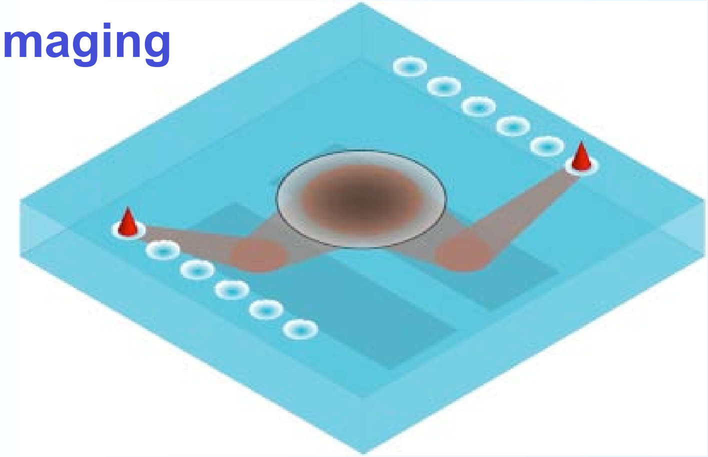
data transfer



implementation: diffractive optics

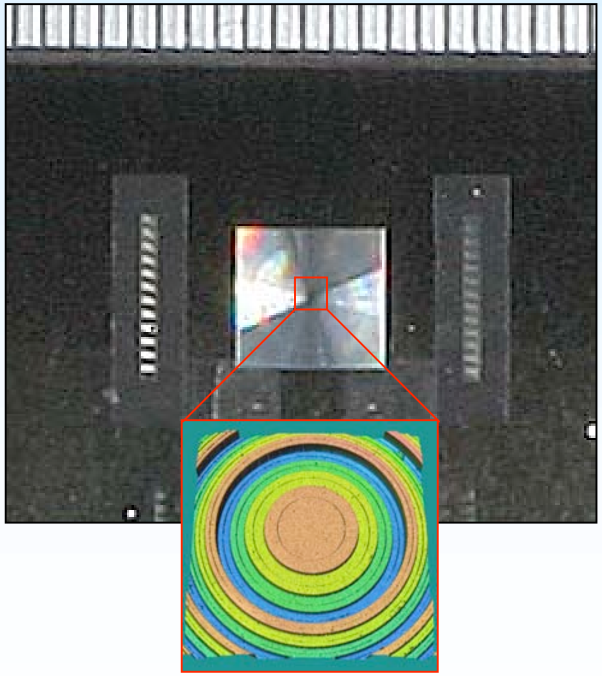
example:

array imaging



fabrication:

- e-beam mask
- lithography
- dry etching (RIE)



characteristics:

$\eta_{theor.}$ = -3.9 … -5.6 dB

$\eta_{exp.}$ = -3.6 … -6.6 dB

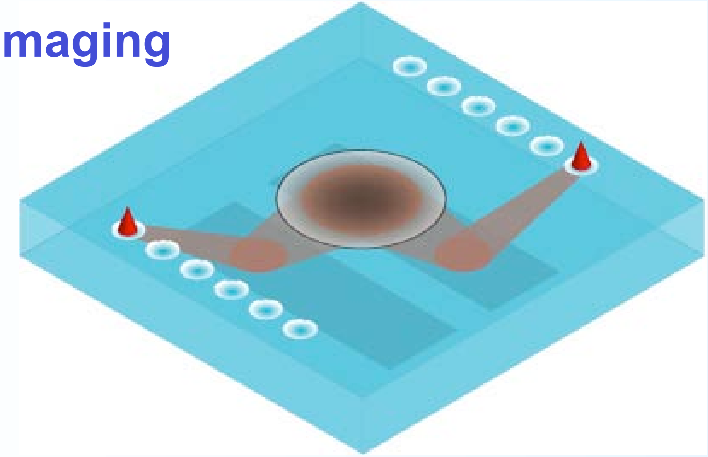
crosstalk suppression: > 31 dB

single-mode operation

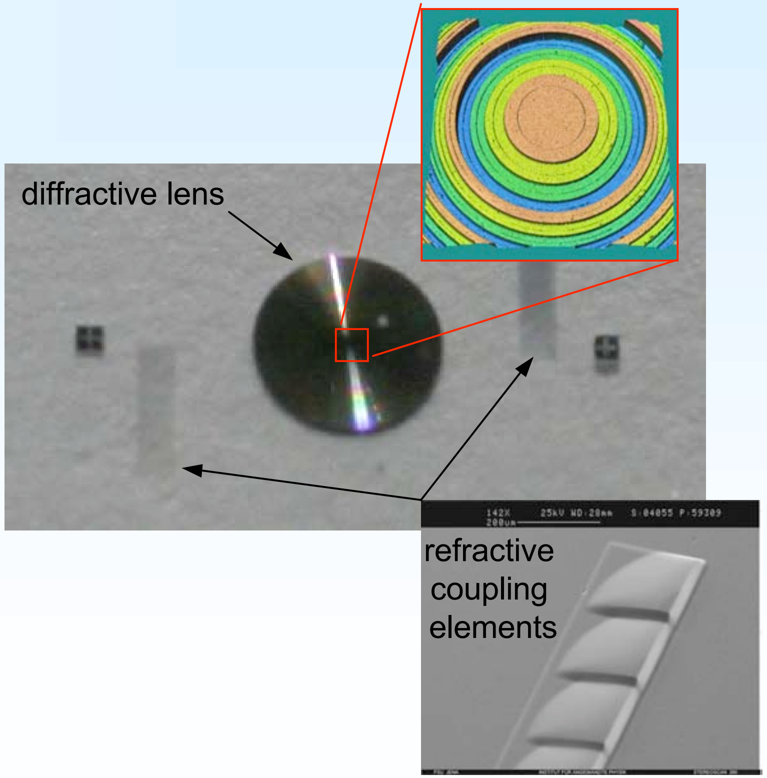
M. Jarczynski, J. Jahns, "Planar integrated free-space optics for optical interconnects ...", SPIE Proc. 5556-02 (Inv. Pap.), Denver (CO), 2004

implementation: refractive optics (1)

example:
array imaging



fabrication:
- HEBS mask
- gray-scale lithography (master)
- replication



characteristics:

$\eta_{theor.} = -2.1$ dB

$\eta_{exp.} \approx -4.4$ dB

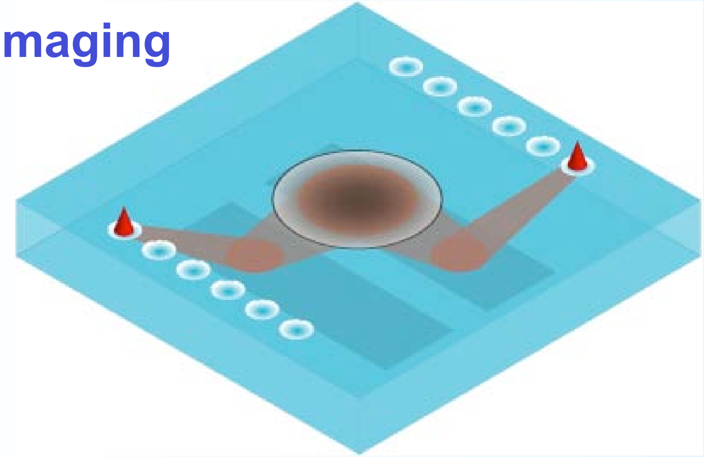
crosstalk suppression: > 38 dB

single-mode operation

in cooperation with: IAP/FSU Jena and IOF/FhG Jena (2004/2005)

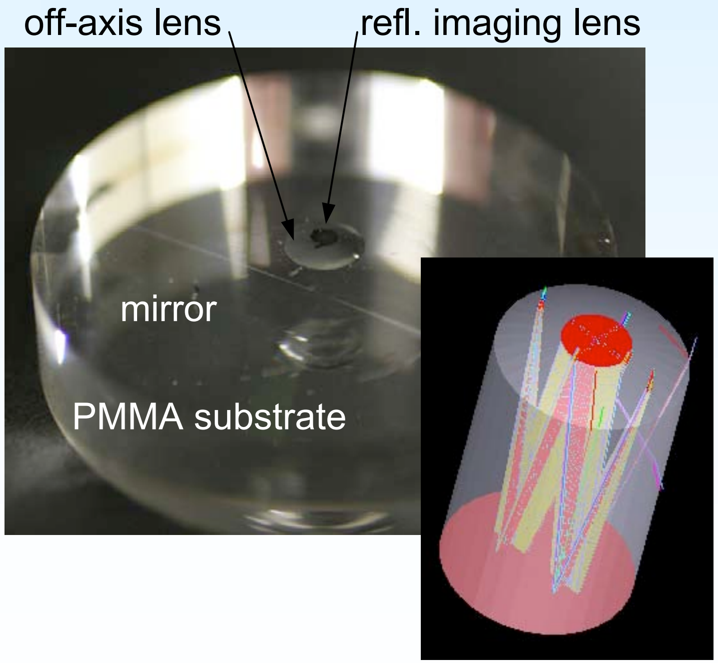
implementation: refractive optics (2)

example:
array imaging



fabrication: - diamond turning

- PMMA substrate



characteristics:

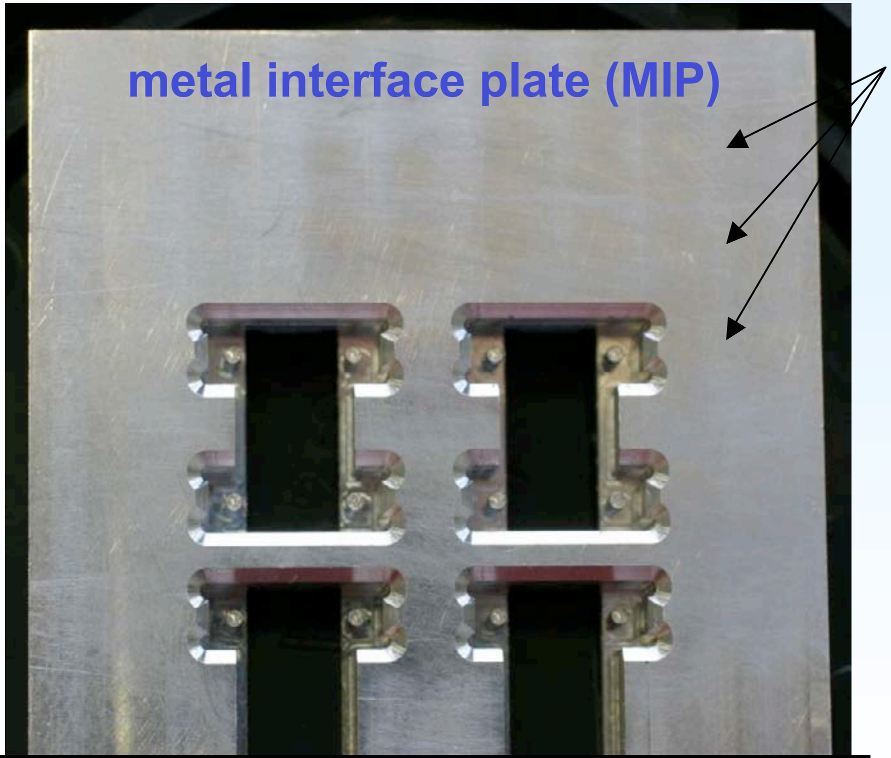
$\eta_{theor.}$ = -3.4 dB

$\eta_{exp.} \approx$ n.a.

crosstalk suppression: n.a.

in cooperation with: IEO/NCTU, Taiwan (2005)

MT-interconnection

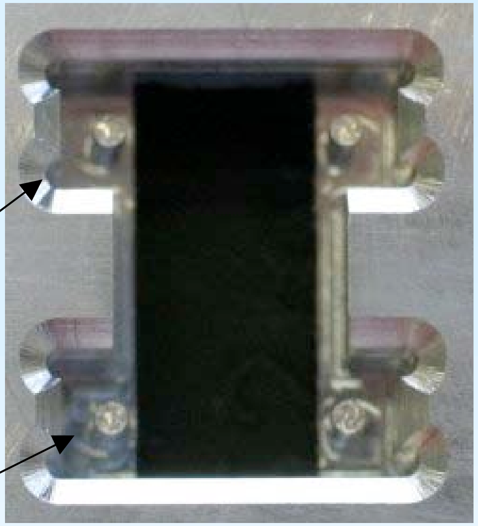


metal interface plate (MIP)

[redacted]

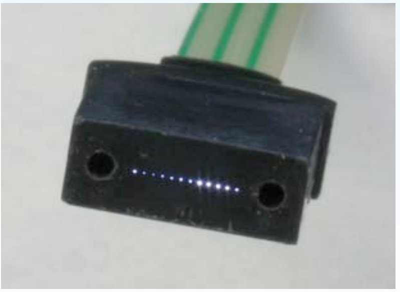
PCB-alignment

MT-sockets



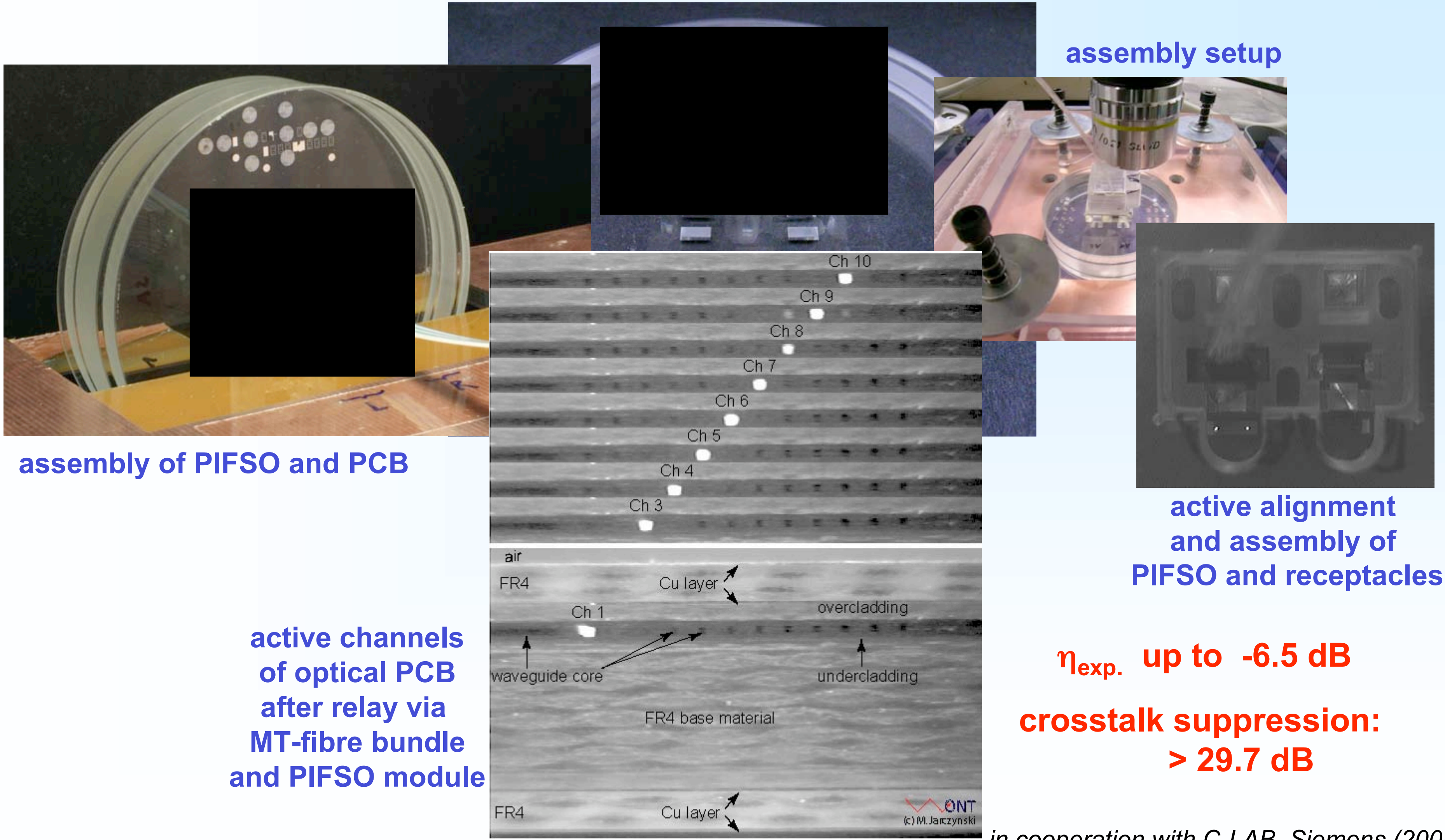
MT-pins

MT-connector



PIFSO-PCB interface

PIFSO module with assembled receptacles



[redacted]

[redacted]

[redacted]

assembly setup

assembly of PIFSO and PCB

active alignment and assembly of PIFSO and receptacles

active channels of optical PCB after relay via MT-fibre bundle and PIFSO module

$\eta_{exp.}$ up to -6.5 dB

crosstalk suppression: > 29.7 dB

in cooperation with C-LAB, Siemens (2005)

laser sources - high density arrays

Photonik 5, 2003

VCSEL auf Glassubstrat

054 Die oberflächenemittierenden GaAs-Laserdioden der Baureihe Transsub-VCSEL (vertical cavity surface emitting laser) wurden für Emission bei 850 nm und 3,125 Gbps entwickelt. Als Substrat können 100 bis 300 µm dicke Wafer aus Glas anstelle von GaAs eingesetzt werden. Die P- und N-Kontakte (s. Bild, 5 x 5 VCSEL Array „von hinten") sind wie bei einem SMD-Bauelement (surface mounted device) zugänglich, auch schon für den kostengünstigen Funktionstest im Wafer-Stadium. Das transparente Substrat schützt die Emitter-Oberseite und macht den VCSEL robust, auch z.B. für Anwendungen im Fahrzeugbau. Die Glasoberflä
oder Verbir
rührt werd
nehmen.

ULM Phot
Tel. 0731/5
Fax -02
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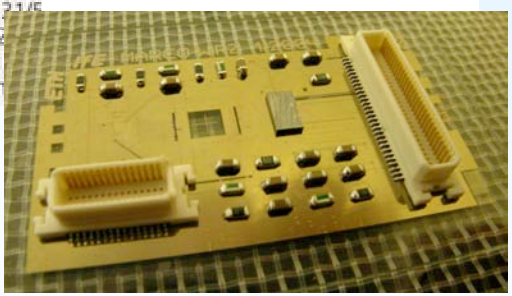
ulm-ph

opto-electronic multichip module



in cooperation with ETHZ and HWU, 2005

- integrated VCSEL-arrays on glass-substrates
- typical pitch 250 µm
- pitch of 50 µm and below are possible [1]
- typical SM power 1.5 mW [1]
- SM power ~ 5 mW achieved
- wavelength range 700 -1000 nm[2] and 1300-2050 nm [3]

[1] M. Grabherr, R. Jäger, R. King, B. Schneider, D. Wiedenmann, “Fabricating VCSELs in a high tech start-up”, SPIE-4942, 2002

[2] M. Grabherr, D. Wiedenmann, R. Jäger, R. King, “… tuneable single-mode VCSELs… 750 to 1000 nm range”, SPIE-5737, 2005

[3] www.semiconductorcompound.net, “Vertilasreleases32mW VCSEL arrays”

Important issues in real-world applications

- **insertion loss**
  - ! efficiency of optical elements
  - ! reflectivity of mirror coatings

- **tolerance**
  - ! optical
  - ! mechanical
  - ! thermal

- **competitiveness on the market**
  - ! cheap fabrication (replication technology)

- **compatibility within complex systems**
  - ! PIFSO - VCSEL/PD coupling
    - fiber/waveguide coupling

- **reliable systems**
  - ! packaging

summary

- **competences:**
  - micro-optical system integration
  - optical design
  - packaging for interconnects (PIFSO-to chip, -to-fibre, -to-PCB)
- **technical choices**
  - operational wavelength: 850 nm - 1500 nm
  - favored: VCSEL-arrays (singlemode)
  - transmission medium: typically quartz glass, but other possible
- **environmental issues**
  - good reliability of PIFSO
  - stable integration platform
- **figures of merit**
  - optical connectivity 1000 to 10000 mm^{-2}
  - opto-electronic connectivity ~ 1000 mm^{-2}
  - on-hand powerbudget for each optical stage ~ 20 dB