TECHNISCHE UNIVERSITÄT DRESDEN

Institut für Aufbau- und Verbindungstechnik der Elektronik

**Faculty Electrical & Computer Engineering,** Institute of Electronic Packaging Technology

# Elektro-optische Kointegration

## Vorstellung von Projektergebnissen aus HAEC, Atto3D & Optaver

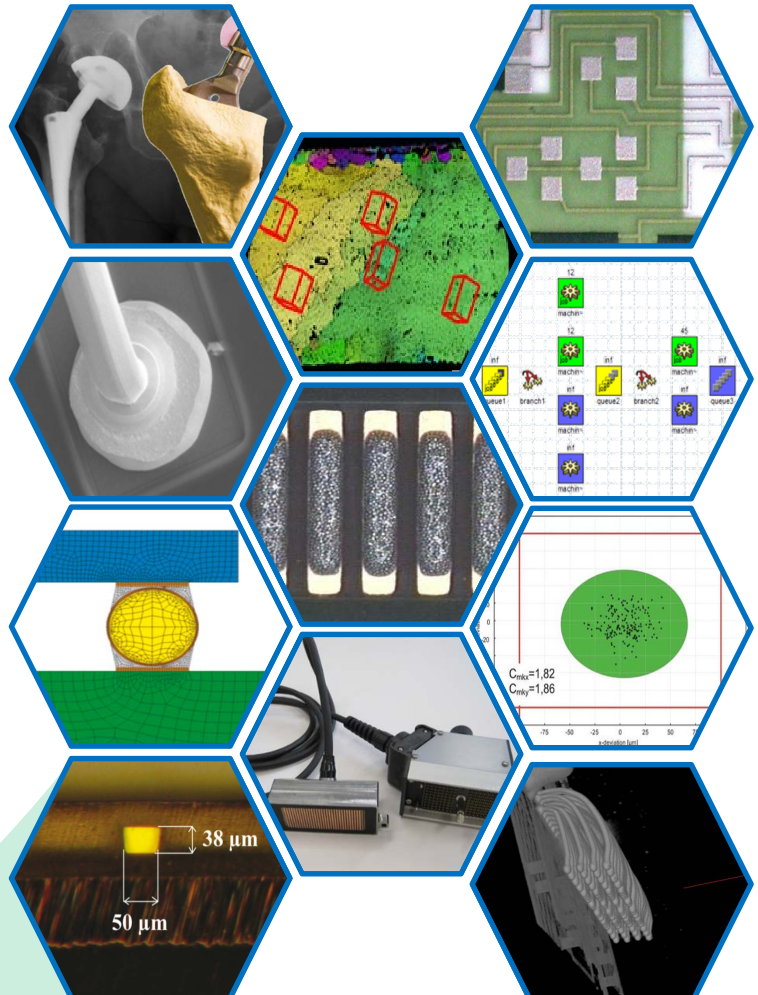

Krzysztof Nieweglowski, Lukas Lorenz, Sebastian Lüngen, Tobias Tiedje, Karlheinz Bock


68. Treffen des SAET
Dresden, 30 September 2016

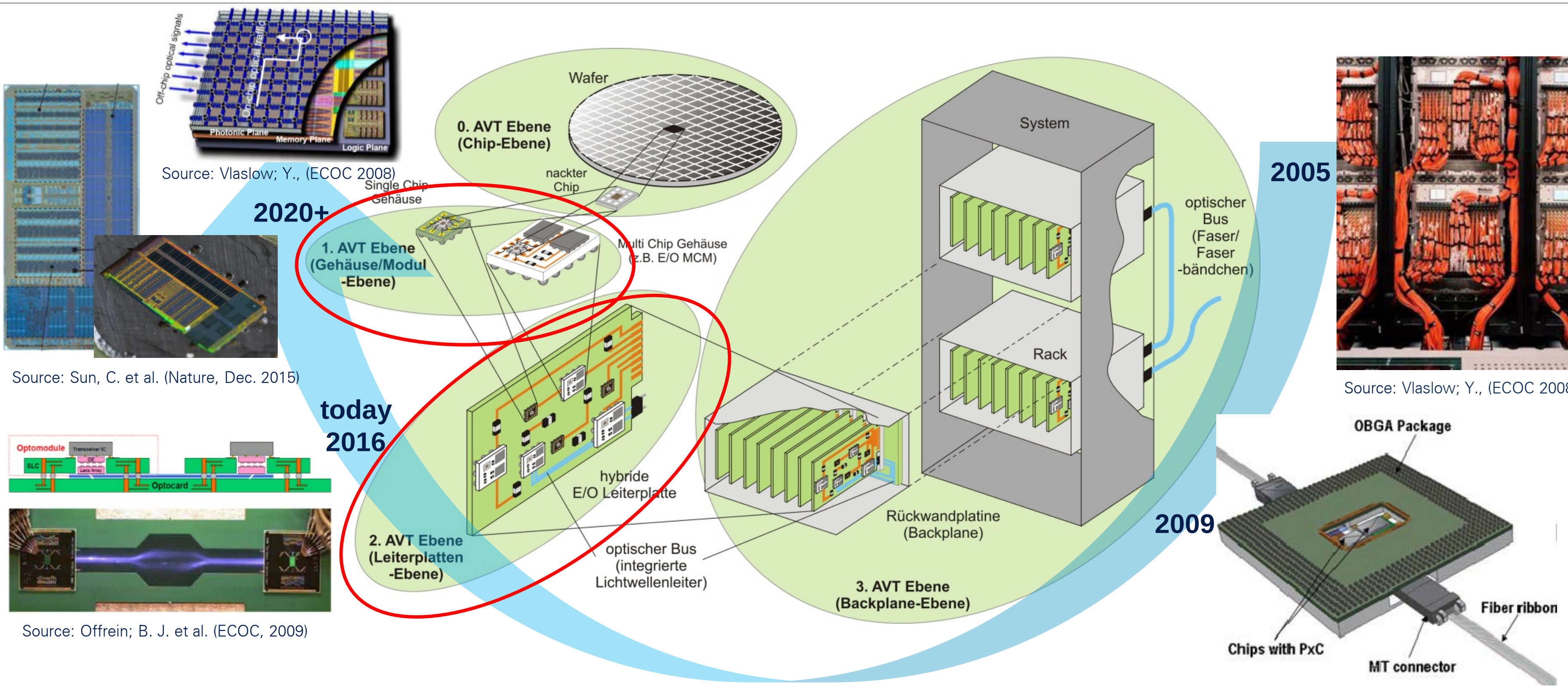
SACHSEN
VDE / VDI
*Sächsischer Arbeitskreis Elektronik-Technologie*

# Arbeitsrichtungen der AVT

- Biokompatible AVT
- Dickschichttechnik
- Mikrostrukturcharakterisierung
- Mikroverbindungstechniken
- Modellierung, Simulation, Optimierung von Prozessen
- Montagetechnologien
- Zuverlässigkeit auf Baugruppenebene
- Qualitätssicherung in der Fertigung
- Sensoren für zfP und SHM
- Zerstörungsfreie Prüfverfahren
- Optische Verbindungstechnik



# Elektro-optische Kointegration
# Motivation & Treiber




Source: Vlaslow; Y., (ECOC 2008)

Source: Sun, C. et al. (Nature, Dec. 2015)

Source: Offrein; B. J. et al. (ECOC, 2009)

Source: Vlaslow; Y., (ECOC 2008)

Source: Zheng; X., et al. (ECTC2009)

## Treiber

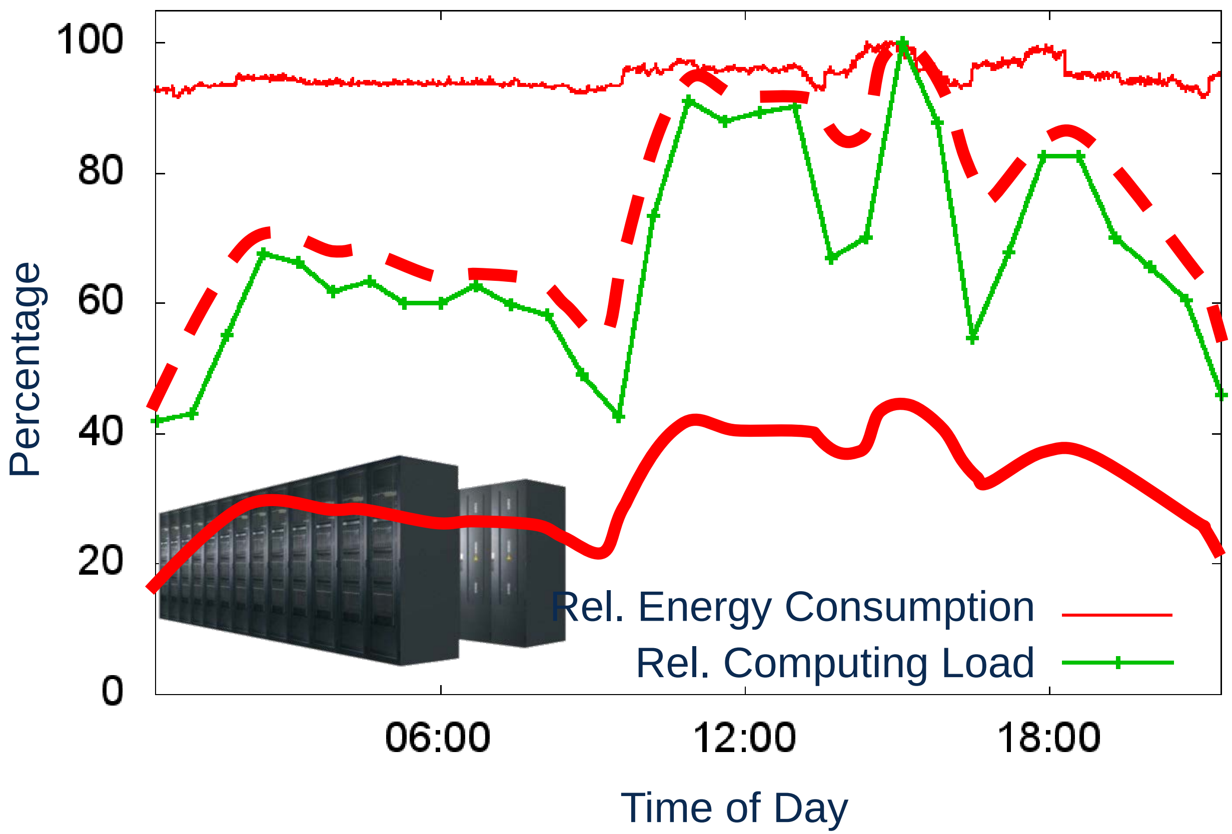
- wachsender Bandbreitenbedarf
- Energieeffizienz (mW/Gbps)
- Bandbreitendichte (Gbps/mm$^2$)

**Kosten der E/O Packaging bestimmen die Gesamtkosten**

**Neue Ansätze für E/O-Kointegration und and low-loss robust coupling needed**

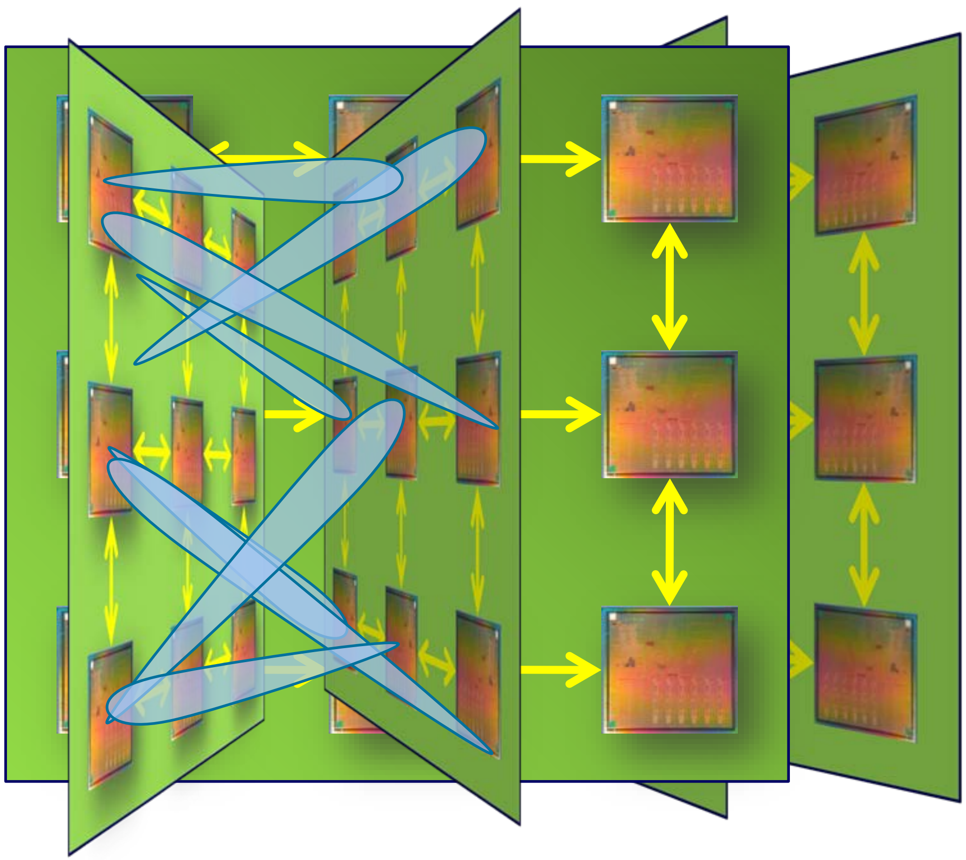
# **H**ighly **A**daptive **E**nergy-Efficient **C**omputing **(HAEC)**

Center for Information Services and High Performance Computing (ZIH)
Measurement at June 20, 2008




**Goal:**
Minimizing Energy
by
Multi-Layer SW/HW
Adaptivity

# Hybrid approach for intra-rack communication

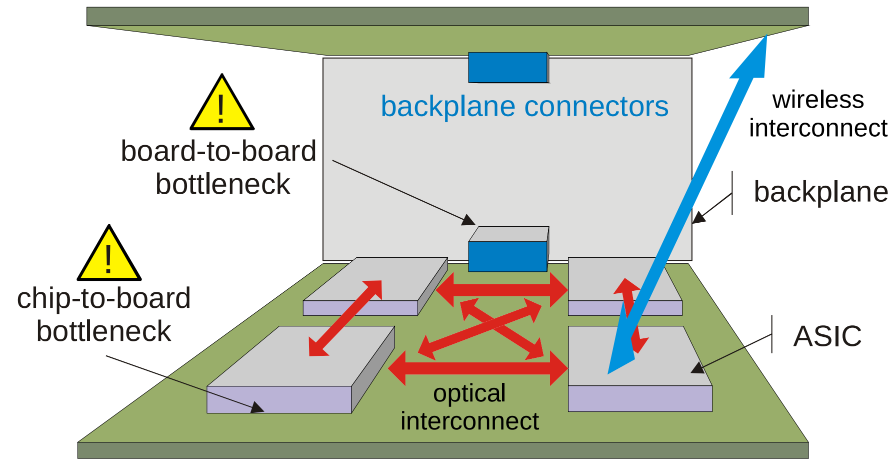


**Optical Interconnect**
- adaptive analog/digital circuits for e/o transceiver
- embedded polymer waveguide
- packaging technologies (e.g. 3D stacking of Si/III-V hybrids)
- 90° coupling of laser

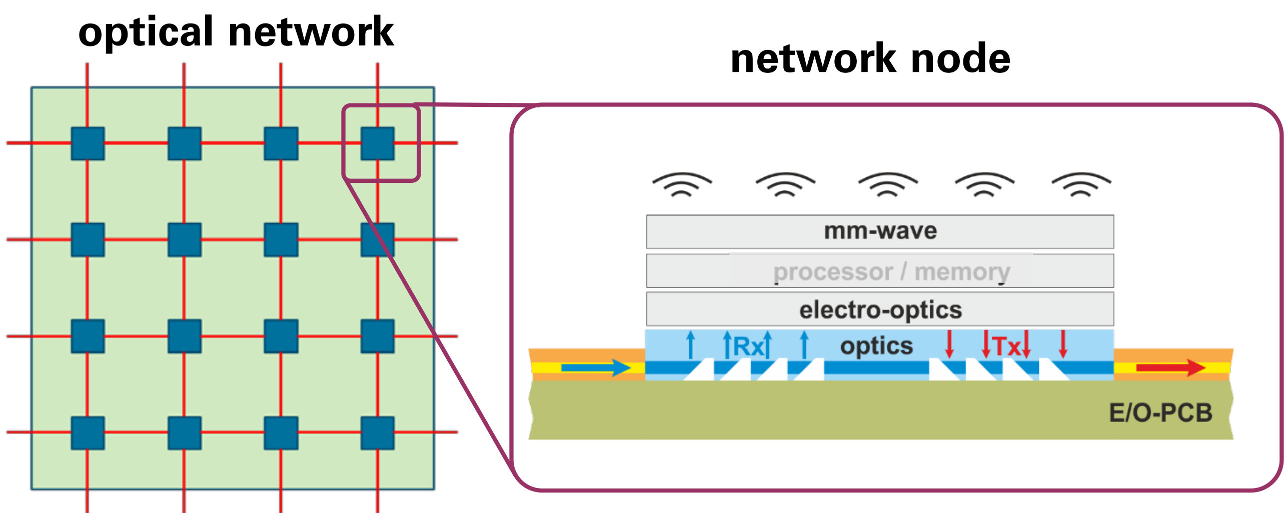
**Radio Interconnect**
- on-interposer/on-package
- antenna arrays
- analog/digital beam steering and
  interference minimization
- 100Gb/s
- 25 GHz channel @ 200GHz carrier
- 3D routing & flow management

# Optical and wireless C2C communication in HPC - HAEC approach -

- Chip-to-chip bandwidth limits system performance
- Hybrid (HAEC) approach for intra-rack communication
  - *Wireless* board-2-board links
  - *Optical* on-board links

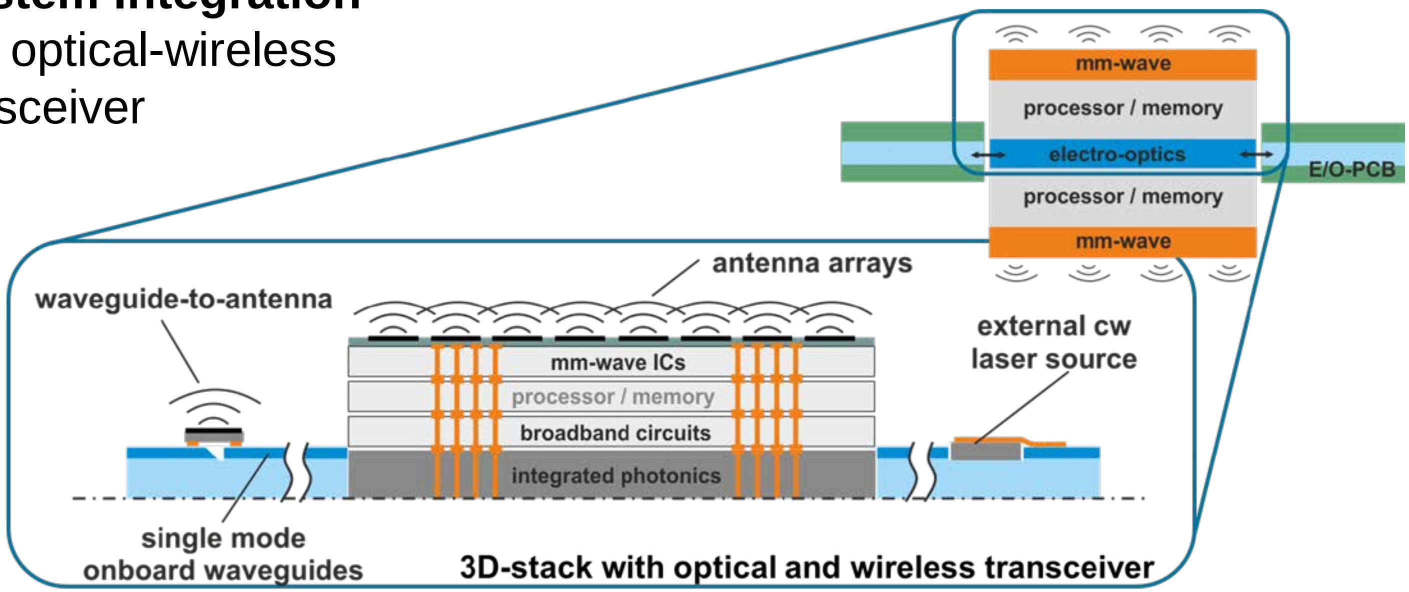



## ↳ E/O integration of optical and wireless transceivers for high performance



# Electro-Optical System Integration

3D-heterogeneous optical-wireless node transceiver



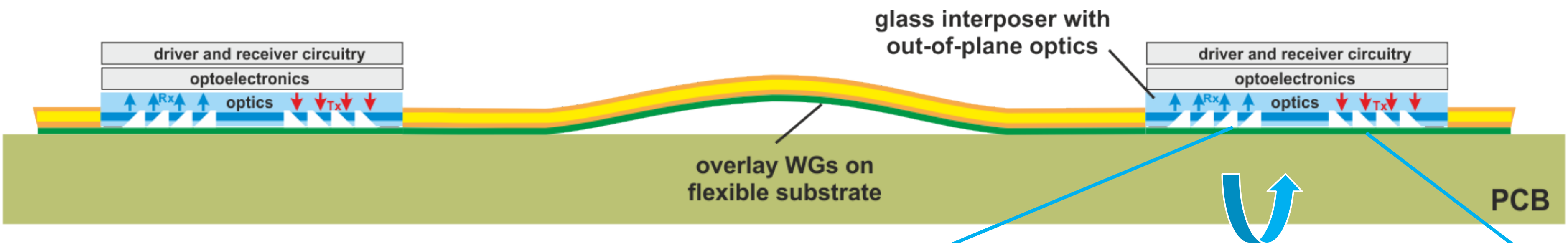

**electro-optics**

- Optical data throughput of 60 Tbit/s per node
- Integration of monolithic photonic ICs
- Single mode onboard WG-technology
- Novel coupling schemes

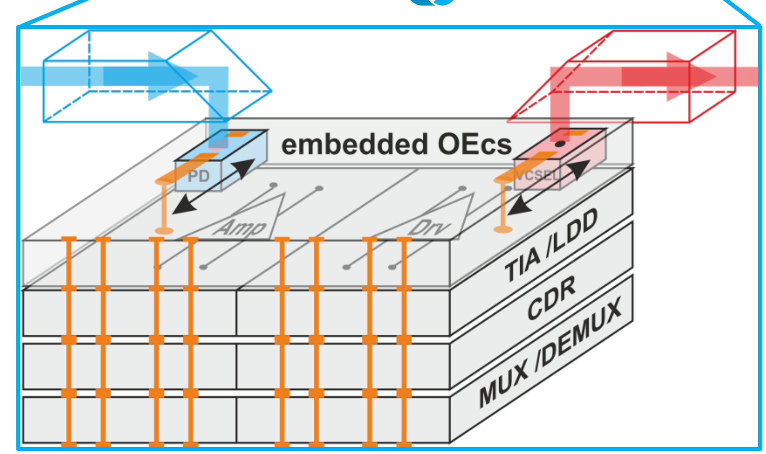
**mm-wave**

- RF performance beyond 200 GHz
- Embedding of antenna arrays and MMICs
- Direct interface for feeding of HF-signals
- Novel optical waveguide-to-antenna functionality

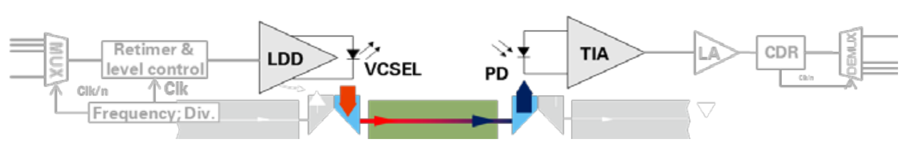
# VCSEL based optical C2C interconnect




- Onboard overlay flexible multimode optical polymer waveguides
- Out-of-plane coupling using µ-mirror array
- Glass interposer with electrical wiring for chip assembly
- 3D vertical chip stacking possibility




Channel cell configuration - vertical arrangement of subsequent link components using TSVs and chip stacking

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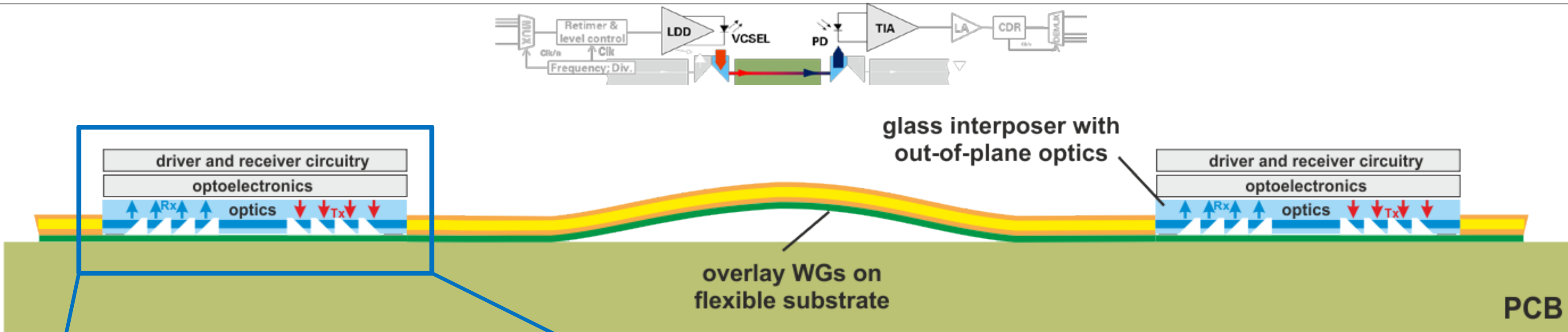
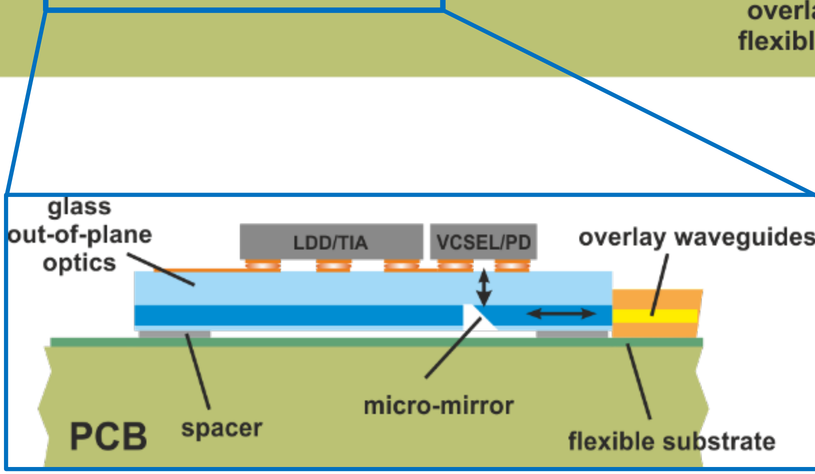
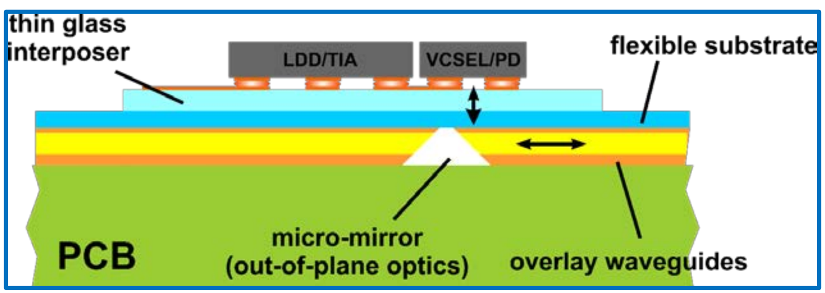
# VCSEL based optical C2C interconnect



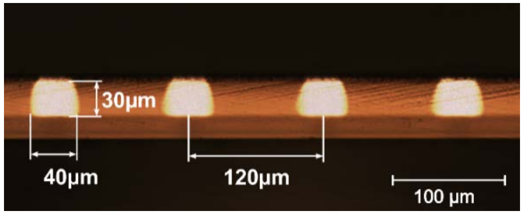




- ❑ Onboard overlay flexible multimode optical polymer waveguides
- ❑ Out-of-plane coupling using µ-mirror array
- ❑ Glass interposer with electrical wiring for chip assembly
- ❑ 3D vertical chip stacking possibility

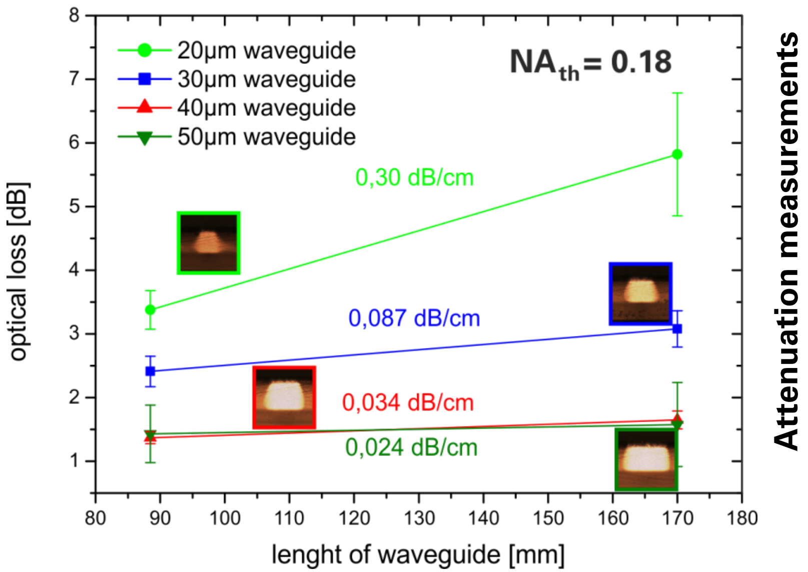
# Flexible optical WGs

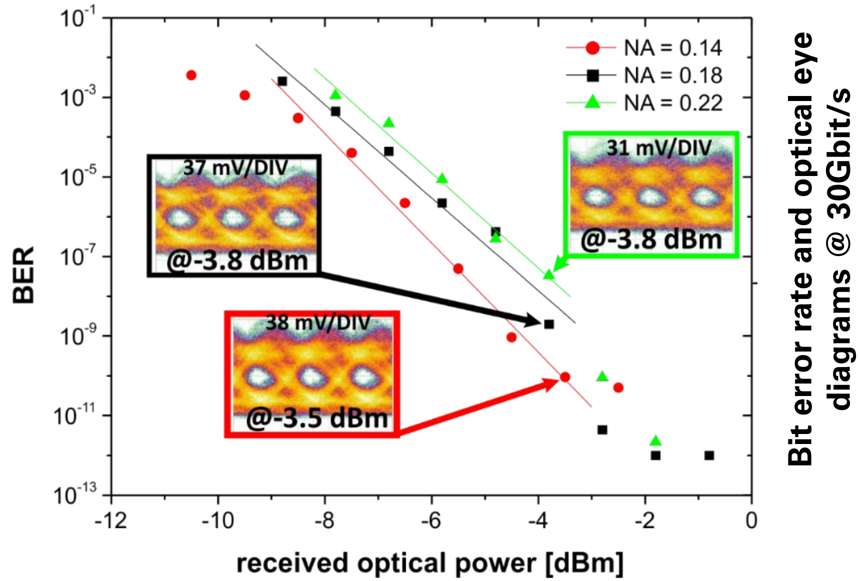
- Onboard overlay flexible multimode optical polymer waveguides for improved yield and flexibility
- mask based UV-photolithography for structuring of WG material - inorganic-organic hybrid material ORMOCER®
- Heat-stabilized PEN-foil (Teonex®) as flexible substrate suitable for temporary bonding on carrier wafer
- Good transmission characteristics at cw-operation and high data rates verified




Cross section of waveguides

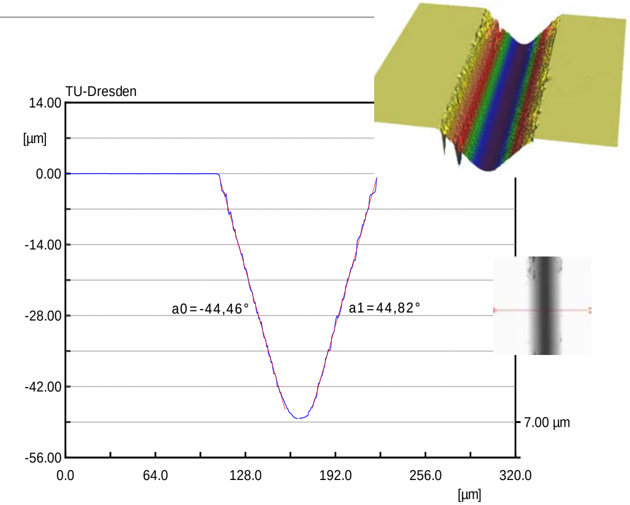
Optical waveguides on PEN-foil



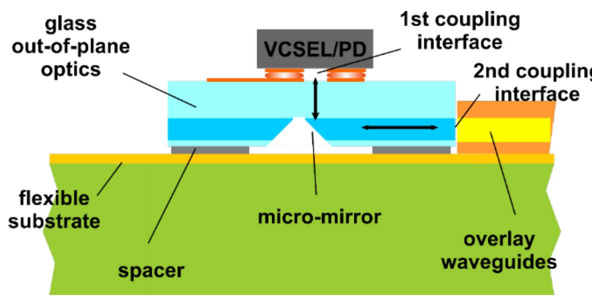



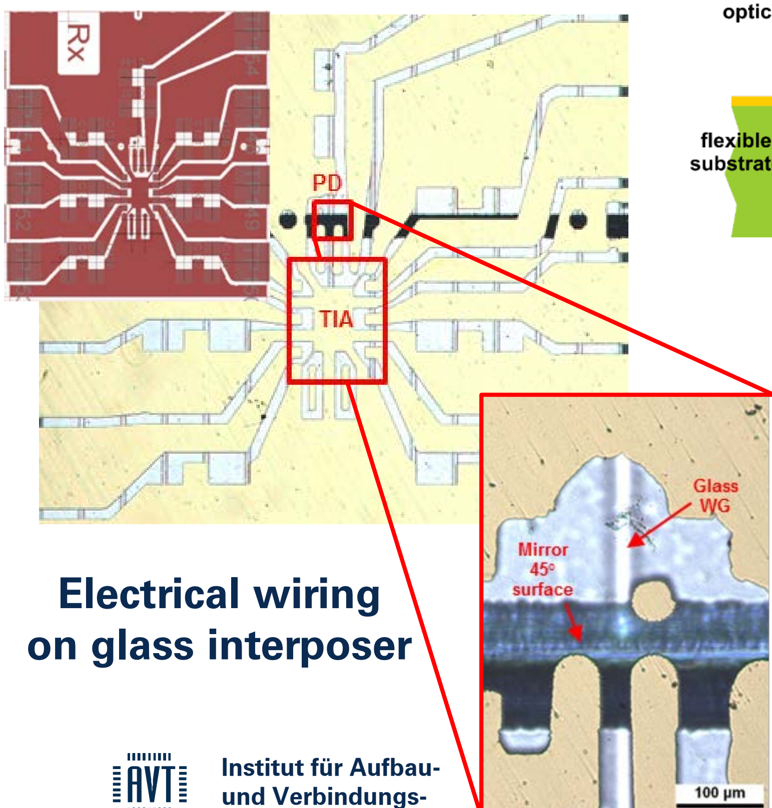
# Optoelectronic transceiver subassembly

- Glass interposer with with electrical wiring for chip assembly (flip-chip)
- Out-of-plane coupling using diced µmirrors
- Optical coupling scheme with passive alignment

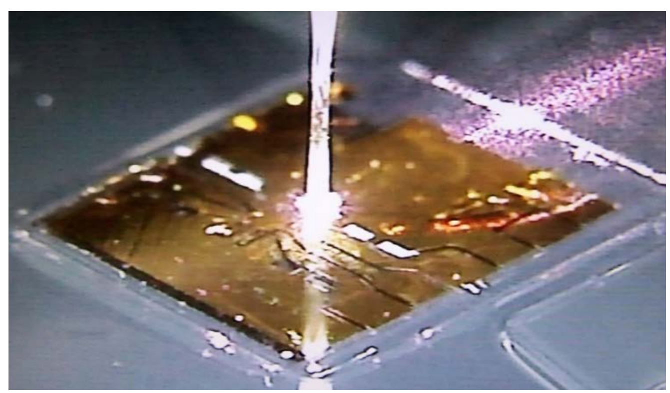



Profile of diced µ-mirror

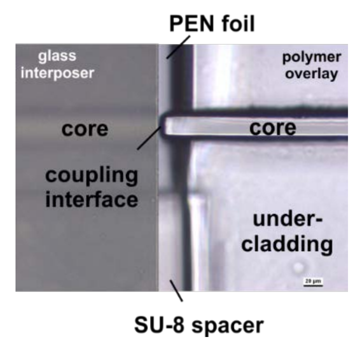


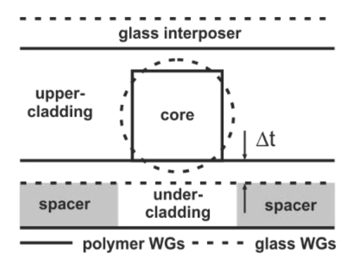




Electrical wiring on glass interposer



Glass interposer mounted on optical foil

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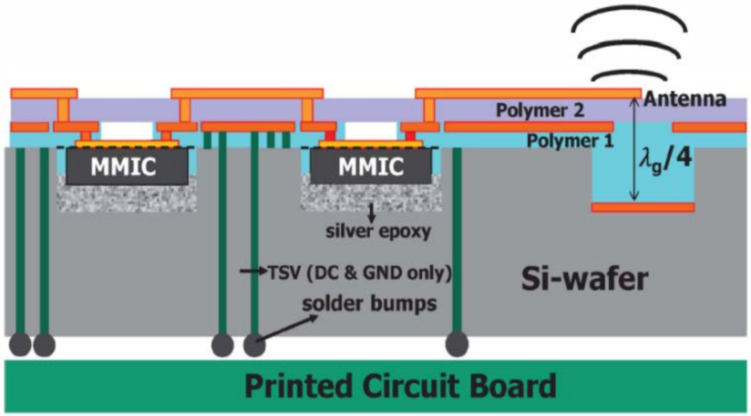
# Heterointegration of mm-wave and optical system

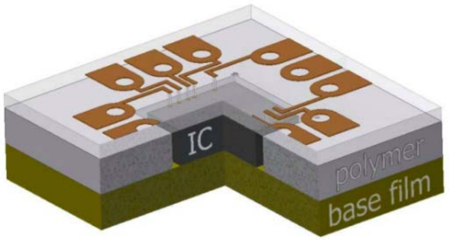
## State-of-Art

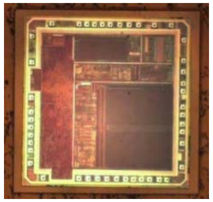
### Si-Interposer System up to 170 GHz




Source: E. Topak,..., K. Bock et al., Proc. of EMW 2013

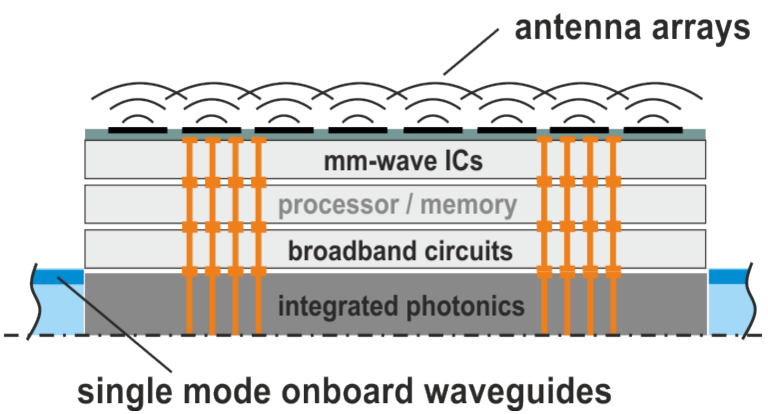
### 3D chip in foil stacks



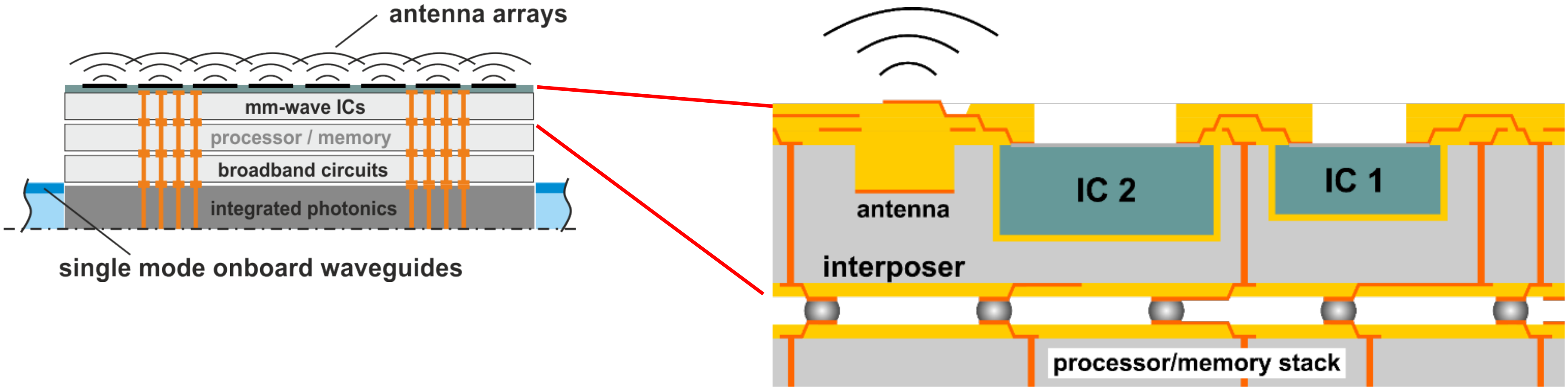
Source: K. Bock et al., Proc. of ECTC 2014

## Optical and Wireless Integration




- ❑ RF performance beyond 200 GHz
- ❑ Embedding of antenna arrays and MMICs
- ❑ Direct interface for feeding of HF-signals
- ❑ Novel optical waveguide-to-antenna functionality

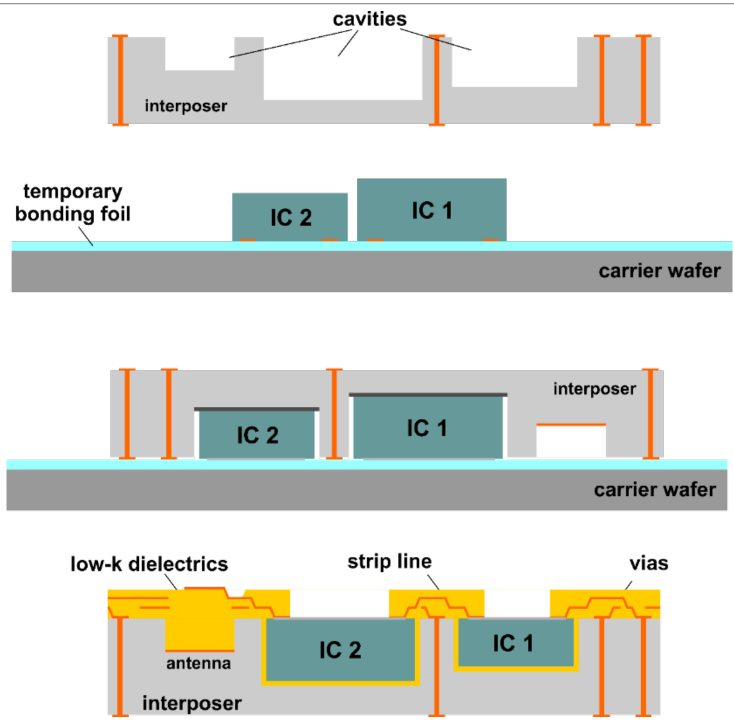
# Transceiver integration for wireless communication



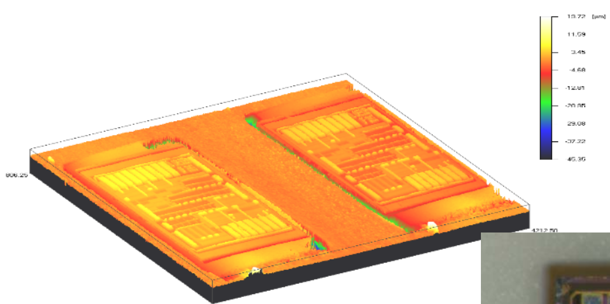

## Goals/Tasks

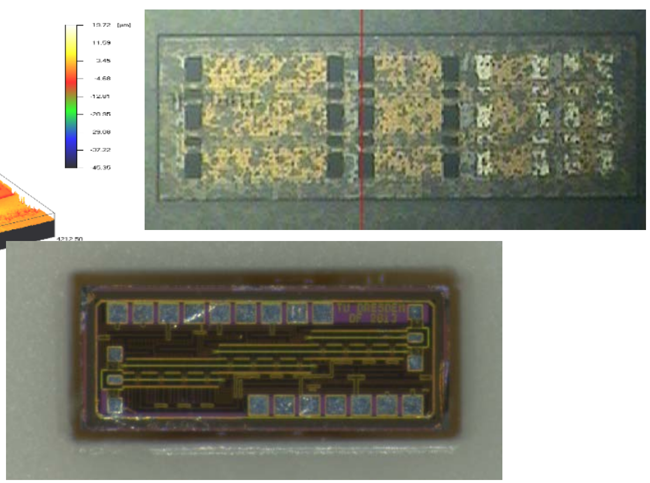
- Integration of MMICs and antennas into interposer
- Polymer-based build-up multilayer for low-loss HF-interconnect

# Embedding of mm-wave ICs

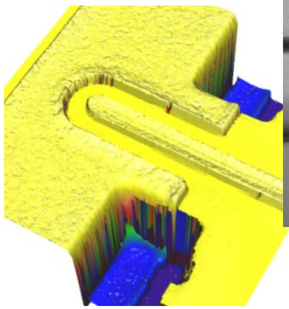


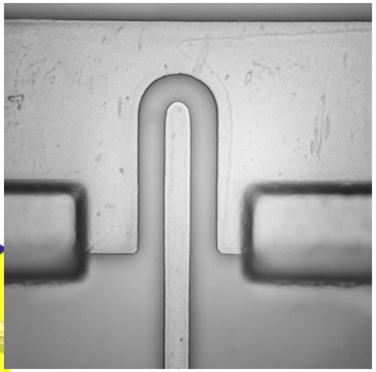

- Structuring of interposer (cavities & through interposer vias)
- Alignment and temporary bonding of ICs
- Bonding of ICs with interposer
- Debonding & fliping
- Sequential build-up of metal/low-k dielectrics multilayer





Chip embedding





RF waveguides

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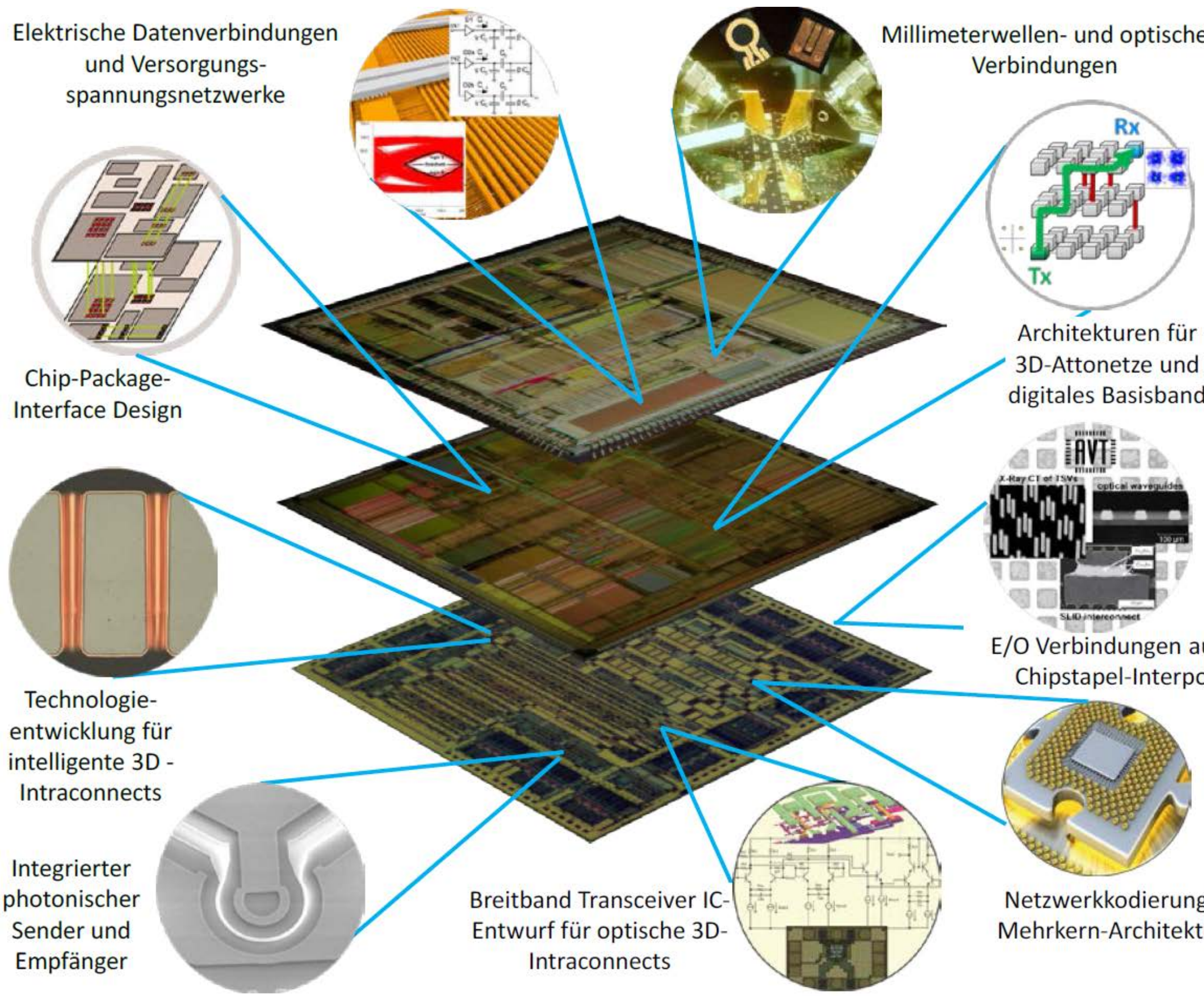
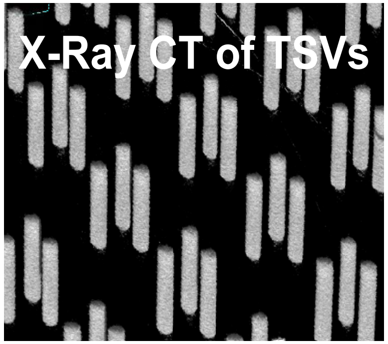
## „Kommunikationsinfrastrukturen für Attonetze in 3D Chipstapeln (Atto3D)“

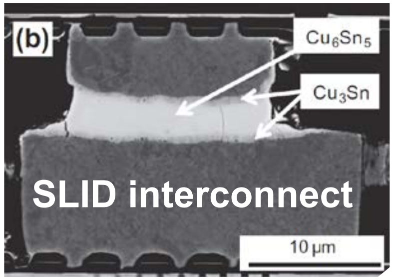


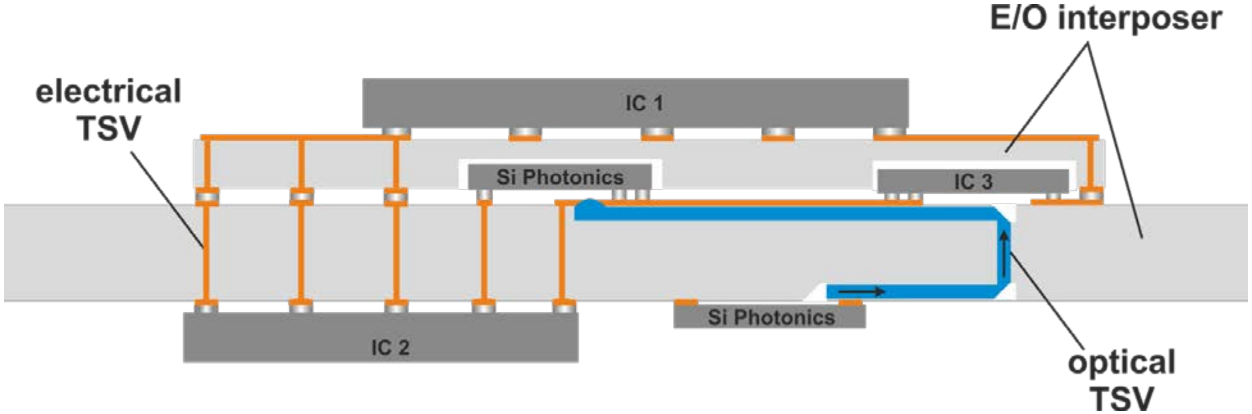
# Electro-optical integration in 3D-chip stacks

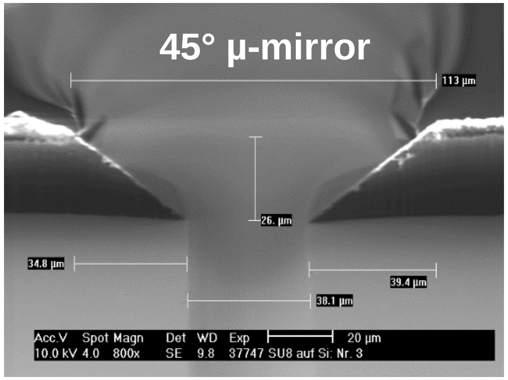
Technology plattform for electro-optical intraconnects on 3D-chip stack interposer:

- Parallel fabrication of electrical and optical interconnects on interposer-level (interconnect to electrical and optical TSVs)
- Technologies for assembly and chip placement for 3D-chip stack
- Microanalysis and reliability investigation



**Förderzeit: 01/15 – 12/17**

TP1

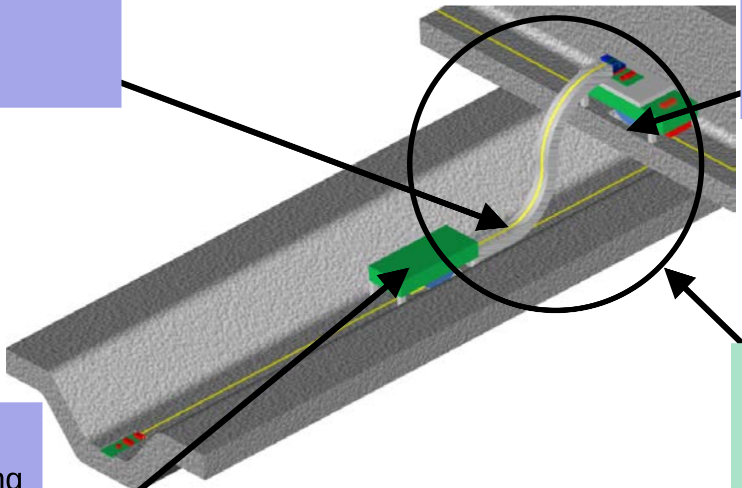
Konditionierung von Substraten zum Auftrag optischer Wellenleiter

*Prof. L. Overmeyer (ITA),*
*Dr. O. Suttmann (LZH)*

TP3

Technologien zur robusten optischen Ankopplung von integrierten Lichtwellenleitern bei der Feldmontage in ausgedehnten Strukturen

*Prof. K.-J. Wolter (IAVT)*



TP2

Dreidimensionale additive Herstellung von lichtleitenden Strukturen auf spritzgegossenen Schaltungsträgern

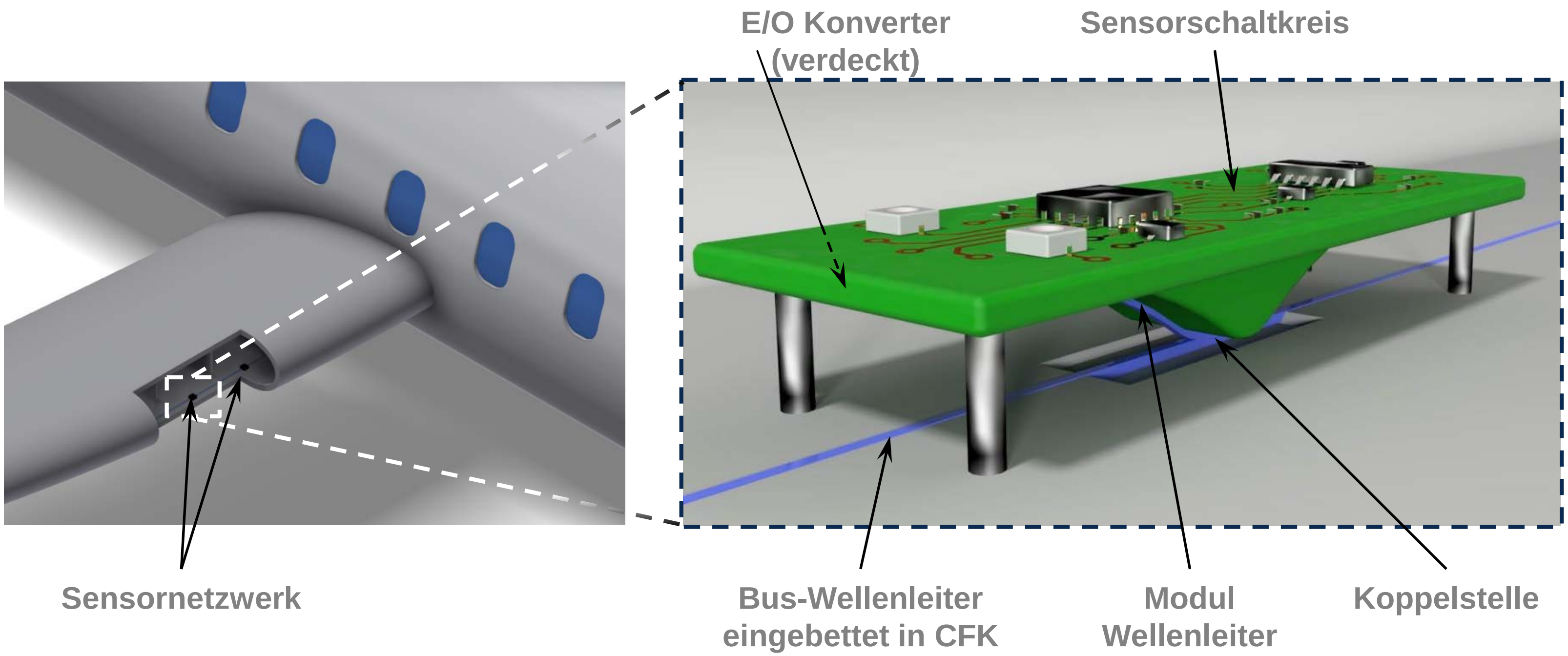
*Prof. J. Franke (FAPS)*

TP6

Integrierte Informationstechnik für die optische Simulation und das funktions-/fertigungsgerechte Design räumlicher optomechatronischer Baugruppen

*Prof. J. Franke (FAPS),*
*Prof. N. Lindlein (ODEM)*

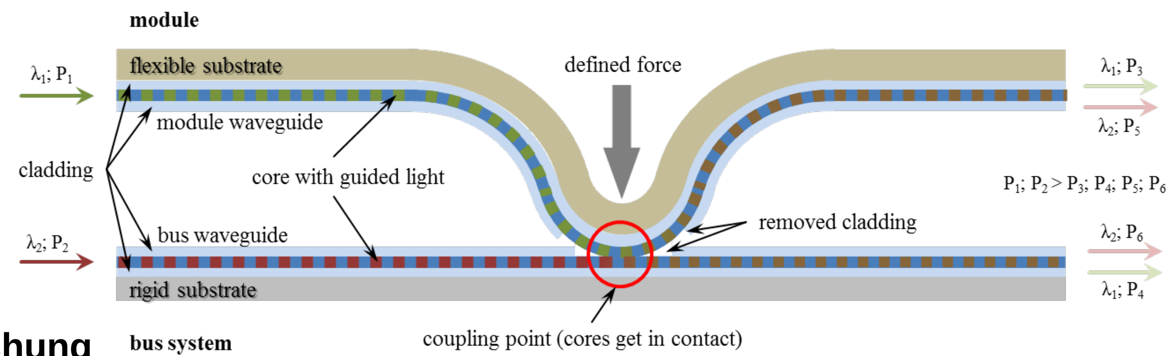
# Zielstellung
# TP3 - Im Feld montierbarer optischer Netzknoten




- **Verbindungsherstellung ohne Wellenleiterunterbrechung**
- **Verbindung mehrerer E/O Baugruppen mit einem Bus-Wellenleiter**
- **Einstellbare Koppelraten**
- **Asymmetrische Kopplung abhängig von der Koppelrichtung (Modul → Bus oder Bus → Modul)**

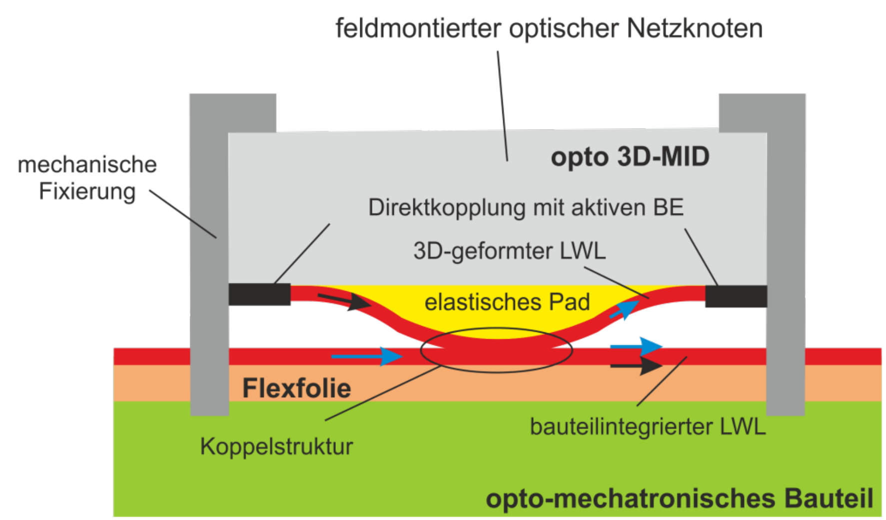
# TP3 - Im Feld montierbarer optischer Netzknoten

- **Die robuste optische Ankopplung** für **optische Netzknoten**
- Die Integration der optischen Funktionen in mechatronische Bauteile entfaltet ihr volles Potential erst bei **kompletter technologischer Beherrschung und Integration in den Fertigungsprozess**
- Biegekoppler mit evaneszentem Koppelprinzip



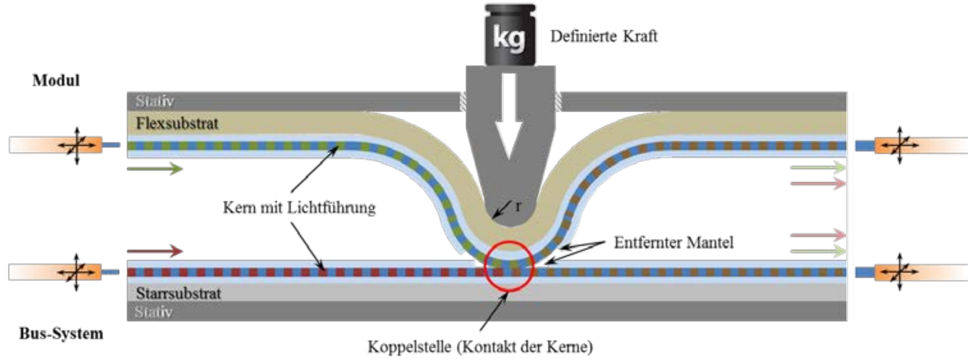

## Herausforderungen

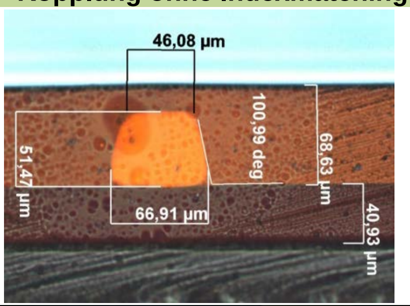
- Geringe Toleranzanforderungen an die Positionierung bei der Montage → passive Justage
- Gezielte Einstellung des Koppelverhältnisses des Kopplers → Anpressdruck
- Hohe Zuverlässigkeit/Robustheit der optischen Verbindung

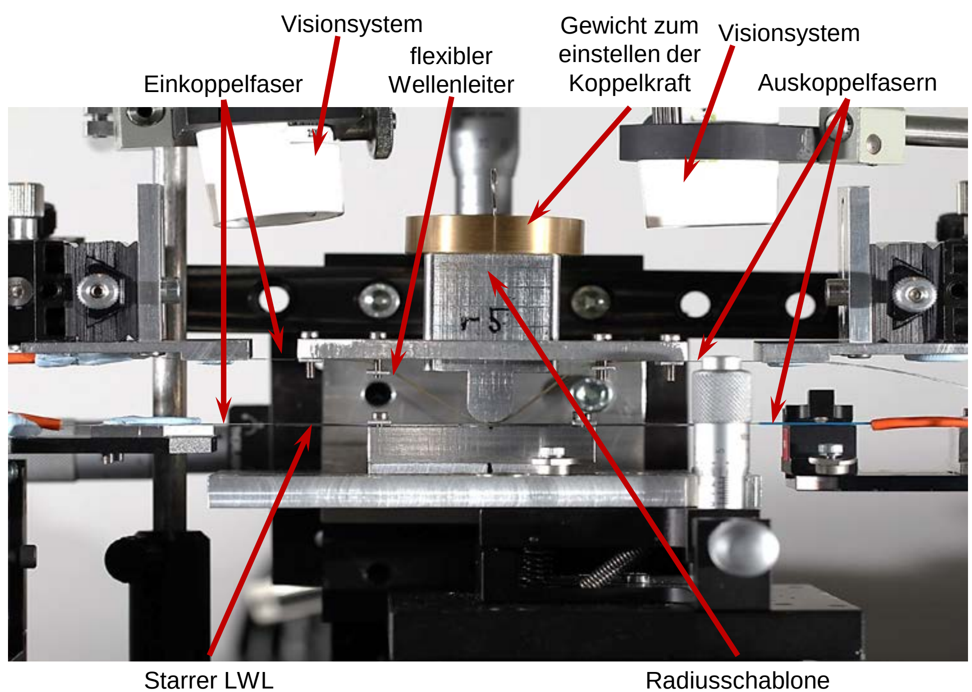


# Versuchsaufbau / Eingangsbedingungen

| Ausgangsbedingungen | | |
|---|---|---|
| Messaufbau | Wellenlänge | 850nm |
| | Referenzleistung | 250µW |
| | Launchfiber | 10µm NA=0,1 |
| | Detectorfiber | 200µm NA=0,39 |
| Wellenleiter | Herstellungs-verfahren | Fotolithografisch |
| | LWL Breite x Höhe (beide) | 50x50 µm |
| | **Kopplung ohne Indexmatching** | |

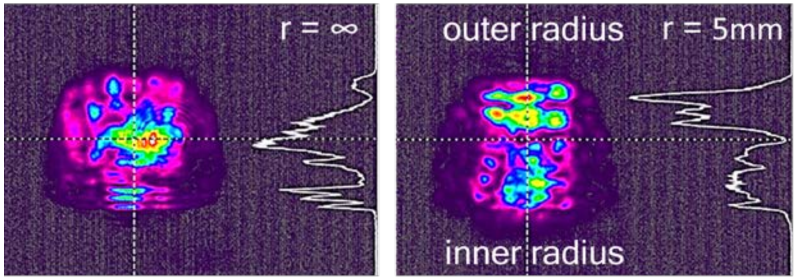


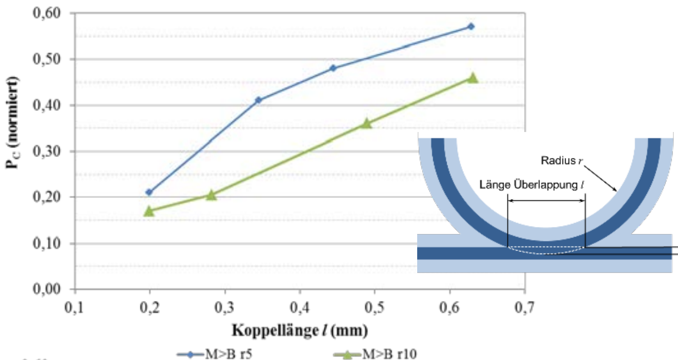



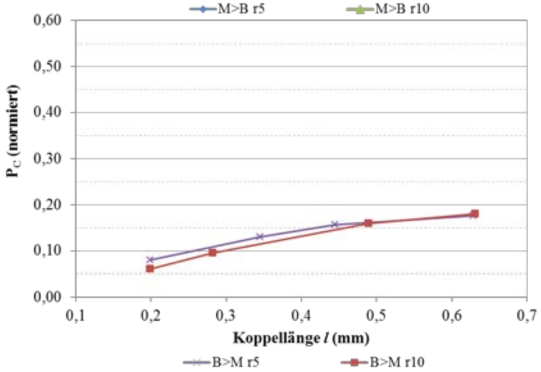
# Evaneszente Koppelprinzip

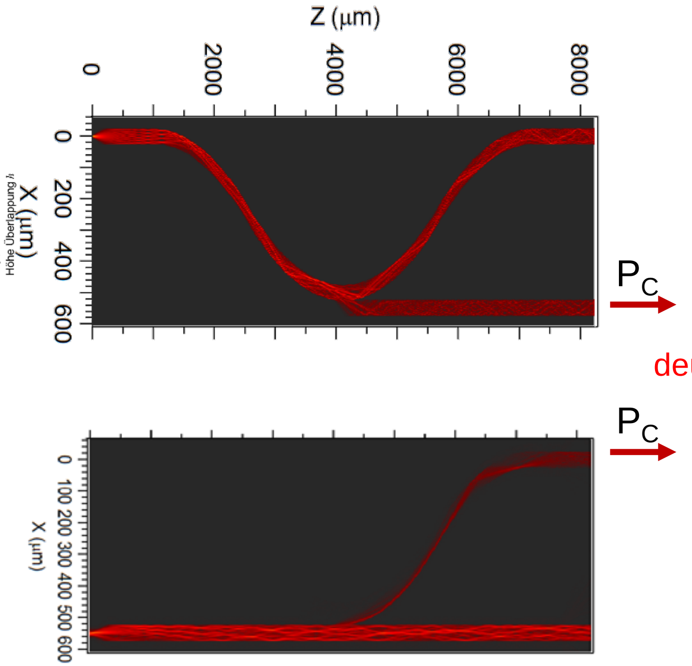
- Biegung verursacht eine Modenumverteilung
  → Auswirkung auf den Koppelgrad
- Radiusabhängigkeit nur bei Kopplung von Flex nach Starr
- Asymmetrisches Kopplerdesign möglich




**Durch Biegung verursachte Modenumverteilungsänderung**




0,39

0,30

0,02

0,70

0,77

0,03

deutlich asymmetrische Kopplung

**BPM simulation of coupling scheme**

**Messung**

# Zusammenfassung

- Motivation & Treiber für E/O Integration in elektronischen Systemen
- HAEC Ansatz: optische und drahtlose Kommunikation in Hochleistungsrechnern
- Erforschung von neuartigen Kommunikationsinfrastrukturen für 3D Chipstapeln – NFG Atto3D
- Biegekoppler mit evaneszentem Koppelprinzip für optische Bussysteme – FG Optaver

# Danke für Ihre Aufmerksamkeit!!

**Kontakt:**

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DFG Forschergruppe: Optaver
Optische AVT für 3D-opto-mechatronische Baugruppen

ESF Nachwuchsforschergruppe: Atto3D
Kommunikationsinfrastrukturen für Attonetze in 3D Chipstapeln

CRC 912: HAEC − Highly Adaptive Energy-Efficient Computing

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