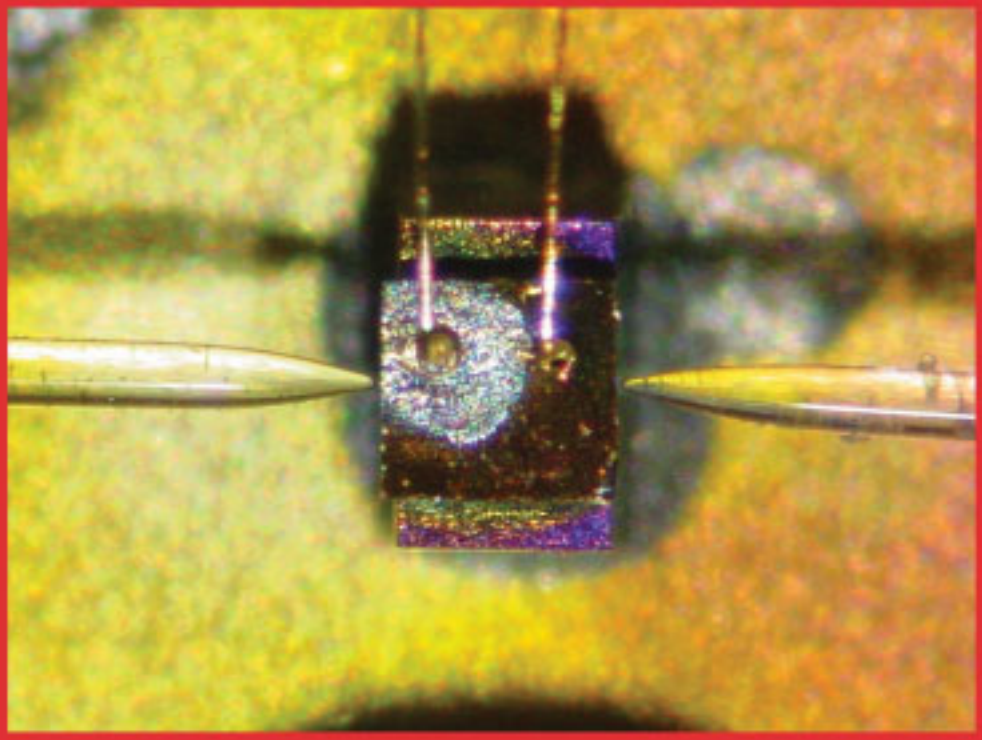
Lehrstuhl für Kommunikationstechnik
Hochschule Harz (FH)

No. 07, 2009

U.H.P. Fischer-Hirchert (Hrsg.)



VII. ITG Workshop

Photonische Aufbau- und Verbindungstechnik

7./8. Mai 2009

Hochschule Harz, Wernigerode
Hörsaal C, Friedrichstr. 55
38855 Wernigerode, Germany

Cuvillier Verlag Göttingen

VII. ITG-Workshop

Photonische Aufbau- und Verbindungstechnik

ITG
Photonische
AVT

7./8. Mai 2009

Hochschule Harz, Wernigerode
Hörsaal C, Friedrichstr. 55
38855 Wernigerode, Germany

VDE

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Einladung zum ITG-Workshop "Photonische Aufbau- und Verbindungstechnik"

Die Informationstechnische Gesellschaft im VDE vertreten durch die ITG-Fachgruppe 5.3.2 „Photonische Aufbau- und Verbindungstechnik“ und die Hochschule Harz werden am **7./8. Mai 2009 (Do. 14:30 bis Fr. 13:00)** einen Workshop ausrichten, zu dem alle Interessenten herzlich eingeladen sind.

Themen:
- Einzel- und Multifaserkopplung
- Buttfaserkopplung, Fasertaperkopplung
- Mikrooptik
- Klebetechnik, Laserschweißtechnik
- Spot-size Konverter für InP- und Silica-Komponenten
- optische Steckverbinder für Multifaserkopplungen
- hybride elektro-optische Leiterplatte
- Flip-Chip-Technik für optische Justage
- Automatisierung
- Messtechniken für opt. Felder
- Gehäusetechnik

Hintergrund
Die optische Nachrichtentechnik ist die Basis moderner Kommunikationssysteme, welche zu einem der wichtigsten infrastrukturellen Grundpfeiler der modernen Gesellschaft geworden sind. Schlüsselkomponenten sind neben der Übertragungsfaser die optischen und optoelektronischen Komponenten, d.h. die photonischen Komponenten. Der Aufbau dieser Komponenten und die Ankopplung an die Faser stellt wegen der erforderlichen Justagegenauigkeit im Sub-Mikrometerbereich höchste Anforderungen an die photonische Aufbau- und Verbindungstechnik (PAVT). Die Techniken der klassischen elektrischen Aufbau- und Verbindungstechnik (EAVT), wie Bonden, Kleben, Löten oder Dickschicht- bzw. Dünnschichttechnik, werden ebenso zum Aufbau eines optoelektronischen Bauteils (OEIC) eingesetzt, wie Techniken aus der Mikrosystemtechnik. Dazu gehören das Ätzen von Siliziumsubstraten oder Maskentechniken und die Benutzung feinmechanischer Stellelemente mit Nanometerauflösung. Der systemtechnische Einsatzbereich der OEICs bestimmt maßgeblich den Aufbau der Modulgehäuse zur Aufnahme der OEICs Für den Masseneinsatz, z. B. im Teilnehmerbereich oder im Auto, müssen die Module sehr preiswert sein. Sie können aber auch sehr teuer und aufwändig werden, wenn spezielle Funktionen für Weitverkehrsstrecken benötigt werden.

Die Erhöhung der Integrationsdichte in kommenden Systemkomponenten durch monolithische und hybride Integrationstechniken ist ein wichtiger Aspekt, der bei der Entwicklung neuer Techniken für die Photonische Aufbau- und Verbindungstechnik zu berücksichtigen ist.

Themen und Zielstellung
Im Kontext der rasanten Entwicklung photonischer Technologien sind die Aktivitäten der Fachgruppe „Photonische Aufbau- und Verbindungstechnik“ auf die Anwendungsbereiche Telekommunikation, Datacom und Automotive ausgerichtet.

Ziel der Fachgruppe ist es, eine nationale Plattform zur Diskussion oben genannter Themen zu bilden und darüber hinaus den Know-How-Aufbau und den Wissenstransfer durch Austausch und Auswertung von Erfahrungen und Informationen aktiv zu begleiten. Dazu gehören die Durchführung und Förderung nationaler und internationaler Diskussionsforen, Durchführung und Förderung nationaler und internationaler Tagungen, Erarbeitung von Richtlinien und Empfehlungen und auch die Initiierung von und Mitarbeit bei nationalen und internationalen Forschungs- und Entwicklungsprojekten im Bereich photonischer Aufbau- und Verbindungstechniken.

Organisation und lokale Ausrichtung :

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MergeOptics GmbH, Berlin

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Ficontec GmbH, Bremen

Dipl.-Ing. G. Walf,
FhG-Institut für Nachrichtentechnik,
Heinrich-Hertz-Institut, Berlin

Richard Pitwon
XyrATEX Ltd, United King

Tagungsprogramm V. Workshop „Photonische Aufbau- und Verbindungstechnik“ Wernigerode

Donnerstag, 7. Mai 2009

12:30-14:00 Registrierung

14:00 Begrüßung durch Rektor Prof. Willingmann, Prof. Fischer-Hirchert

Session 1: " Mikrooptiken"

Chairman: H. Schröder

14:15 „Mikrooptiken“
A. Bräuer, Fraunhofer IOF, Jena

15:00 "Optische AVT mit Polymermikrobauteilen“
S. Karl, JENOPTIK Polymer Systems GmbH, Triptis

15:30 „40 – 100 GHz Packaging & Bonding“
Ö. Karpuzi, Fraunhofer HHI, Berlin

16:00 Kaffeepause (Foyer)

16:30 „Solderjet bumping for the assembly of optical fibers“
T. Burkhard, Fraunhofer Gesellschaft, Jena

Session 2: "Schlüsselelemente für den Zugangsbereich"

Chairman: U. Fischer-Hirchert

17:00 „From the idea to the prototype, a Demultiplexer for WDM over POF“
M. Haupt, Hochschule Harz, Wernigerode

17:30 „Access Networks for 10 Gbit/s everywhere“
G .Walf, Fraunhofer HHI, Berlin

Ab 18:00 Come Together mit Imbiss und der Möglichkeit zur Laborbesichtigung im Foyer von Haus 3

Freitag, 8. Mai 2009

Session 2 Fortsetzung: "Schlüsselelemente für den Zugangsbereich"

09:00 „Modul-Bauformen und Bauformen von ROSA und TOSA“
K. Schulz, SODAJA/Mergeoptics, Berlin

09:30 „Modulare Systemkomponenten auf Basis planar-optischer Polymerchips“
Ch. Kutza, Fiber Optical Components, Berlin

Session 3: "Optical Interconnects"

Chairman: G. Walf

10:00 „Optical coupling using planar thin glass based waveguide components“
H. Schröder, Fraunhofer IZM, Berlin

10:30 Kaffeepause (Foyer)

11:15 " Optical link for high-speed board-level parallel interconnections “
K. Nieweglowsky , TU-Dresden, Dresden

11:45 „Mehrkanalige Koppelelemente für optische Leiterplatten und optische Backplanes“
M. Schneider, Forschungszentrum Karlsruhe, Karlsruhe

12:15 „Pluggable Connector Technologies for Polymeric Electro-Optical Backplanes“
R. Pitwon, Xyratex, Hampshire GB

12:45 Abschlussworte und Ende des Workshops

Im Anschluss Möglichkeit zur Mittagsmahlzeit in der Mensa der Hochschule Harz

Im Foyer sind an beiden Tagen Exponante von verschiedenen Herstellern und Distributoren ausgestellt.

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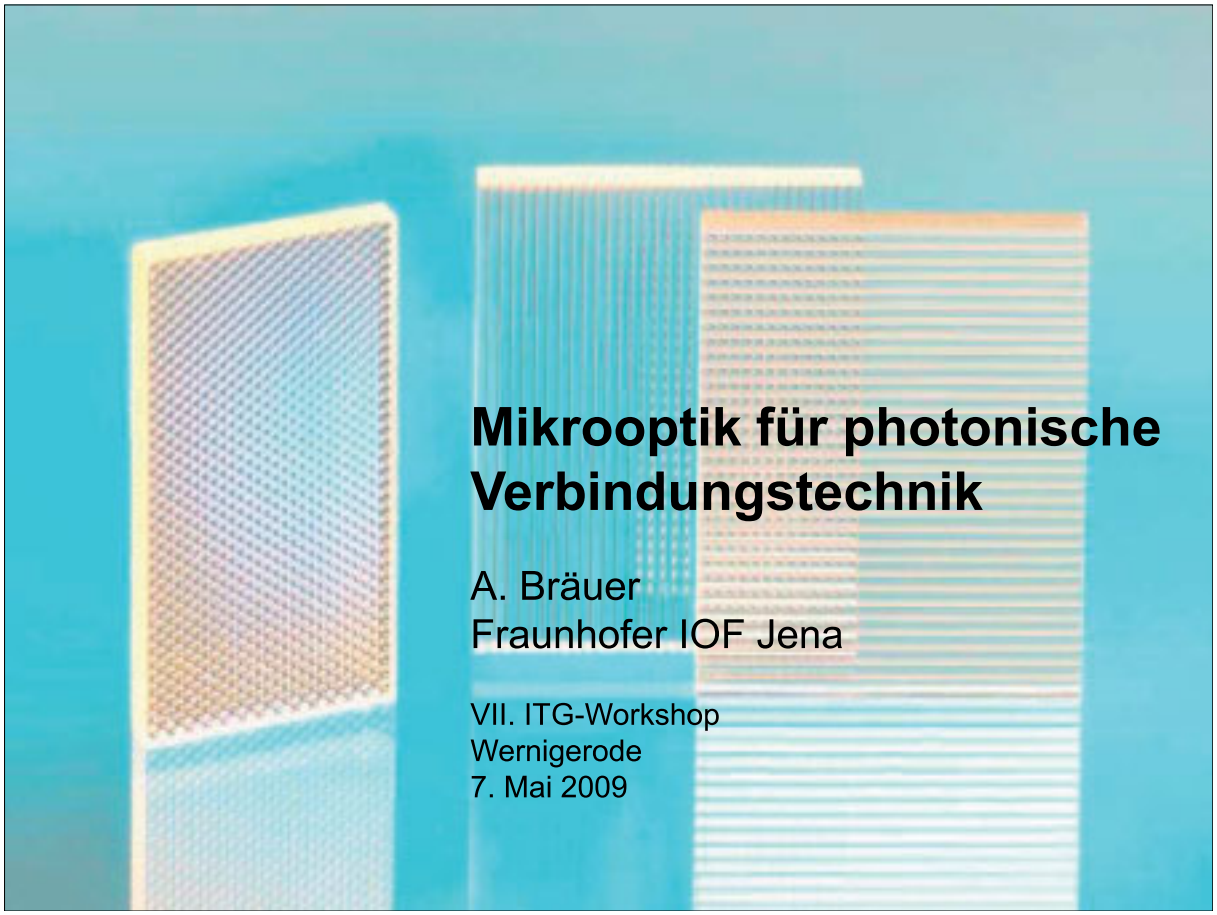
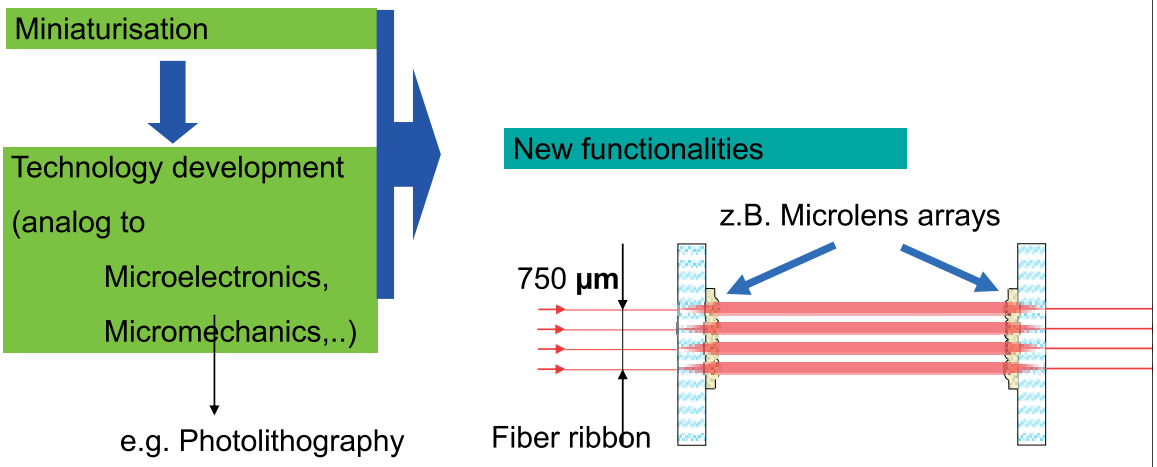
Pluggable Connector Technologies for Polymeric Electro-Optical Backplanes 119



Tailored Light - Licht nach Maß

Definition of Microoptics ?

- „...efficient exploitation of light opening up new applications for optics ...“ (Fa. Heptagon)
- „enabling technology using microelectronical equipment“
- NOT ONLY ‚miniaturised, low-cost optics‘, BUT:



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Tailored Light - Licht nach Maß

“Mikrooptik für photonische Verbindungstechnik”

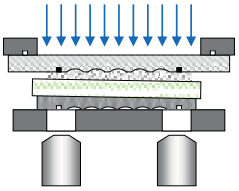
Wesentliche Rahmenbedingungen sind (Zitat Klaus Schulz):

- Kosten
- Baugröße
- Energie
- Packungsdichte
- Funktionsdichte

Wie können mikrooptische Bauelemente dem am besten Rechnung tragen ?

- Wafer-level Optik-Technologie

- UV-Replikationstechnologie zur Herstellung



- Gleichzeitige Herstellung von Mikrooptik und Koppelstelle

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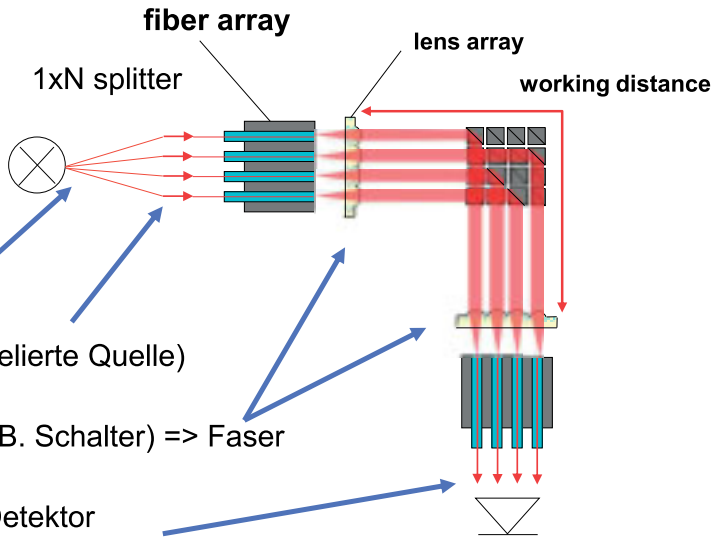
Mikrooptik für photonische Verbindungstechnik

Wesentliche Koppelstellen



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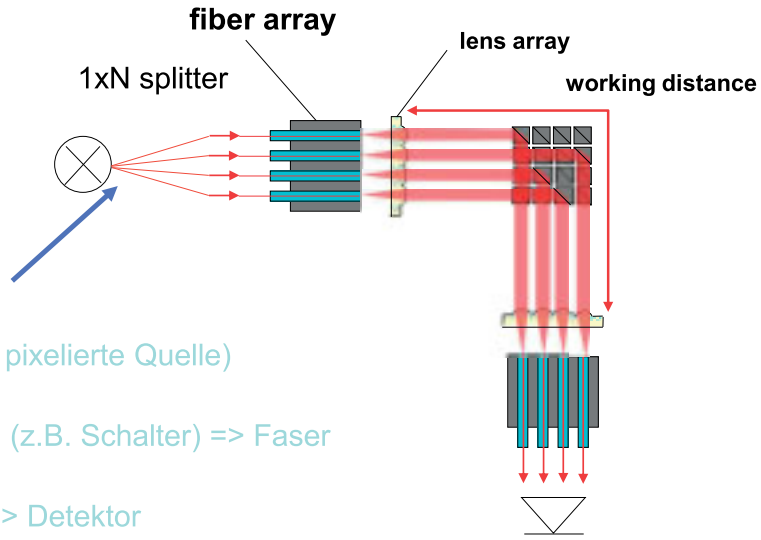
Mikrooptik für photonische Verbindungstechnik

Wesentliche Koppelstellen



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Tailored Light - Licht nach Maß

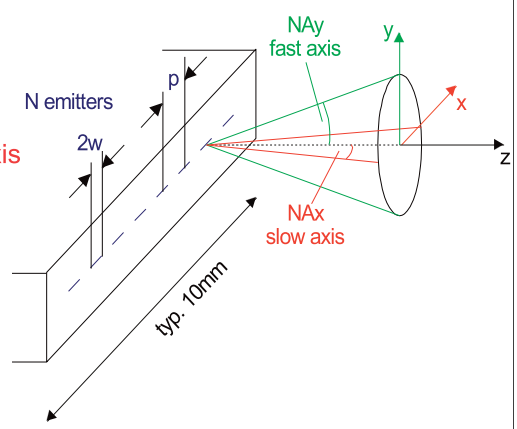
Etch-emitting Laser => Fiber coupling

Requirements for Laserdiode to-fiber-coupling:

Beam parameter product $w_0 \cdot NA = M^2 \lambda/\pi$

Single emitter (typ.): $M_y^2 < 1.5$ fast axis
$M_x^2 \approx 15...50$ slow axis

Fiber 100/200µm 0.22NA $M_x^2 \approx 43 / 86$



Efficient coupling for $M_{laser} < M_{fiber}$

>> Main problem: Slow axis beam quality
>> Solution: Optical rearrangement of emitters – several principles

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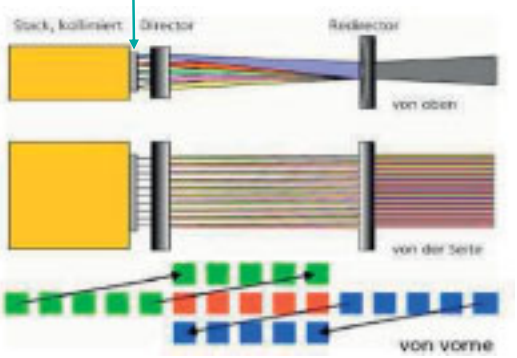
Tailored Light - Licht nach Maß

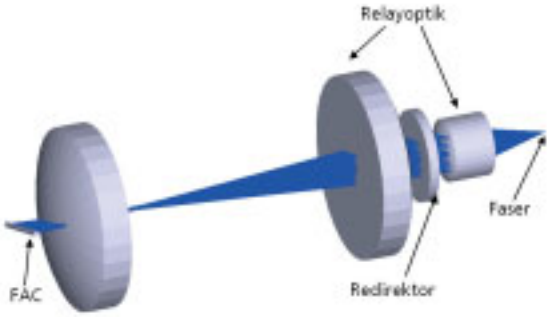
Laser => Fiber coupling: Skew ray imaging coupler

Principle

FAC ‚inclined' (‚fast axis collimation')



Design



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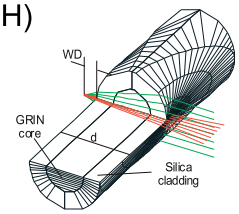
Tailored Light - Licht nach Maß

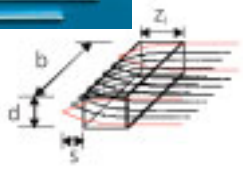
Laser => Fiber coupling - Micro-optical components

1. Fast axis collimation: High-NA cylindrical lens **with large field: GRIN lenses** (DORIC, GRINTECH)

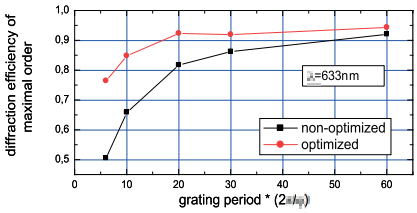
DORIC

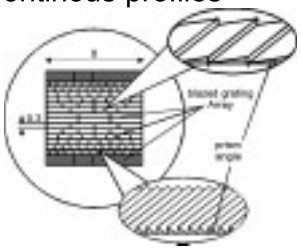


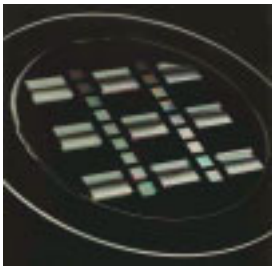
GRINTECH



2. Redirector: Blazed grating array
   - Replication of direct laser-written continous profiles







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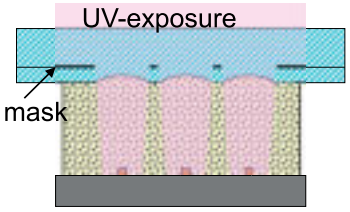
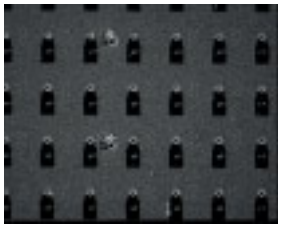
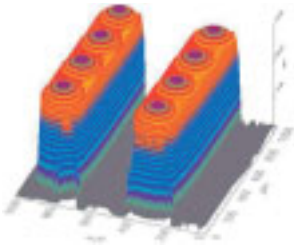
Tailored Light - Licht nach Maß

VCSEL-collimation optics on wafer scale

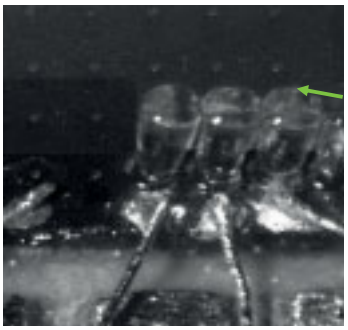




VCSEL array, x-pitch = 250µm



surface profile
Ø250µm lenses
polymer pedestals



row of
microlenses
pitch 250µm

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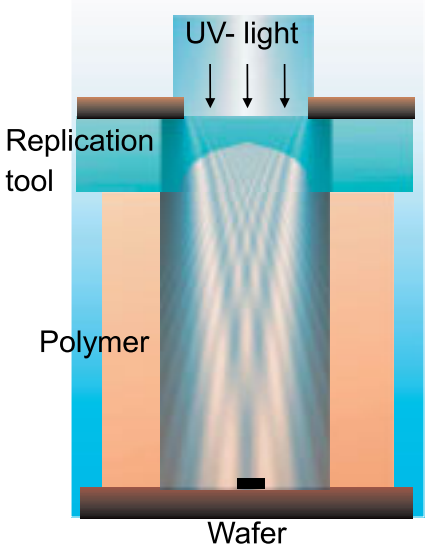
VCSEL-collimation on wafer scale

Combination of replication und selective photopolymerisation



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Tailored Light - Licht nach Maß

VCSEL-collimation on wafer scale

Selective UV- Replication !

Material: ORMOCER

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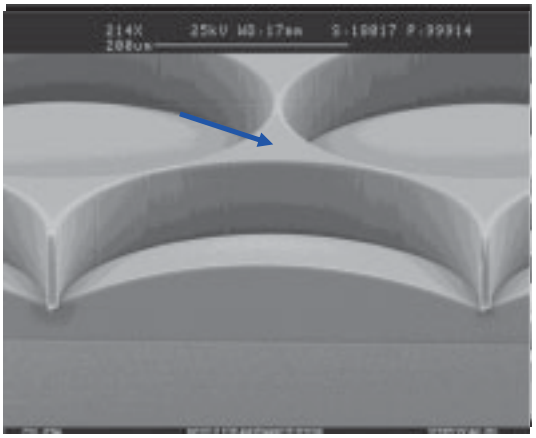
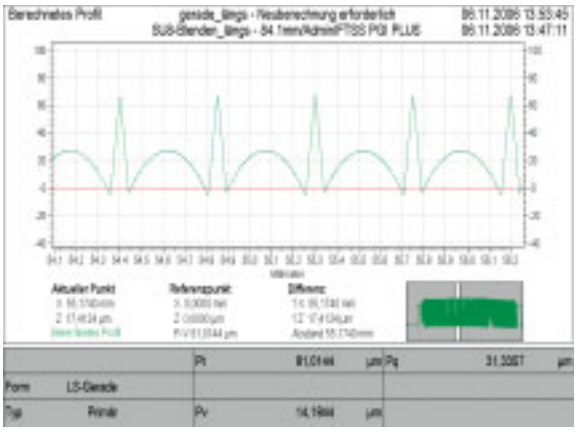
Tailored Light - Licht nach Maß

Collimation optics and holding structure (wafer scale)





Material: ORMOCER / SU-8

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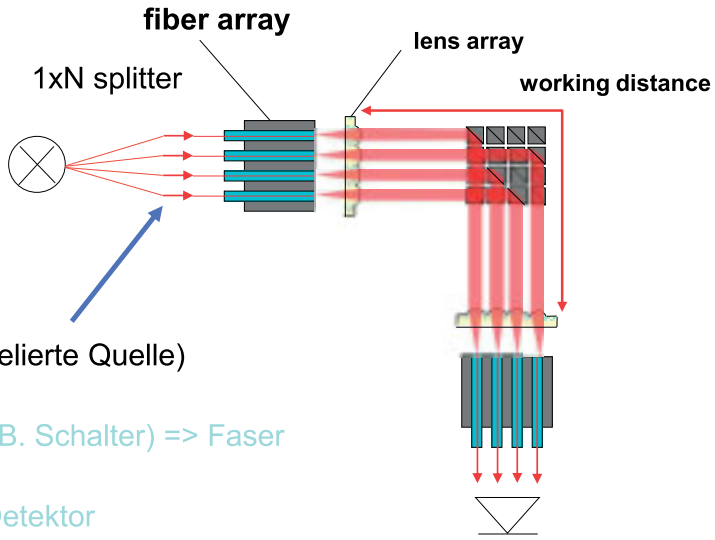
Tailored Light - Licht nach Maß

Mikrooptik für photonische Verbindungstechnik

Wesentliche Koppelstellen



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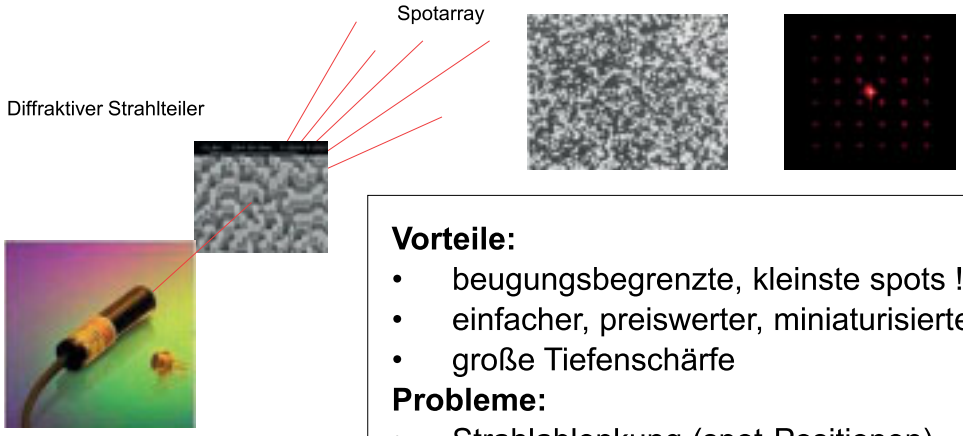
1xN Splitter mit Laserquelle

Typischer Ansatz: Kollimierte Laserdiode mit diffraktivem Strahlteiler



Vorteile:
- beugungsbegrenzte, kleinste spots !
- einfacher, preiswerter, miniaturisierter Aufbau
- große Tiefenschärfe

Probleme:
- Strahlablenkung (spot-Positionen) ~ λ (!!)
- Streulicht: Speckle und 0. Ordnung

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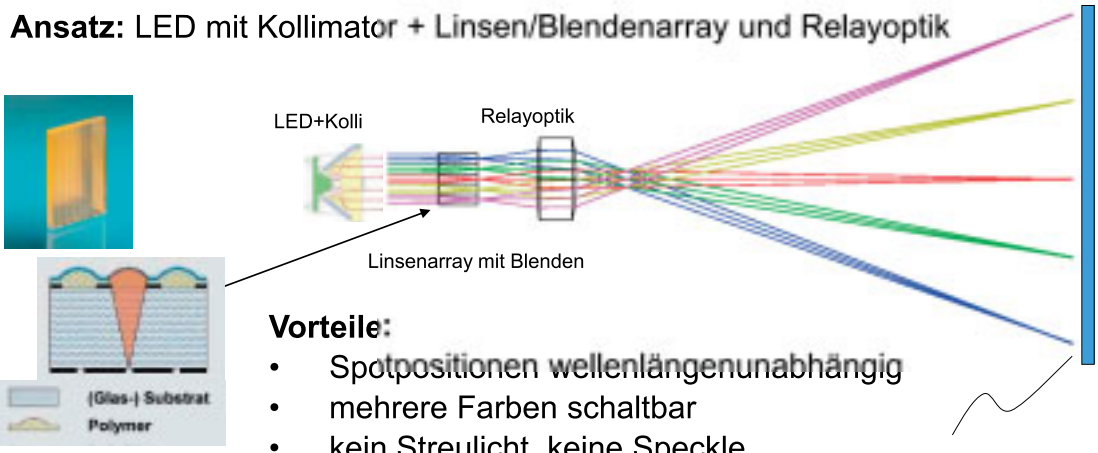
Tailored Light - Licht nach Maß

LED – 1xN Splitter

Ansatz: LED mit Kollimator + Linsen/Blendenarray und Relayoptik



Typ. Arraypitch

200-800µm

Vorteile:

- Spotpositionen wellenlängenunabhängig
- mehrere Farben schaltbar
- kein Streulicht, keine Speckle
- hohe optische Leistung

Probleme:

- Spotgröße, Tiefenschärfe
- mehrstufige Optik

21x21 Punkte
Ø 4 mm
auf 380x380 mm²

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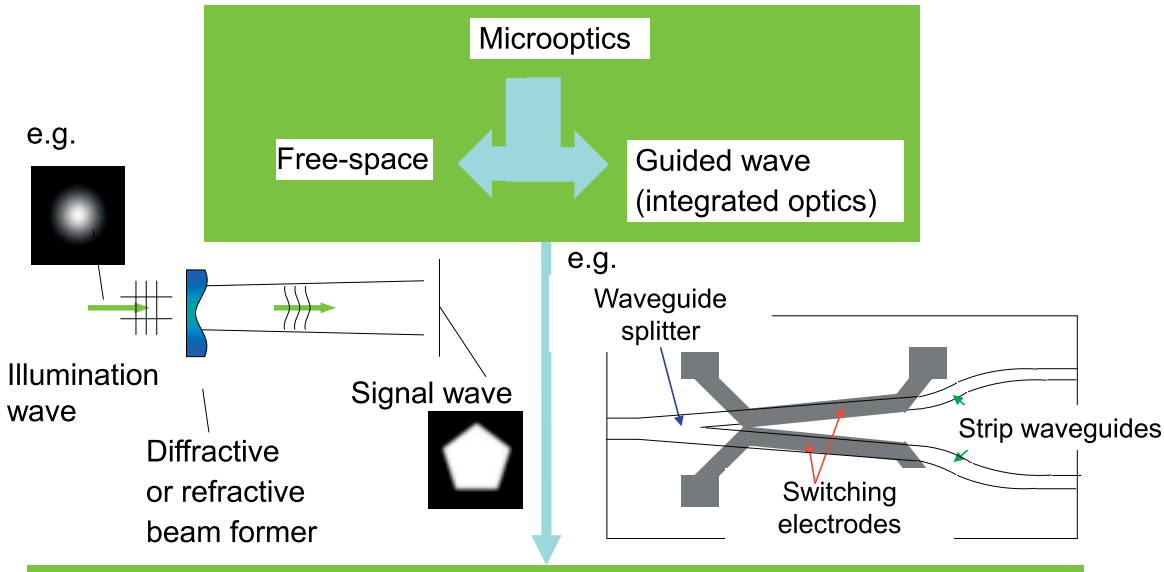
Tailored Light - Licht nach Maß

Two directions of microoptics



Free-space and waveguide optics demand for **similar technologies**

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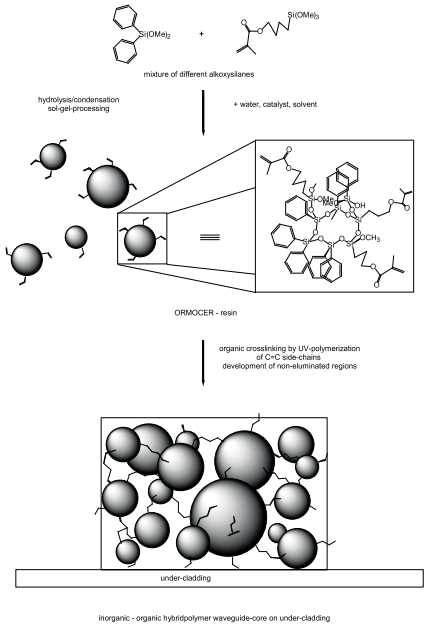
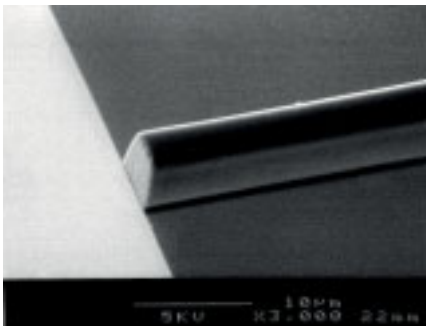
Strip waveguides by UV-Lithography





Strip waveguides on SiO_2-Substrat

Material: ORMOCER with photostarter

Process: UV-illumination through mask, Intensity 20 mW/cm ^{2,} ca. 10 s

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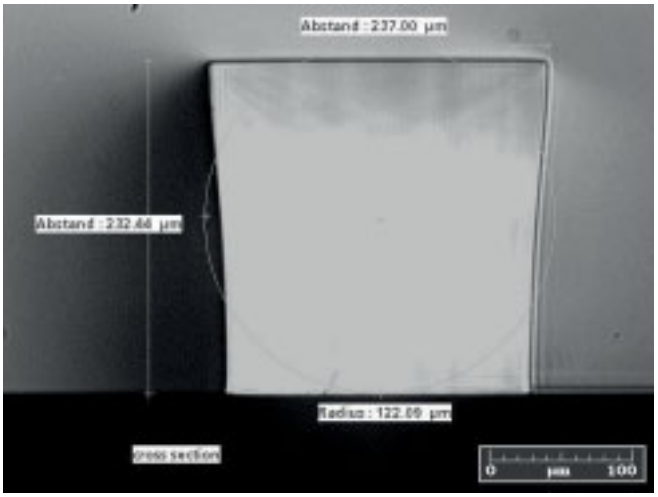
Tailored Light - Licht nach Maß

UV-lithography for multimode waveguide technology

- Cross section of polymer multimode waveguide
- POF for comparison
- Typical loss 0.3 dB/cm



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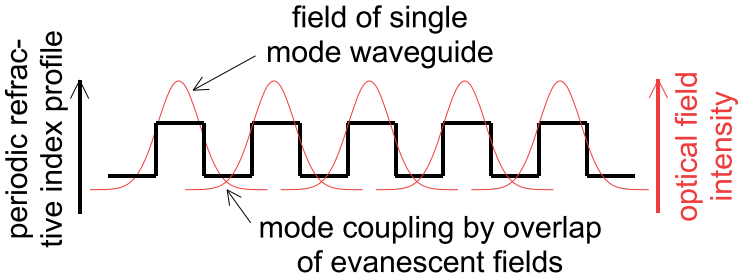
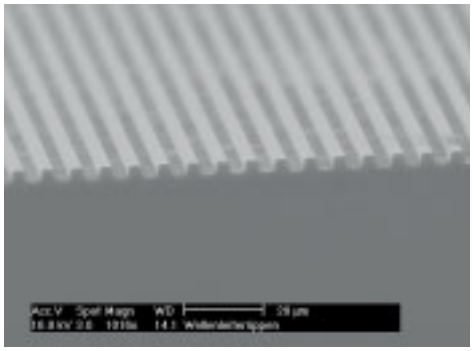
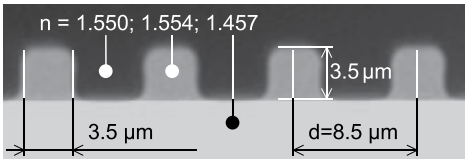
High precision Optical waveguide arrays (UV-Lithography)





Fabrication technology

- 75 waveguides in a thermo-optic polymer
- single mode, < 0.5 dB/cm, λ = 633 nm
- 4.5 cm long, 800 µm wide samples



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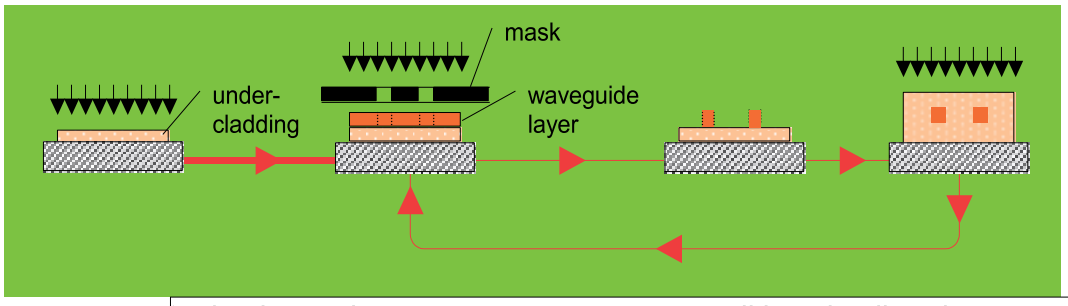
Stacks of Single Mode Waveguides – vertical coupling

Idea of stacking process :

- extend methods for planar single layer devices
- simple repetition of planar process ?



➢ basic requirement: same exposure conditions in all cycles

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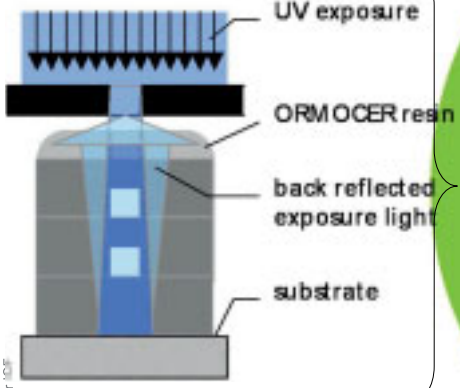
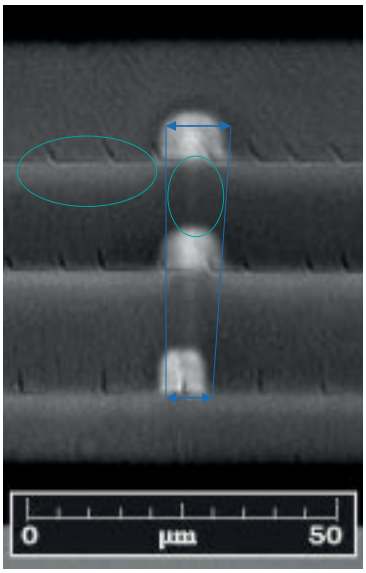
Stacks of Single Mode Waveguides

Stacking: Fundamental effects



- broadening of structures with increasing stack height
- index gradients in cladding layers (diffusion, imperfect passivation)



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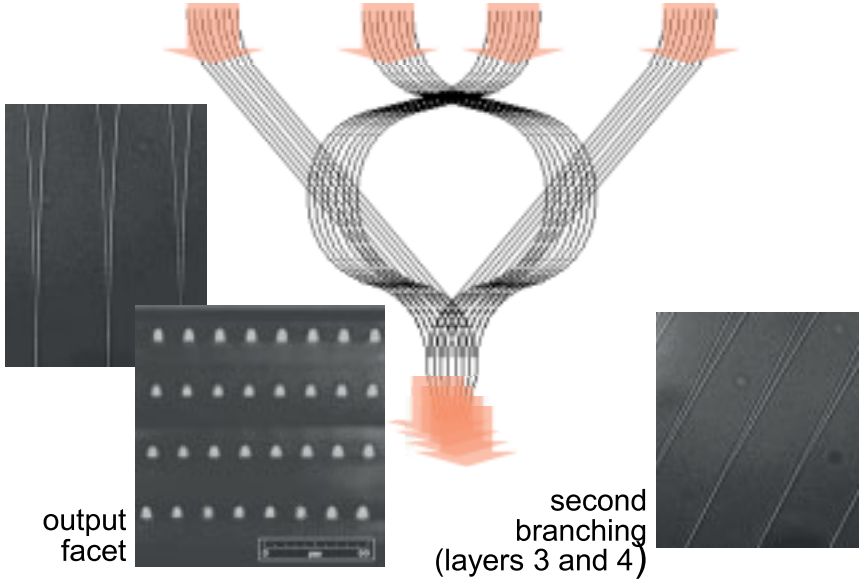
NxM coupler (Single Mode Waveguides)



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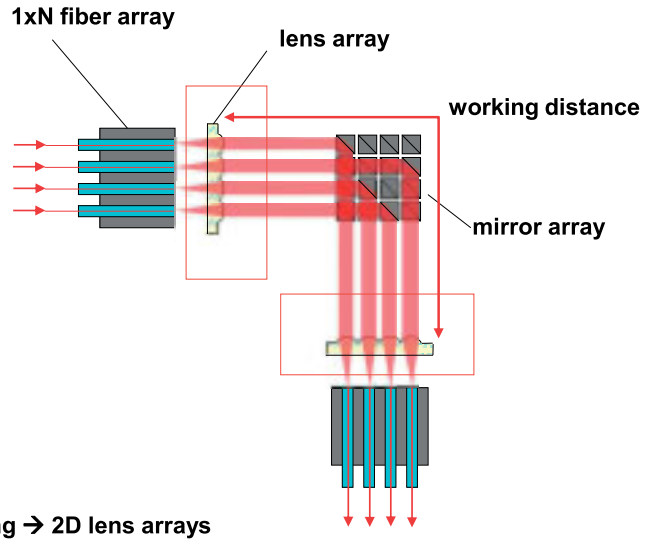
N x M switching geometry using micro-mirror arrays



3D switching → 2D lens arrays

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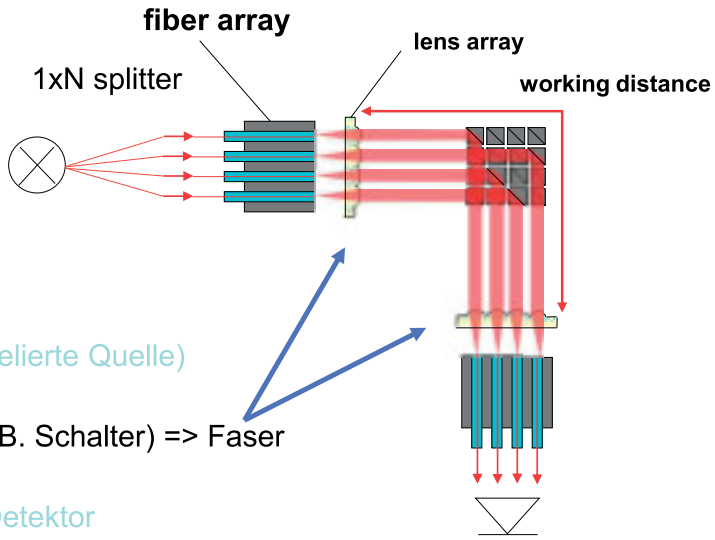
Tailored Light - Licht nach Maß

Mikrooptik für photonische Verbindungstechnik

Wesentliche Koppelstellen



- Quelle => Faser
- NxM-Splitter (oder pixelierte Quelle)
- Faser => Freiraum (z.B. Schalter) => Faser
- Faser / Freiraum => Detektor

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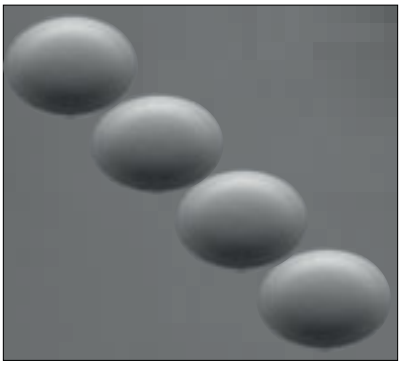
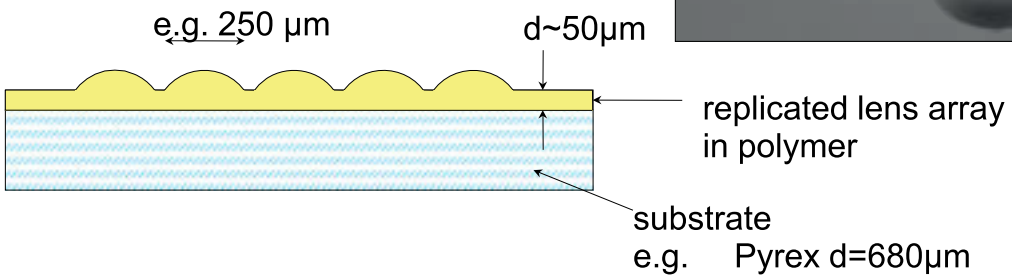
Tailored Light - Licht nach Maß

Fiber collimation by spherical lens arrays

Thin polymer layer on inorganic substrate
- ➡ low thermal expansion
- ➡ low wavefront deformation
- ➡ high temperature stability
- ➡ sag of up to 90µm





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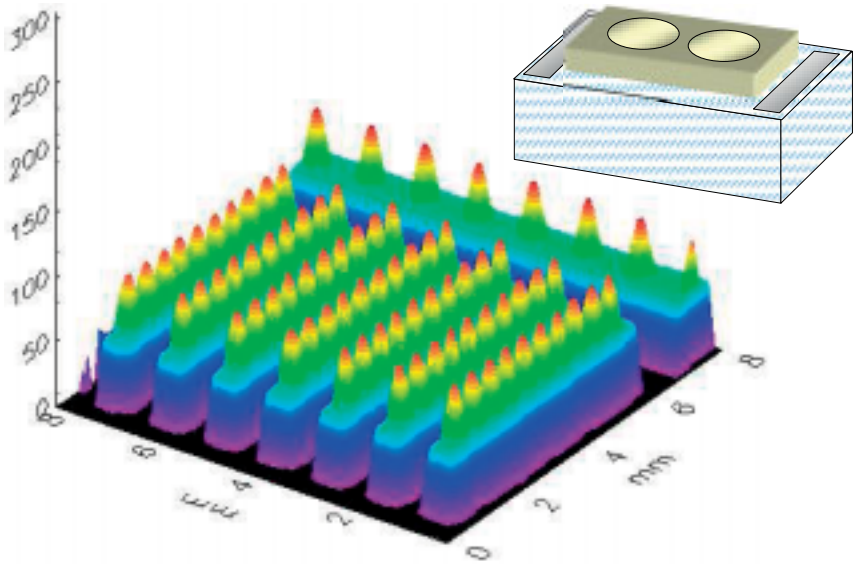
Fiber collimation by spherical lens arrays



Lens arrays fabricated by selective replication

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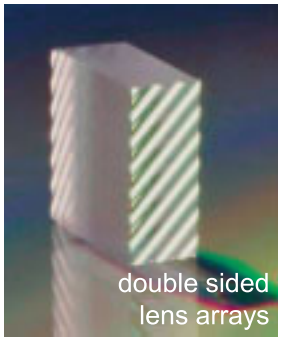
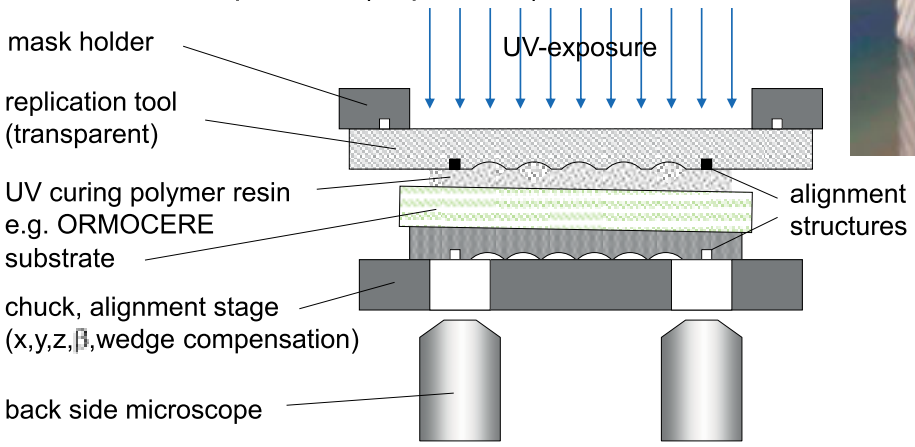
Tailored Light - Licht nach Maß

Production Technology: Polymer on glass

- tool: MA6 mask-aligner (SUSS Microtec)
- double sided replication by UV-reaction molding
- highly precise alignment of both sides
- 6” wafer scale process (8” planned)





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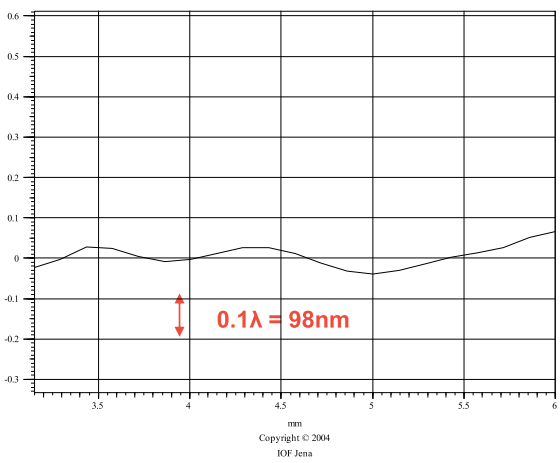
Tailored Light - Licht nach Maß

Microoptics with nanometer accuracy

Residual wavefront deformation



rms value in units of wavelength λ for different samples on the wafer, (measured at 980nm)

rms pv	0,03512 0,1772	0,0502 0,2820	0,03533 0,2671
rms pv	0,04027 0,218	0,05449 0,3169	0,03233 0,1956
rms pv	0,04164 0,1839	0,04827 0,3286	sample holder

Nanometer wavefront accuracy!

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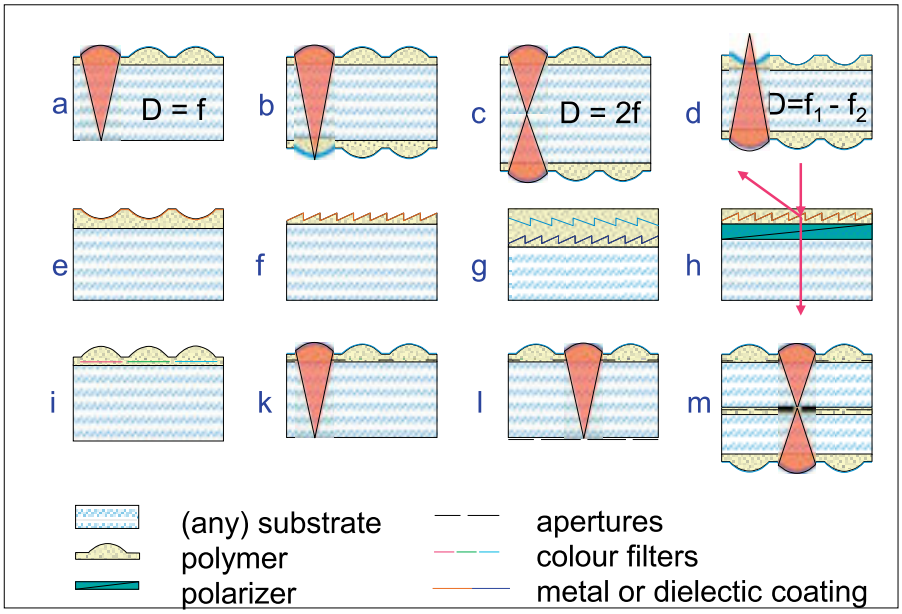
Wafer-scale micro-optical modules - examples



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Kollimationslinsenarrays für Faserschalter 1xN, MxN

hohe Kanalzahlen (1x32, 1x64, 16x16,
laterale Präzision (CTE matching)

→ORMOCER/ Polymer auf B33 Glas

Alternative Technologien
→ Geätzte (RIE) Linsenarrays in B33 (CTE=3.3E6/K)
→ RIE Linsenarrays in Si
→ Glaslinsenarrays durch Glaspressen
→ Stumpfe Kopplung von Fasern (Brennweite ~ Substratdicke Array)

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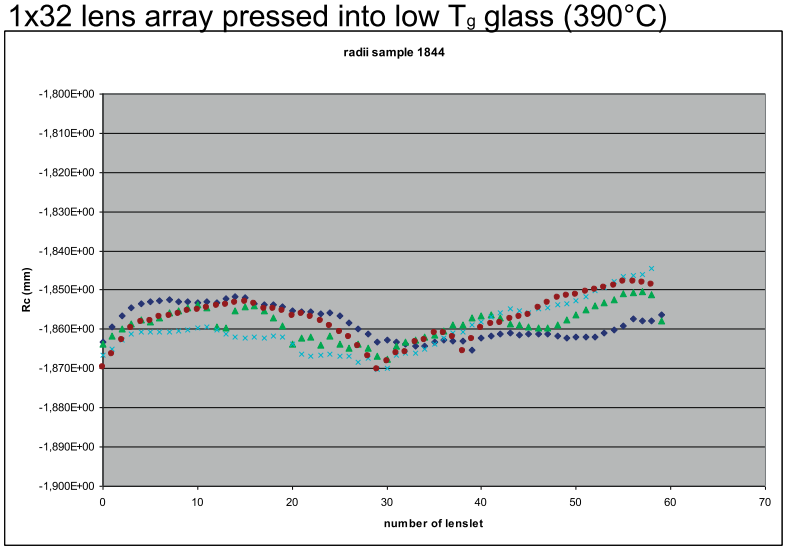
Also: collimation lenses by **glass molding**

1x32 lens array pressed into low T_g glass (390°C)



CTE matching!

Shrinking !

homogeneity lenslet radii across wafer is +-0.5% (4 different scans)

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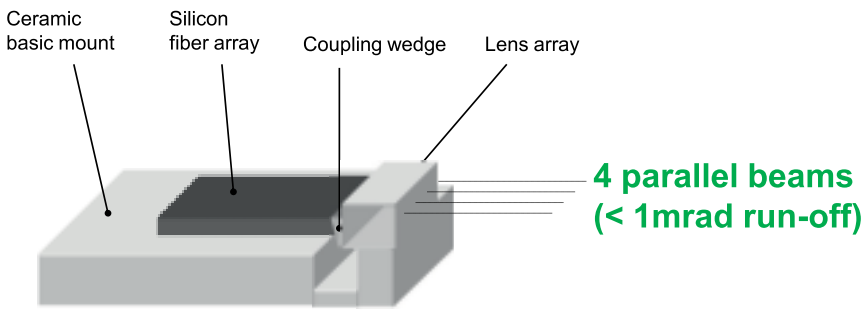
Lens array coupled to fiber array:

- angle polished fiber array (reduction of back reflection)
- Coupling wedge between fiber array and lens array, direct gluing for high mechanical stability



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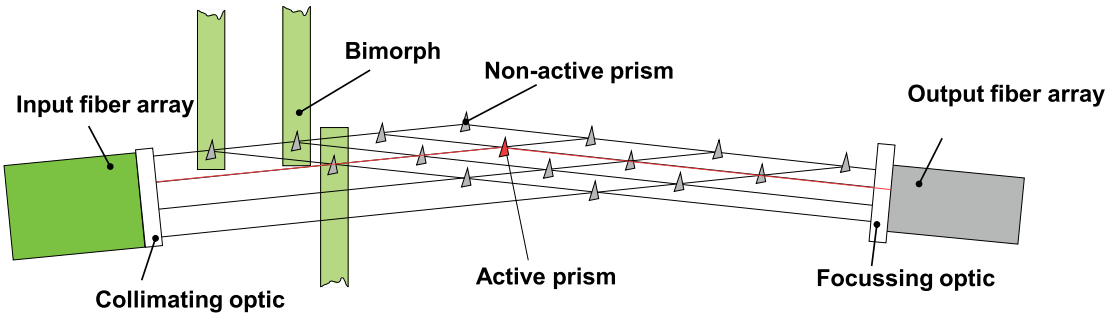
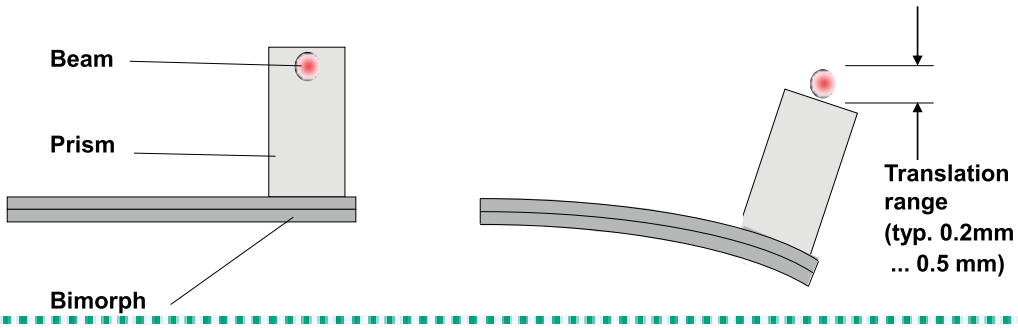
Beam deflection by microprisms (4 x 4 switch)





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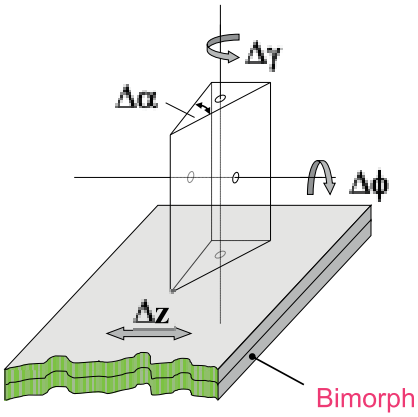
Microprism parameters and mounting tolerances:

- Δz = +/- 150 µm
- $\Delta\alpha$ =0.05° (Variation between all prisms in the switch)
- $\Delta\phi$ = 0.3°
- $\Delta\gamma$ = 2.5° in case of minimum deflection angle condition



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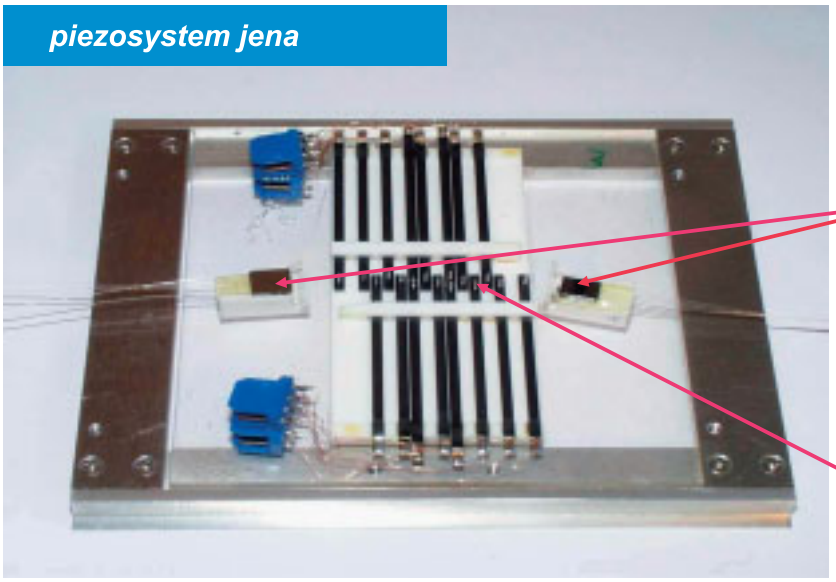
Tailored Light - Licht nach Maß

4 x4 switch matrix module



Completely assembled 4 x4 switch matrix module

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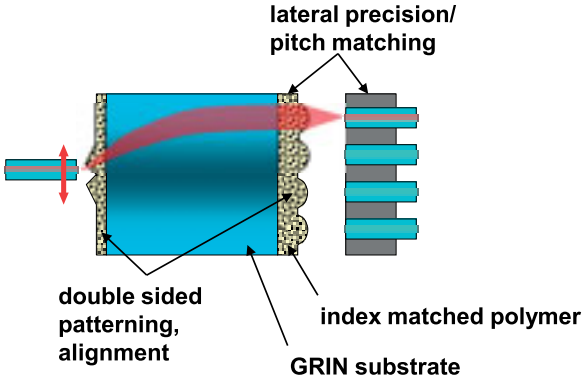
Tailored Light - Licht nach Maß

Compact 1 x N switching

- lateral precision/ pitch matching
- index matching
- stability requirements
- low birefringence



~~injection moulding/ diamond machined tools~~

lithographic patterning → resist forms (lenses, prisms)
UV-moulding, inorganic-organic copolymer
or RIE proportional transfer

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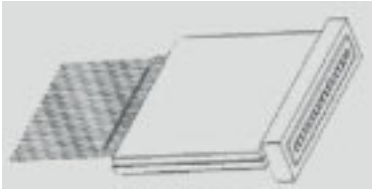
Tailored Light - Licht nach Maß

Lens arrays for collimation of fiber array output

All Pyramid Optics' collimator arrays are constructed with a silicon V-groove fiber array mounted with microlens array.
The microlens arrays are replicated in a ORMOCER thin film on a BK7 glass substrate.
The new collimator arrays are offered for several wavelength regions: 630 – 690 nm; 780 – 850 nm and 1250 1650nm.

Other wavelengths are possible on request.

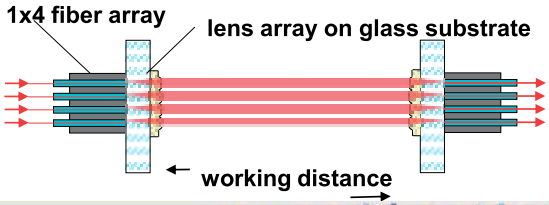


Features

no. of channels	up to 16
beam separation	0.5mm
microlens focal length	1.6mm
beam diameter	300µm, max.
back reflection	<-65dB
insertion loss (collimator pair)	<0.7dB
working distance	40mm, max.
run-off between beams	1 mrad, max.

Applications

- Switches
- Splitters
- OADM
- Parallel measurement systems



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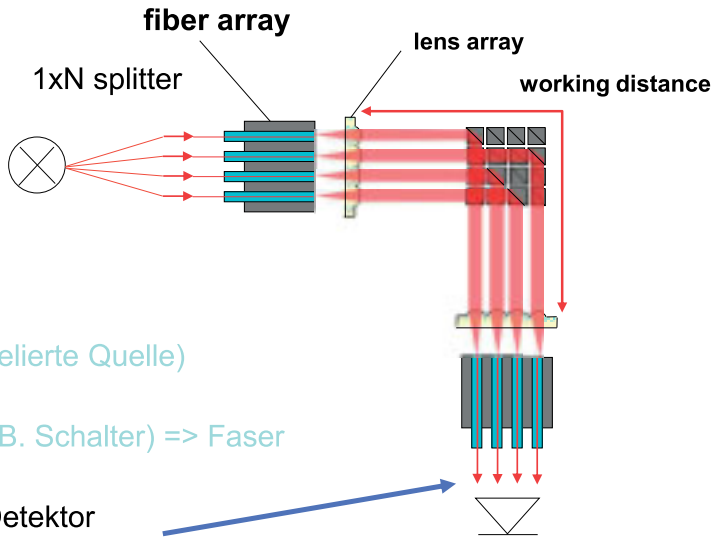
pyramid optics
... we move light

Tailored Light - Licht nach Maß

Mikrooptik für photonische Verbindungstechnik

Wesentliche Koppelstellen



- Quelle => Faser
- NxM-Splitter (oder pixelierte Quelle)
- Faser => Freiraum (z.B. Schalter) => Faser
- Faser / Freiraum => Detektor

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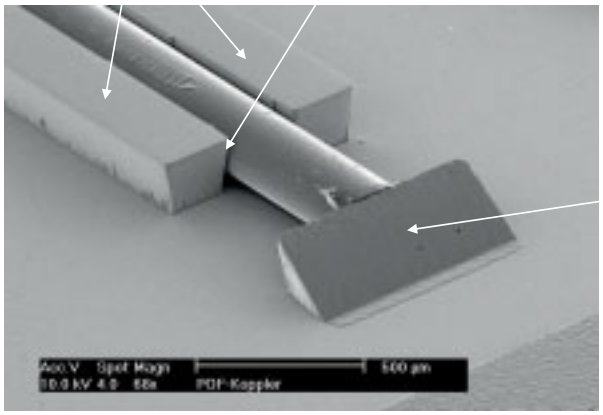
Combined uv-replication and selective photopolymerization

- Multimode waveguides, fiber clamps + deflection prism

thin film features

undercut
(not possible with replication)



replicated surface (not possible with thin film technology)

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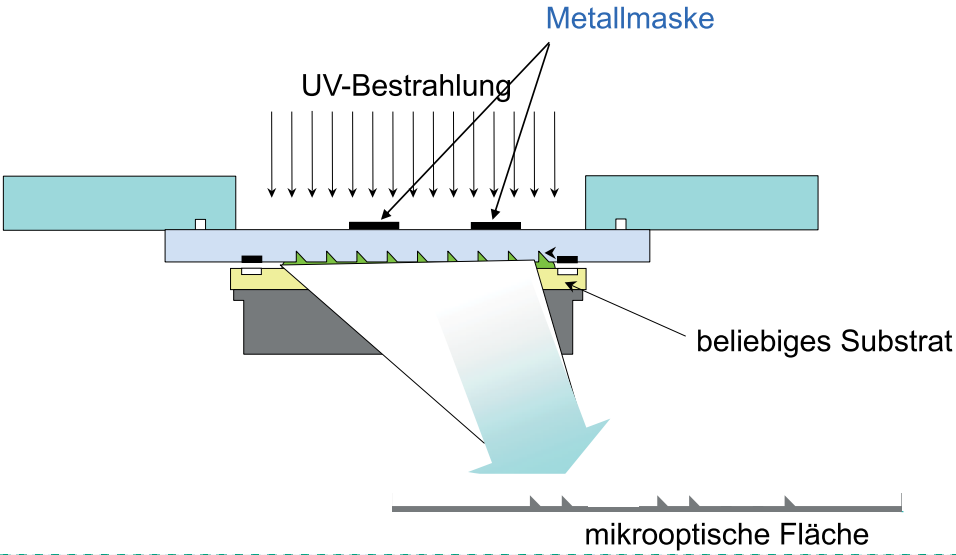
Tailored Light - Licht nach Maß

Selektive UV- Replikation - Technologie

bei einseitiger **mikrooptischer Strukturierung**:



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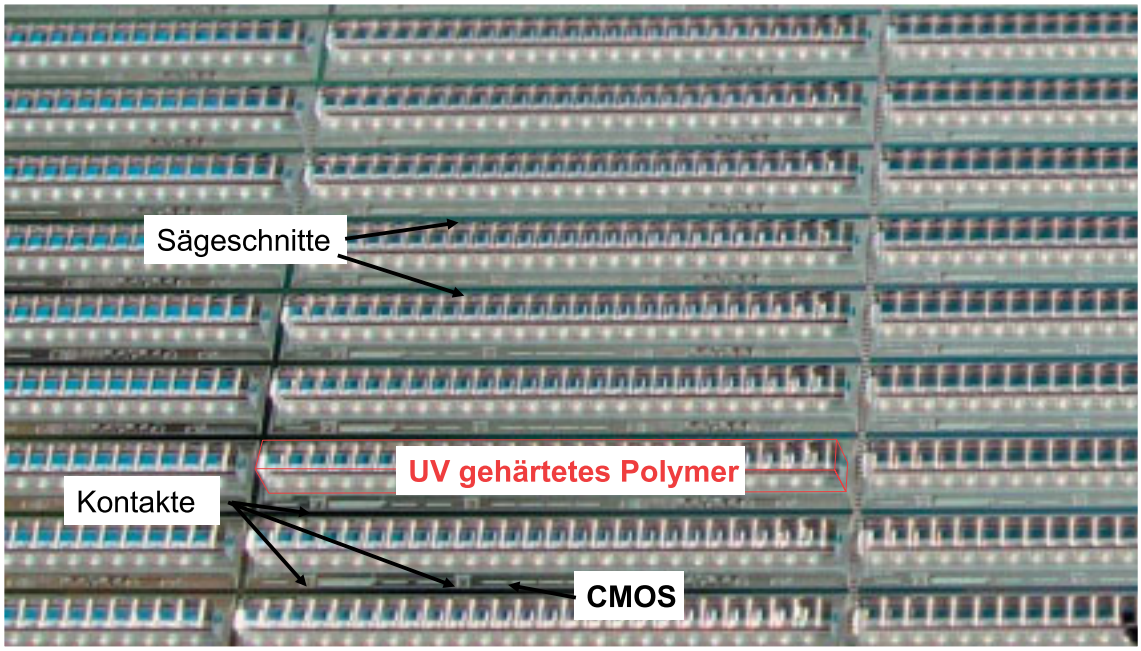
Tailored Light - Licht nach Maß

Selektive UV Replikation auf CMOS Siliziumwafern



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Photonische AVT
Wernigerode 2009

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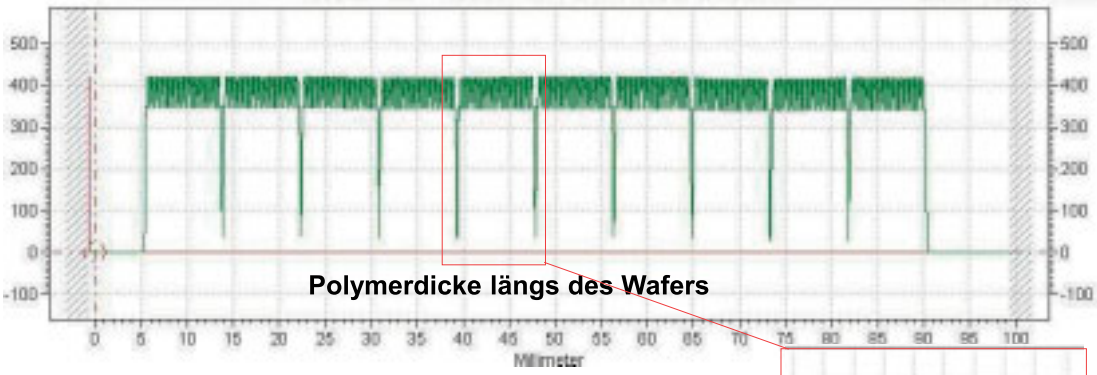
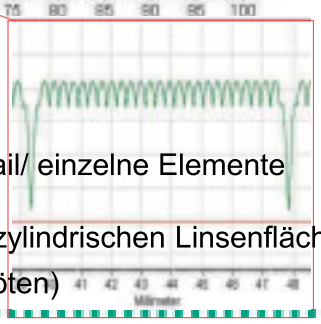
Tailored Light - Licht nach Maß

Selektive UV Replikation auf CMOS Siliziumwafern



- gleichmäßige Polymerdicke ~400µm
- Linsenhöhe ~80µm
- homogene UV-Härtung/ Brechungsindex
- vereinbar mit nachfolgenden Prozessen:
  - Sägen
  - Bonden
  - Thermische Belastung (z.B. ~150°C/ aushärten oder löten)



Detail/ einzelne Elemente

mit zylindrischen Linsenflächen

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Photonische AVT
Wernigerode 2009

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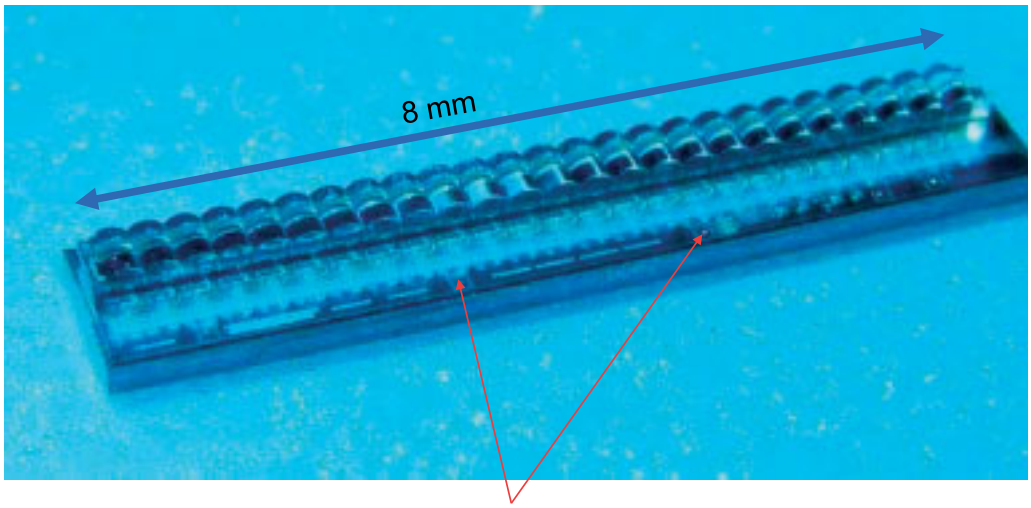
Tailored Light - Licht nach Maß

Selektive UV Replikation auf CMOS Siliziumwafern

einzelne CMOS- Bausteine + Linsenanordnung



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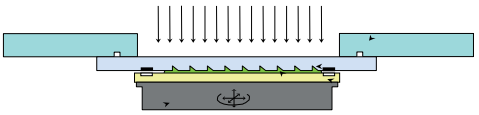
Tailored Light - Licht nach Maß

Zusammenfassung

Polymer-auf-Glas(POG)-Technologie sehr gut geignet für photonische Verbindungstechnik **höchster Präzision**

Technologie (UV-Replikation)

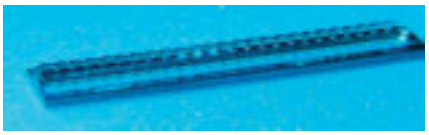


Geeignete Materialien verfügbar (z.B. ORMOCERE, lötbar!)

Technologie geeignet sowohl für Wellenleiter, als auch einseitig und doppelseitig UV-replizierte Mikrooptiken

Selektiv UV-replizierte Mikrooptiken

z.B. Konzentratoren für CMOS-Empfänger



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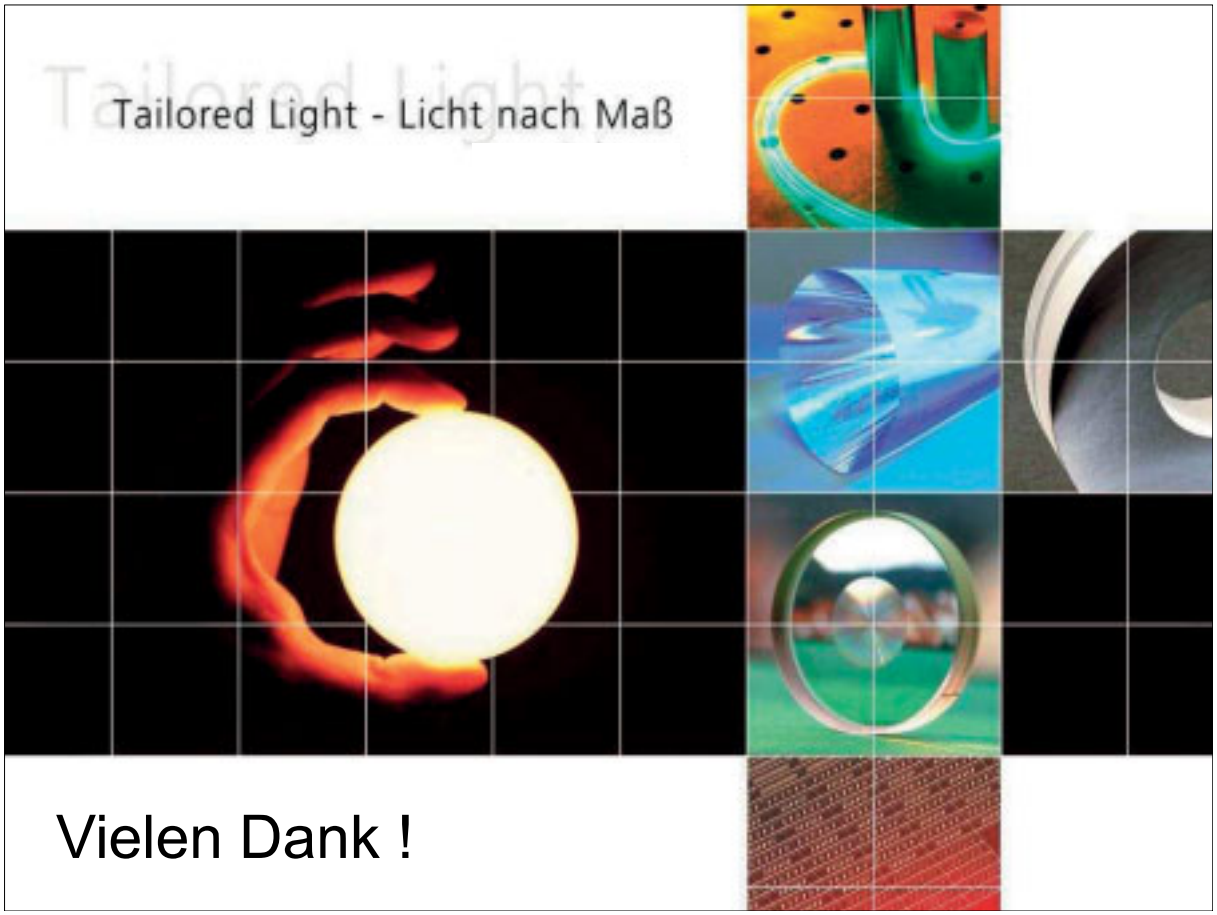


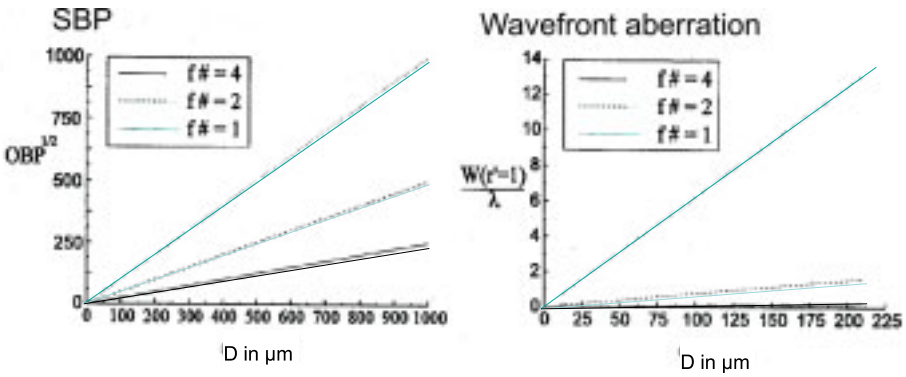
Criteria for optical systems: Space bandwidth product (SBP)

Number of non interacting data channels

=> equal to number of resolvable image points in the image plane

$$SBP = \frac{Lens\ area}{PSF} = \frac{D^4}{(2\lambda f)^2}$$

f#=f/D



SBP ⇔ Aberrations: contradicting dependencies on size of optical elements

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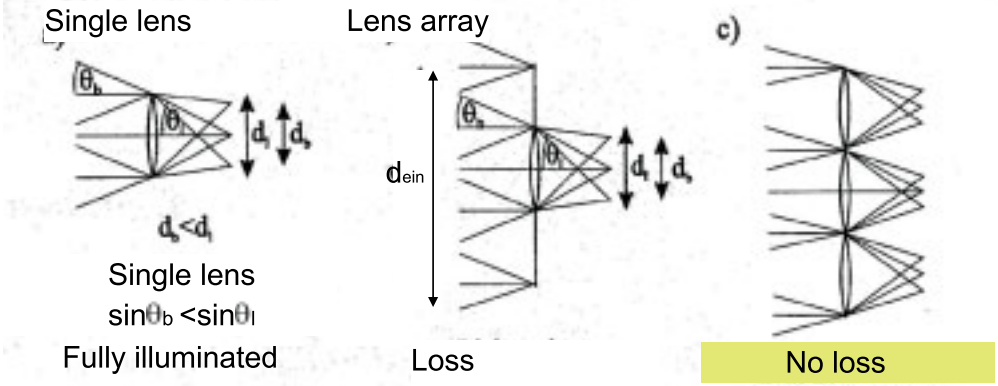
Microoptical systems: high SBP by parallel processing

Tailored Light - Licht nach Maß



$$SBP_{out} = \frac{d_l^2}{d_{in}^2} SBP_{in}$$

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Demands to free space microoptics - technologies

Tailored Light - Licht nach Maß

Controllability	Optical and geometrical parameters (focal length, NA,...) determined by optical design must be realized
Accuracy	The parameters must vary only within the allowable tolerances defined by the application (e.g. pitch accuracy <0.5µm,..)
Uniformity	The elements of microoptical arrays may have only a certain deviation from the mean parameter (e.g. 1% focus homogeneity over 4“ distance,...)

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Content „Microoptical Technologies“

Tailored Light - Licht nach Maß

1. Explanation „Microoptics“
2. Background and scaling of optical parameters
   - 2.1 Free space microoptics
   - 2.2 Guided wave optics
3. Microoptical Technologies
4. Application examples: microoptical elements and systems

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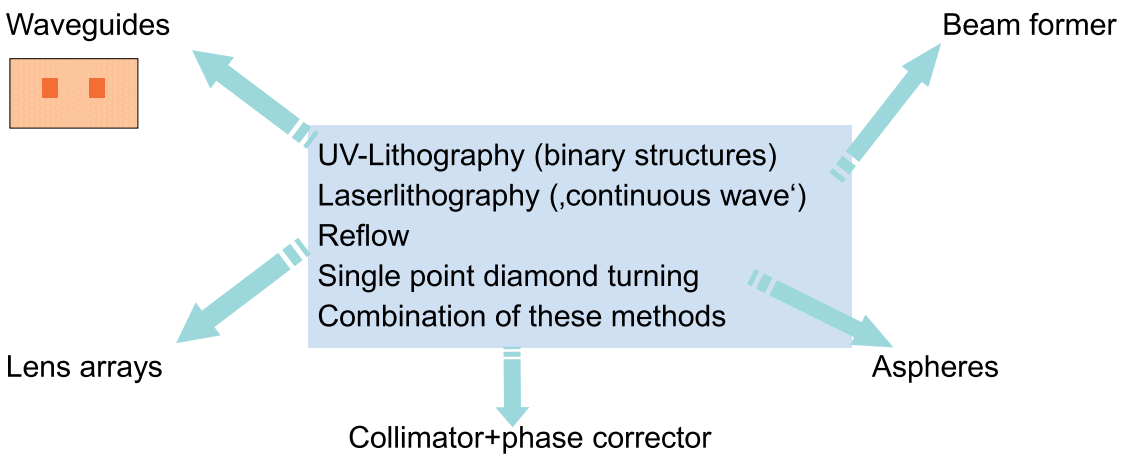
ORIGINATION for precise microoptical elements

Tailored Light - Licht nach Maß



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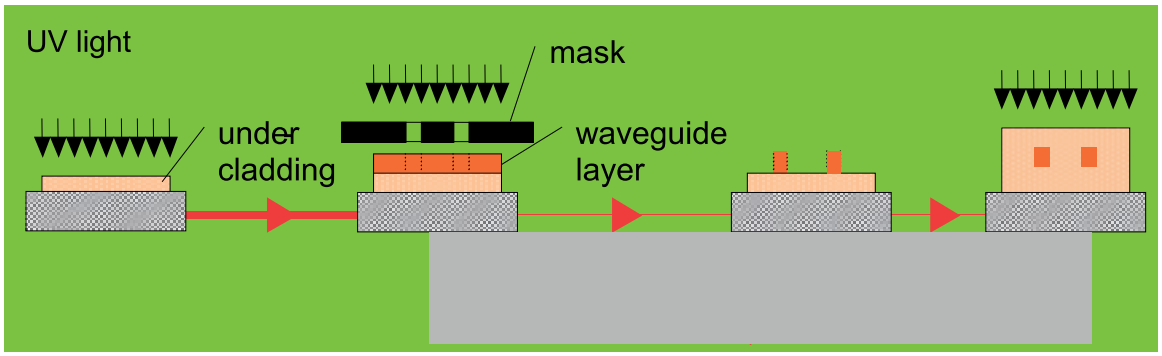
Binary structures - waveguide fabrication by UV-lithography

Tailored Light - Licht nach Maß



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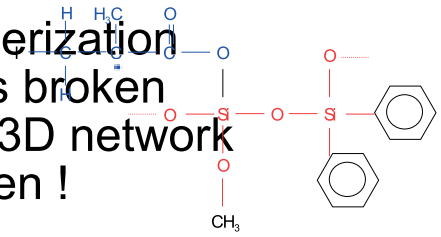
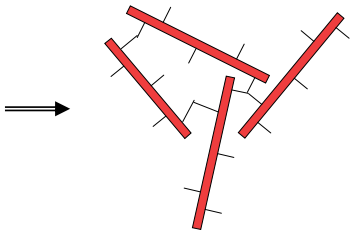
Photolithography: UV-induced polymerisation

Tailored Light - Licht nach Maß

Example: UV-curable polymer: ORMOCER B59

- UV curing of B59:
  - free radical polymerization
  - C-C double bonds broken
  - polymerization in 3D network
  - inhibition by oxygen !





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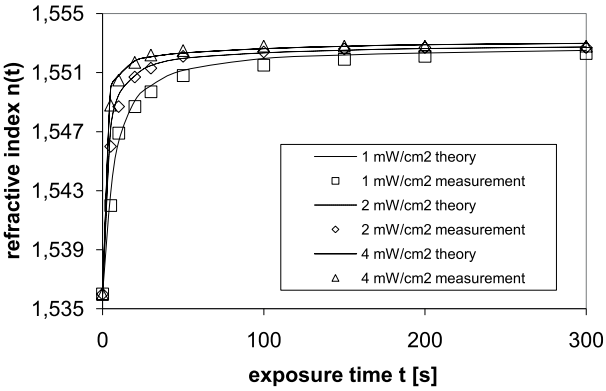
UV-induced refractive index change

Tailored Light - Licht nach Maß



➢ dose E*t is

E: exposure i

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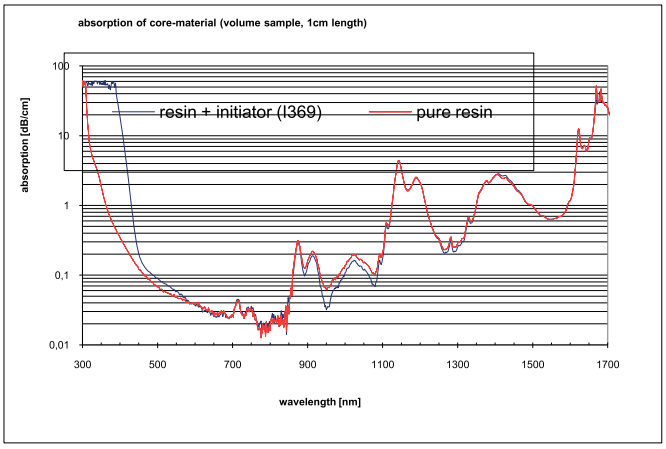
Important: low material absorption

Tailored Light - Licht nach Maß

ORMOCER® : Attenuation (NIR)

- reduction of Si-OH groups
- no fluorination (core material)
- optimized size of Si-O-Si backbone (catalysts, process temperature)
- 0.5 – 0.6 dB/cm @ 1550 nm



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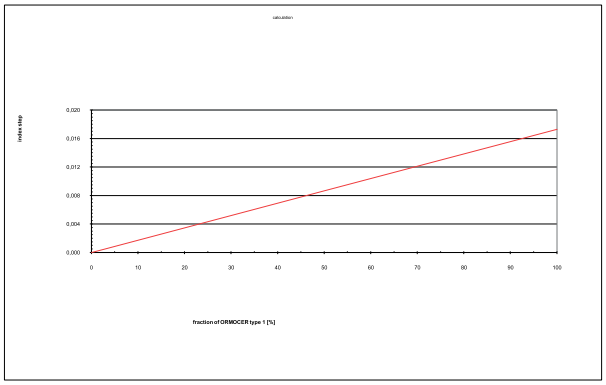
Refractive index tuning

Tailored Light - Licht nach Maß

ORMOCER® : Index tuning properties

- mixing compounds
- tuning range from 1.47 to 1.56



Mixture of ORMOCER types 1 and 2

ORMOCER® : General properties

- temperature stability up to 300°C
- good adhesion (e.g., to silicon, glass, FR4)

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ORIGINATION for precise microoptical elements

Tailored Light - Licht nach Maß

Waveguides

Beam former

UV-Lithography (binary structures)
Laserlithography (‚continuous wave')
Reflow
Single point diamond turning
Combination of these methods

Lens arrays

Aspheres

Collimator+phase corrector

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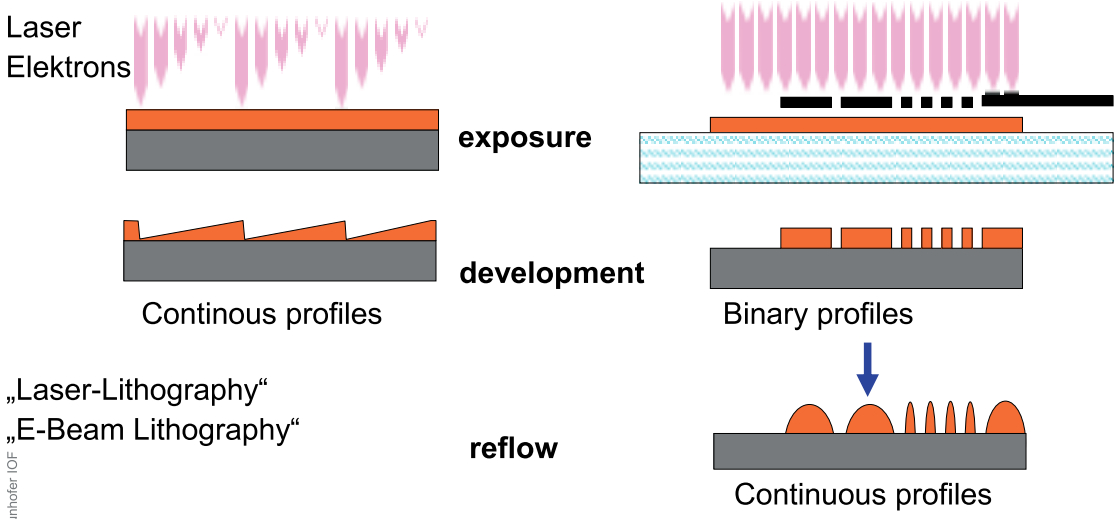
Two types of lithography for microoptical surfaces

Tailored Light - Licht nach Maß

Process: UV (or electron)-induced (de)-polymerisation

A: dose dependent penetration

B: conventional UV-lithography



„Laser-Lithography“
„E-Beam Lithography“

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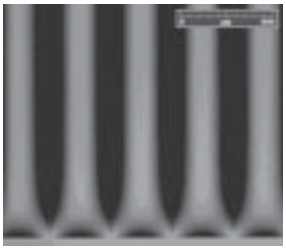
UV-Lithography + Reflow -Technology

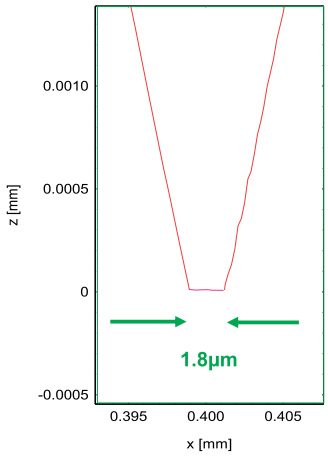
Tailored Light - Licht nach Maß

Reflow-Process

Example: cylindric lens array



99,5% fill factor



→ Minimal surface

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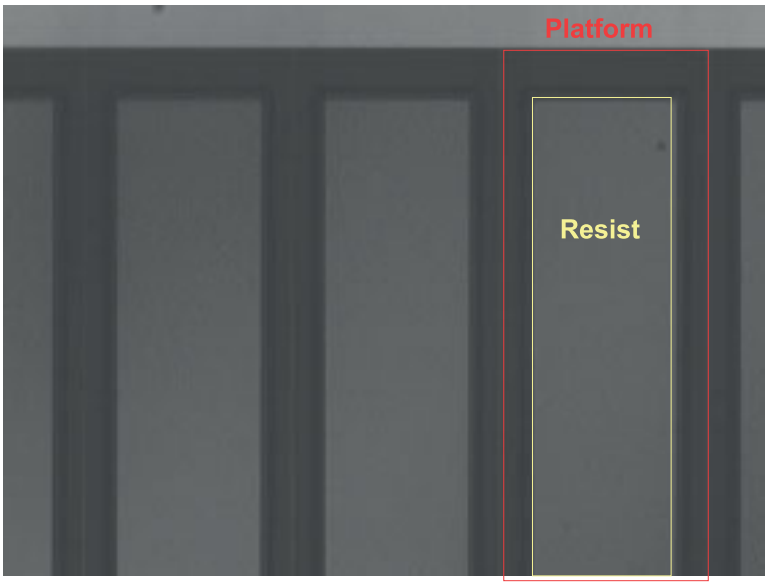
Tailored Light - Licht nach Maß

Origination for cylindric microlenses



Photolithographically patterned resist
– subsequent reflow

Edges defined by platforms
in the substrate

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Tailored Light - Licht nach Maß

2. PIFSO Artikel

Abformung refraktiver und diffraktiver Elemente für Jahns-Variante
Polymer auf Glas hier fast einzige Realisierungsvariante

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40 GHz bis 100 GHz Bonding und Packaging

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ABSTRACT

Anhand eines am Fraunhofer Heinrich-Hertz-Institut entwickelten und aufgebauten Höchstfrequenz-Photodetektormoduls in InP-Technologie wird die Problematik und Lösung der „face-up"-Technik für Grenzfrequenzen von 40 bis 100 GHz diskutiert.

Keywords: RF-Bonding, Coplanar-Waveguide, V-Connector, RF-Packaging

1. EINLEITUNG

In der nach immer höheren Datenraten bestrebten Entwicklung von Halbleitern für zukünftige Tele- und Datenkommunikation steht die photonische Auf- und Verbindungstechnik vor immer neuen Herausforderungen. Klassische Technologien treffen bei Grenzfrequenzen oberhalb 40 GHz an ihre Schranken [1,2]. Neuere Technologien der Aufbau- und Verbindungstechnik sind in der Regel aufwändig und hierdurch mit hohen Kosten behaftet.

Eine Schlüsselkompetenz des Heinrich-Hertz-Instituts sind monolithisch integrierte und auf Höchstfrequenz ausgelegte Halbleiter. Beim Packaging von Vor- und Kleinserien sind aufwändige Auf- und Verbindungstechniken durch intelligenten Einsatz von klassischen Techniken zu meiden. Durch genaue Betrachtung von physikalischen Gegebenheiten der Leitungstheorie sind am FhG-HHI hierfür wirtschaftlichere Packagingkonzepte entwickelt worden. Diese finden beim Packaging, von verschiedenen Modulen für Grenzfrequenzen von 40 GHz bis 100 GHz, erfolgreich Anwendung. Im Folgenden wird das Packaging-Konzept, mit der zu realisierenden Kontaktierung des Chips zum 1mm-Koaxialstecker und die Faser-Chip-Kopplung anhand des HHI-Detektormoduls beschrieben.

2. FHG-HHI PHOTODETEKTORMODUL

Das HHI-Detektormodul basiert auf InP und beinhaltet eine pin-Photodiode (PD) mit lateraler Lichtzuführung via integriertem Wellenleiter, einen Spot-Size-Konverter für eine effektive Faser-Chip-Kopplung und einen definierten Wellenwiderstand von 50 Ω am Chipausgang. Hierdurch ist eine Detektion von optischen Signalen bei sehr hohen Datenraten möglich. Der Chip ist für die charakteristische Telekommunikations-Wellenlänge von 1,55µm ausgelegt und wir über ein integriertes Bias-Netzwerk versorgt.

Aufgrund der lateralen Zuführung des optischen Signals zur GaInAsP/GaInAs Heterostruktur-Absorptionsschicht sind Grenzfrequenzen über 100 GHz erfolgreich

realisiert. *Abbildung 2.1- links* zeigt das Chip-Konzept mit der stossgekoppelten Glasfaser und der koplanaren GSG-Anschlussstruktur. Auf der rechten Seite ist das assemblierte Photodetektor-Modul abgebildet.

Abbildung 2.1 *PD-Integrationskonzept / assembliertes Modul mit Faserpigtail*

Die Herausforderung an die photonische Aufbau- und Verbindungstechnik stellt hier die Faser-Chip-Kopplung, die Versorgung mit der Bias-Spannung und vor allem die Führung des elektrischen HF-Signals an die 1mm-Koaxialbuchse dar. Dabei soll nach dem Packaging die Performance des Moduls möglichst den Ergebnissen der „on-Wafer“ Vorcharakterisierungen entsprechen. Vorteile von geringen parasitären Induktivitäten und eine hohe Packungsdichte der „face-down“-Flip-Chip-Technik (FC-Technik) soll so gut wie möglich in „face-up“-Technik erreicht werden.

3. HOCHFREQUENZASPEKTE DER LEITUNGEN

In diesem Abschnitt wird die HF-Vorarbeit erörtert. Hierfür wurden am Institut Simulationsmodelle entwickelt und Versuchsmodule aufgebaut und untersucht.

Ziel der Arbeit war der Erhalt der Vorteile der Flip-Chip-Technologie. Hier soll die elektrische FC-Kontaktierung des Halbleiters mittels Bumps, mit dem Vorteil der Minimierung der parasitären Induktivitäten, durch den Einsatz des „klassischen“ Bonddrahts ersetzten werden. Die Zuführung des elektrischen HF-Signals wird als impedanzkontrollierte Koplanarleitung (Coplanar Waveguid, CPW) zum Pin des HF-Steckers realisiert.

3.1 Simulation der Bonddrähte

Zur Bestimmung der optimalen Bonddrahtparameter wurde das Simulationstool „High Frequency Structur Simulator (HFSS)“ der Fa. ANSOFT verwendet. Simulationsmodelle wurden erstellt und hinsichtlich der Bonddrahtanzahl und ihre Positionierung variiert. Die Ergebnisse zeigt *Abbildung3.1.1*.

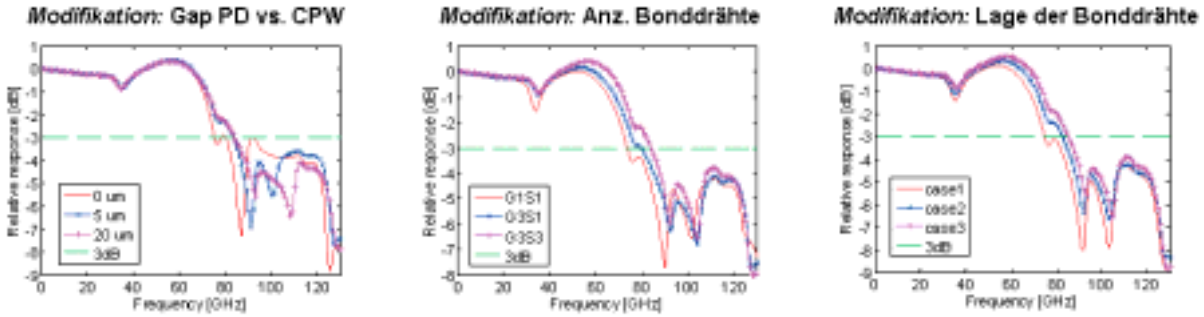


Abbildung 3.1.1 *Modifikation: PD-Gap vs. CPW / Anz. Bonddrähte / Lager der Bonddrähte*

Die Simulationsergebnisse zeigen, dass beim Aufbau die Chip-CPW-Lücke nicht größer als 20µm sein soll – *Abbildung 3.1.1- links*. Die Anzahl von drei enganliegenden Bonddrähten je Pad ist ausreichend – *Abbildung 3.1.1 – mittig und rechts.* Darüber hinaus wurde die Anzahl von drei Bonddrähten als simulationstechnisch gleichwertig zum Ribbon-Bonding gezeigt.

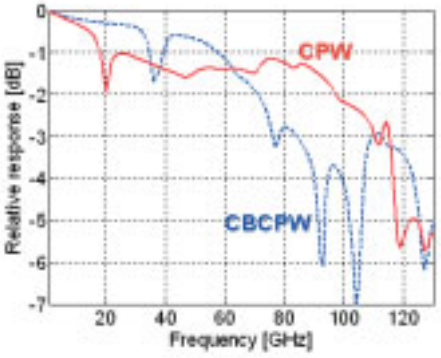
3.2 Simulation Koplanarleitung

Beim Übergang vom Chip zum HF-Stecker wird eine Koplanarleitung verwendet. Auf eine Microstrip-Leitung, trotz erzielbarer Kostenersparnis, wurde wegen dem Verhältnis der Substratdicke zur Leiterbreite (Wellenwiderstand) verzichtet. Darüber hinaus sind mit Koplanarleitungen Grenzfrequenzen über 300 GHz erreichbar [4].

Bei dem Simulationsablauf mit der HFSS-Software, wurde eine CPW-Struktur mit Aluminiumoxid-Subtrat berechnet. Darüber hinaus wurden Koplanarleitungen mit Rückseitenmetallisierung (CBCPW), Rückseitenmetallisierung mit Viaholes und Aussenmassekontaktierung untersucht. Als zweckmäßigste Leitungsart stellte sich die CPW-Struktur ohne Rückseitenmetallisierung dar. Eine Optimierung dieser Leitungsart konnte zusätzlich durch den Austausch des Aluminiumoxid-Subtrats mit Quarz-Substrat erzielt werden.

3.3 Dimensionierung der Leitungen

Durch Variation der Simulationsparameter, speziell der Bondrahtverbindungen vom Chip zur Koplanarleitung und der physikalischen Parameter, wurden folgende Ergebnisse erzielt.



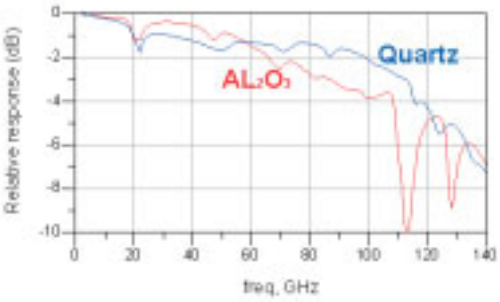


Abbildung 3.1.1 *Relative Responsivität vs. Frequenz: CPW vs. CBCPW / AL_2O_3 vs. Quarz*

In der *Abbildung 3.1.1 – links* zeigt sich die Verbesserung der relativen Responsivität der Koplanarleitung ohne Rückseitenmetallisierung ab 85 GHz bis 110 GHz. Rechts in der Abbildung ist das Simulationsergebnis „Quarzsubstrats vs. AL_2O_3-Substrat“ dargestellt. Mit dem Austausch von Aluminiumoxid durch Quarz ist eine Verbesserung im oberen Frequenzbereich zu erzielen. Das bessere Abschneiden des Aluminiumoxids im unteren Frequenzbereich ist zu vernachlässigen. Die Maße der GSG-Streifenleitung wurden aufgrund der ermittelten Gruppenlaufzeit optimiert. Zur Modenanpassung an die Koaxialleitung wurde die Streifenleitung getapert.

4. PRAKTISCHE UMSETZUNG

Das Packaging ist in der *Abbildung 4.1* dargestellt. Der Aufbau des Fotodetektormoduls erfolgt in einem vergoldeten FhG-HHI-Standard Messinggehäuse. Auf ein Submount wird die CPW unterhalb des Pins des Koaxial-Steckers geklebt. Die Pin-CPW-Kontaktierung wird mit einem leitenden Kleber realisiert. Die Ground-Leitungen der CPW werden mit demselben Kleber mit dem Gehäuse in Kontakt gebracht. Es folgt das Einkleben des Chips mit der nötigen Genauigkeit von $\leq$ 20µm zur CPW-Leitung. Zur Untersuchung der Toleranzgrenzen kommt ein Mikroskop mit Messeinheit zum Einsatz. Sind die Abstände innerhalb der vorgegebenen Toleranzen, wird das Modul zum Aushärten der Klebestellen für mehrere Minuten auf eine Temperatur von 150ºC erhitzt. Die Bonddrähte, je drei pro Pad, werden mit einem 30º-Golddrahtbonder (Wedge-Bonder) gesetzt. Die Faser-Chip-Kopplung erfolgt mittels eines Sechs- und Dreiachsen-Mikromanipulatortisches. Die zu kopplende Faser wird zu Beginn in eine Glass- oder Metallferrule eingeklebt und vor der Chipfacette mit einem Gripper positioniert. Die optimale Position der Faser zum Chip wird durch das Abfahren der Chip-Facette ermittelt und mit UV-Kleber stossgekoppelt geklebt. Weiterhin wird die Faser wahlweise mit zwei Glasblöcken mit dem Gehäuseboden oder in ein V-Nut-Substrat geführt geklebt.

Der Einbau der PI-Filter, Pins und der Leitungskeramik erfolgt mittels Standardlöten bzw. Kleben mit nichtleitendem Kleber vor der Faser-Chip-Kopplung und wird hier nicht weiter beschrieben.

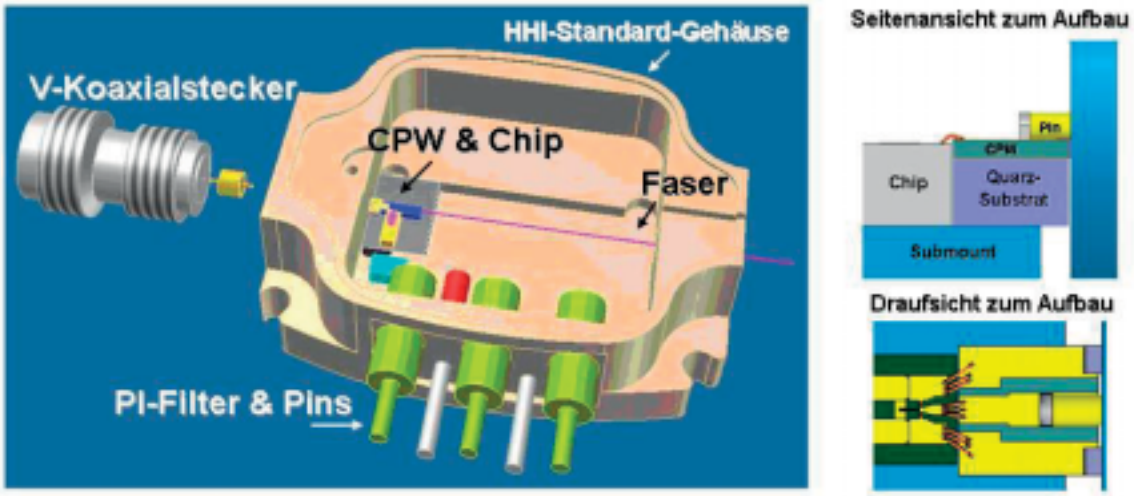


Abbildung 4.1 *CAD-Zeichnung des PD-Moduls / Seiten- und Draufsicht zum Aufbau*

Die realisierten Module zeigen bei Messungen gute Grenzfrequenzen. Weiterhin ist der Aufbau im Vergleich zur FC-Technik kostengünstiger, überschaubarer und schnell neuen Vorgaben anzugleichen. Aufwändige Koplanar-Strukturen werden nicht benötigt. Ein weiterer Vorteil ist die Möglichkeit der verschiednen Faserfixierungstechniken, die je nach Lage der zu fixierenden Faser genutzt werden können.

Die folgende Abbildung zeigt den Unterschied in den Simulationen der angewandten Bond-Technik zur FC-Technik. Der Frequenzverlauf zeigt, dass die beschriebene Aufbau- und Verbindungstechnik der FC-Technik ebenbürtig ist.

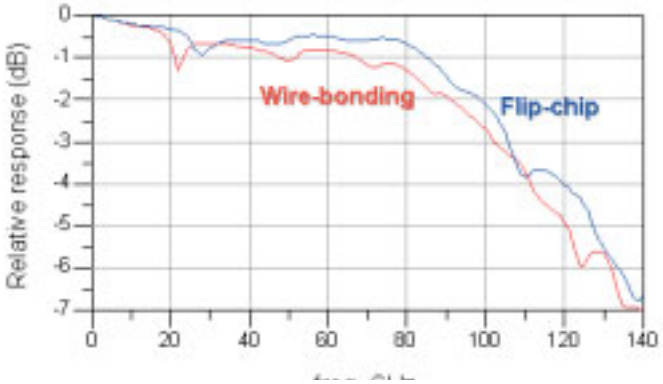


Abbildung 4.2 *Wire-Bondig vs. FC-Technik*

5. ZUSAMMENFASSUNG DER ERGEBNISSE

Ein Photodetektor-Modul mit integriertem Wellenleiter und Pin-Photodiode wurde erfolgreich in „face-up"-Technik simuliert, aufgebaut und gekoppelt. Das Modul beinhaltet einen 1mm-Koaxialstecker, der via einer definierten CPW-Leitung mit dem Chip verbunden ist. Der Aufbau ist mit 50 Ω impedanzkontrolliert. Die Anwendung der hier gezeigten Technik eignet sich für Versuchs- und Kleinserien monolithisch integrierten Halbleiter im Frequenzbereich von 40 GHz bis 100 GHz.

Im Institut aufgebaute und gemessene Module zeigen gute Bandbreitenergebnisse. Die erzielten Ergebnisse demonstrieren das Potential der „face-up“-Technologie für den Einsatz in Modulen mit sehr hohen Grenzfrequenzen.

DANKSAGUNG

Ich danke Herrn Chenhui Jiang (University Denmark) für die HFSS-Simulationen und den Kollegen D.Pech, Dr. T.Rosin, Dr. H.-G. Bach, G.G. Mekonnen und Herrn R. Zhang des FhG Heinrich-Hertz-Institutes für Chip- und HF-Design sowie Charakterisierungen.

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Solderjet bumping for the assembly of optical fibers

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ABSTRACT

Further miniaturization of 3D-integrated hybrid optical systems on smart system platforms requires a fast and flexible joining technology that overcomes limitations of standard bonding processes in optics. Laser-based solder bumping with its complete integration of solder alloy preform handling, reflowing and application of the solder volume simplifies the joining process and enables for flux-free soldering of micro-optical components with localized and time restricted energy input within a local nitrogen atmosphere. Solder joints provide increased mechanical strength, a higher long term, thermal and radiation stability and good thermal and electrical conductivity compared to polymeric adhesives commonly used for optical bonding. A demonstrator system of a fiber-coupling unit using a polarization maintaining optical fiber (PMF) that is soldered to a V-groove by solderjet bumping with submicron accuracy is described in this work. The development of a device for batch PVD-metallization of the fibers for the creation of necessary wetting surfaces and a miniaturized mechanical gripper enabling for both translational adjustment and the axial alignment of the fiber at the joining geometry is reported.

Keywords: Micro assembly, micro manipulation, micro-optical system integration, solder bumping, laser beam soldering, lead-free solder, optical fiber

1. INTRODUCTION

Fiber-optical assemblies with polarization maintaining fibers (PMF) are used in applications in the fields of information and communication technology, medical engineering as well as measurement and sensor engineering. Hybrid system integration of optical, mechanical and electrical components utilizing precise assembly technologies can provide means for miniaturization of complex optical assemblies on smart system platforms, e.g. on ceramic printed circuit boards made of Low Temperature Cofired Ceramics (LTCC). Challenging tasks for assembly of a demonstrator system are the preparation and handling of the fibers including a high precision miniaturized fiber gripper for adjusting the translational and axial orientation of the principal axis of the PMF with respect to the assembly and the use of a long term stable and precise joining technology to maintain the adjusted position. Solder joints promise to overcome drawbacks of adhesive bonding in terms of mechanical

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strength and lower performance degradation over time, temperature cycling and radiation loads and allow for additional functionality due to the integration of mechanical, electrical and thermal contacting.

2. SOLDER BUMPING – PROCESS DESCRIPTION

Solder bumping is a laser-based soldering process that places bumps of a wide variety of soft solder alloys, e.g. tin-based lead free solders or eutectic gold-tin onto different substrates. It was primarily developed for flip chip interconnection of semiconductor devices, e.g. IC chips and MEMS. The solder bumping device integrates the process steps of handling of the spherical solder preforms with a diameter ranging from 100 µm to 760 µm, the reflow and the application to the joining geometry, thus increasing repeatability and enabling for a high degree of automation [1].

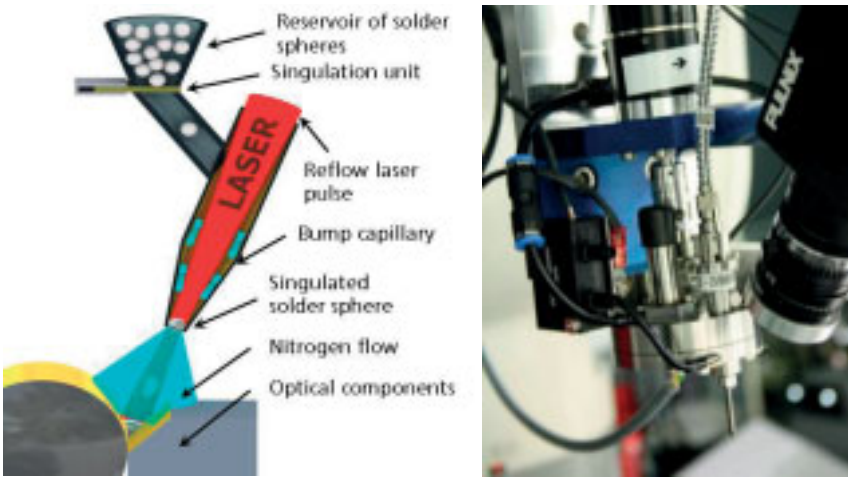

Fig. 1: Simplified schematics of the solder bumping bond head (left) and photograph of bond head with placement capillary, optical fiber and side mounted camera (right).

Fig. 1 shows the basic principle of operation. The solder spheres are separeted by a singulation unit and transferred from the reservoir to the bumping capillary with a conical end that has a slightly smaller diameter than the diameter of the solder balls, thus preventing the solder sphere from falling out of the capillary. With a separated sphere kept in place by the applied nitrogen pressure the bonding capillary is positioned next to the desired joining geometry by an articulated-arm robot or by means of a XYZ-gantry even in complex, miniaturized and highly integrated assembly environments. After positioning of the bond head and proper adjustment of the respective components the solder sphere is melted by means of a fiber coupled laser pulse (Nd:YAG, pulse width up to 25 ms, pulse energy up to 5 J). Due to the nitrogen pressure the liquid solder is then pressed out of the capillary and flying towards the designated joining area within a localized nitrogen atmosphere allowing for a flux-less process preventing the contamination of optical surfaces. Hitting the wetting surfaces of both component and substrate the liquid solder transfers its thermal energy and resolidifies forming the solder joint. The jetting of a liquid solder volume enables for the soldering of complex shaped geometries even from a distance of up to 6 mm and significantly improves thermal contact of solder alloy and component during the soldering process. These features overcome limitations known from preform and thin film solder layer-based laser soldering techniques that usually require a contact force and planar joining surfaces. Solder bumping shows to be a promising joining technology for the assembly of optical components to smart system platforms [2].

3. PREPARATION OF OPTICAL FIBERS

Soldering requires metallic wetting surfaces on the components and on the substrates. Due to the total length of an optical fiber compared to the small part to be metallized and the necessary circumferential metallization a specific apparatus is designed to allow for the batch metallization of 40 fibers per device and a total of 200 fibers in planar sputtering devices that are more common than specialized cylindrical sputtering chambers and that are capable to produce a multi-layer system in a single vacuum cycle, e.g. a Ti/Pt/Au wetting metallization system. After mechanical stripping of the coating and cleaning the fibers are mounted inside the fixture and are covered by a vapour shade mask. The cleaving of the fibers to produce optical end faces for coupling the laser light takes place after two sputtering runs from opposite directions that provide a sufficient circumferential metallization and allow for simplified handling and avoids damaging and contamination of the fibers during processing. The metallization does not interfere with wave guiding parameters of the fiber and allows for subsequent cleaving.

4. ADJUSTMENT AND SOLDERING

The assembly of a fiber-coupling unit using a PMF requires an adjustment of three translational degrees of freedom and of the rotational orientation of the principal axis of the PMF with regard to the laser diode. A miniaturized pneumatic actuated two-fingered gripper is developed utilizing a micro-machined V-groove at the PTFE-clad static finger and a corresponding moving finger with an integrated piezo-actuated stick-slip linear positioner. Fig. 2 shows the working principle: The fiber is held in the V-groove by the pressing force of the moving finger (F_G) and the linear movement of actuator and the corresponding force (F_A) is transformed to a rotation of the fiber by friction.

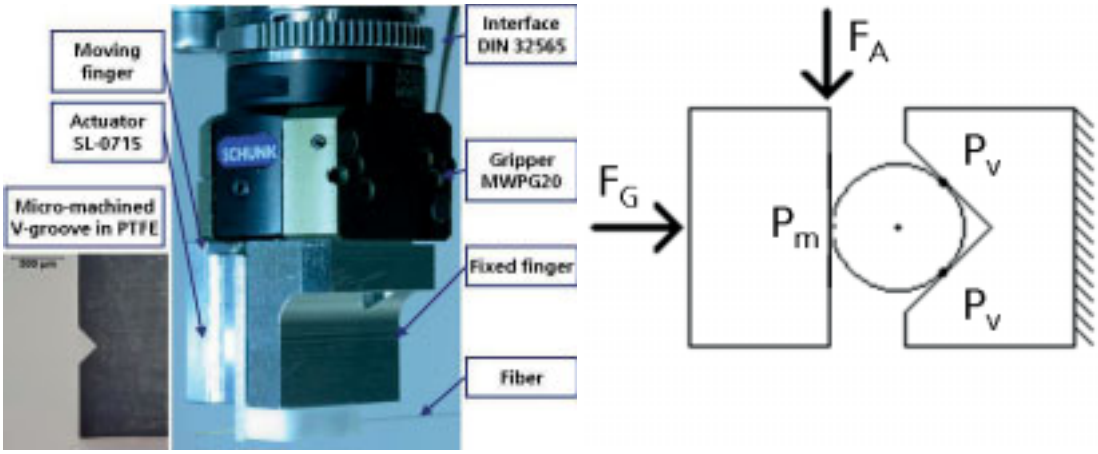

Fig. 2: Picture of the developed gripper and micro-machined V-groove (left) and simplified schematics of working principle; transforming the translation of the moving finger with the force of the actuator (F_A) via friction induced by the pressing force of the gripper (F_G) to a rotation of the fiber held in the V-groove (right).

The gripper with a diameter of 20 mm, a total height of 44 mm, a mass of less than 40 g and an interface in accordance to DIN 32565 can be operated in any installation position. The gripping force can be tuned up to 1.75 N at 2.25 Bar with a slope of 0.92 N/Bar and is set to 0.9 N for the handling of fibers. With an angular resolution of 0.2° and an adjusting range of more than 360° fibers can be gripped with a repeatability better than 1.5 µm.

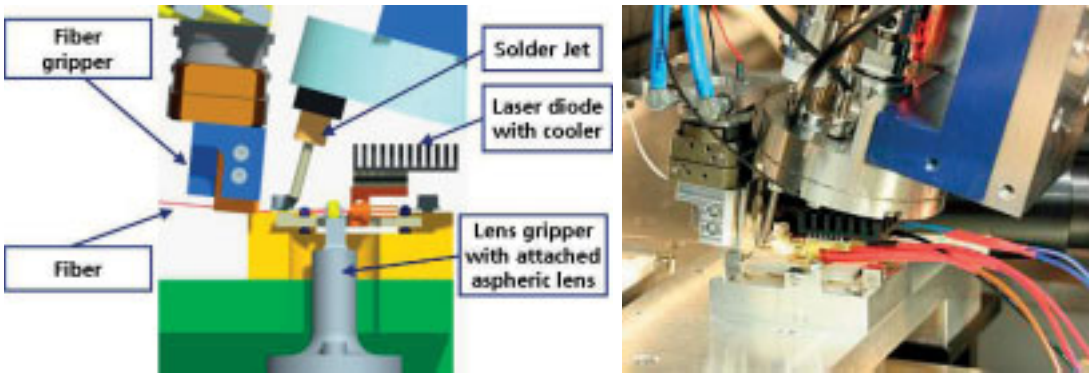

Fig. 3: Schematics of the apparatus for adjustment and joining of the optical fiber to the demonstrating module (left) and photograph of assembly environment (right).

The fibers are adjusted within a V-groove structured in a glass mounting element previously attached to the system platform. The cleaved and metallized fibers showed a very good solderability and wetting behavior. Experimental results of tensile testing approved for a bond strength of more than 7.9 MPa of the solder joint with disruption of fibers not at the solder joint. The experiments indicate that the rupture of the fiber is induced by the mechanical removal of the coating of the fiber prior to metallization. Different approaches on removal of the coating such as laser stripping could decrease damage of the fibers and thus lead to a further increase of bond strength of the assembly.

A coupling efficiency of 52% (with a theoretical limit of approximately 55%) is achieved soldering the actively adjusted fiber to structured V-groove on a hybrid integrated single-lens fiber coupling unit. The resulting displacement of the fiber was calculated to be less than 0.5 µm. Except for this resulting misalignment neither metallization nor the soldering process lead to a significant decrease in coupling efficiency or transmitted power.

5. CONCLUSION AND OUTLOOK

A metallization scheme is presented that provides a sufficient circumferential wetting surface by two sequential runs. A miniaturized fiber gripper providing the rotational adjustment of the PMF with a resolution of better than 0.2° is developed. Translational misalignment during soldering in a V-groove is better than 0.5 µm while providing bond strength of more than 7.9 MPa. The influence of the solder joint on stress related birefringence in the PMF and the corresponding change in the degree of polarization of the transmitted light is still to be investigated. Both the developed fiber gripper and the process of solderjet bumping provide flexible, automatable and highly precise techniques for the assembly of micro-optical and hybrid micro systems allowing for cost efficient and customer-specific solutions.

ACKNOWLEGDEMENTS

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From the idea to the prototype, a Demultiplexer for WDM over POF

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ABSTRACT

Polymer Optical Fibres (POFs) show clear advantages compared to copper and glass fibres. In essence, POFs are inexpensive, space-saving and not susceptible to electromagnetic interference. Thus, the usage of POFs have become a reasonable alternative in short distance data communication. Today, POFs are applied in a wide number of applications due to these specific advantages. These applications include automotive communication systems and in-house-networks. State-of-the-art is to transmit data with only one channel over POF, this limits the bandwidth. To solve this problem, an integrated MUX/DEMUX-element for WDM over POF is designed and developed to use multiple channels. This integration leads to low costs, therefore this component is suitable for mass market applications. The fundamental idea is to separate the chromatic parts of the light in its monochromatic components by means of a grating based on an aspheric mirror. Due to the high NA of the POF the setup has to be designed in a 3D-approach. Therefore this setup cannot be compared with the planar solutions available on market, they would result high losses in the 3rd dimension. To achieve a fast and optimized design an optical simulation program is used. Particular attention has to be paid to the design of the POF as a light source in the simulation program and the optimisation of the grating. The following realization of the demultiplexer is planed to be done with injection molding. This technology offers easy and very economical processing. These advantages make this technology first choice for optical components in the low-cost array.

Keywords: WDM, Polymer Optical Fibers, Demultiplexers, Optical Communication Systems, Multiplexing, Optical Networks

1. INTRODUCTION

1.1 Advantages of Polymer Optical Fibers

Polymer Optical Fibers (POFs) offer many advantages compared to alternate data communication solutions such as glass fibers, copper cables and wireless communication systems. In comparison with glass fibers, POFs offer easy and cost-efficient processing and are more flexible for plug interconnections. POFs can be passed with smaller radius of curvature and without any mechanical disruption because of the larger diameter in comparison with glass fibers.

The clear advantage of using glass fibers is their low attenuation, which is below 0,5db/km in the infrared range. In comparison, POF can only provide acceptable attenuation in the visible

spectrum from 350nm up to 750nm, see fig. 1. The attenuation has its minimum with about 85db/km at approximately 570nm. For this reason, POF can only be efficiently used for short distance communication up to 100m. The disadvantage of the larger core diameter is higher mode dispersion.

The use of copper as communication medium is technically outdated, but still the standard for short distance communication. In comparison, POF offers lower weight and space. Another reason is the nonexistent susceptibility to any kind of electromagnetic interference [1-3].

Wireless communication is afflicted with two main disadvantages. The electromagnetic fields can disturb each other and probably other electronic devices. Additionally, wireless communication technologies provide almost no safeguards against unwarranted eavesdropping by third parties, which makes this technology unsuitable for the secure transmission of volatile and sensitive business information.

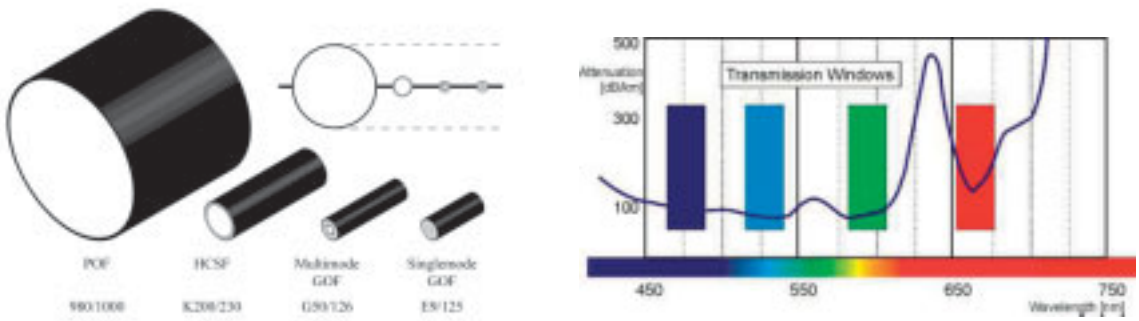

Fig. 1 Principle and attenuation of POF in the visible range [1]

For these reasons, POF is already applied in various applications sectors. Two of these fields are described in more detail: the automotive sector and the in house communication sector.

1.2 POF in the automotive sector

POF displaces copper in the passenger compartment for multimedia applications, see figure 2. It was first introduced by BMW in the 7er series in 2001. Since then not only high class cars were equipped with POF, even volume cars benefit of the advantages of POF [4, 5].

The exchange of the communication medium leads to lower weight. The glass temperature of POF (below 85°C) makes using the fiber in the engine compartment impossible [4], although this problem might be solved in the foreseeable future. Another application in the car, where POF most likely will be used in the future, is as sensors for measuring various in-car pressures or forces.

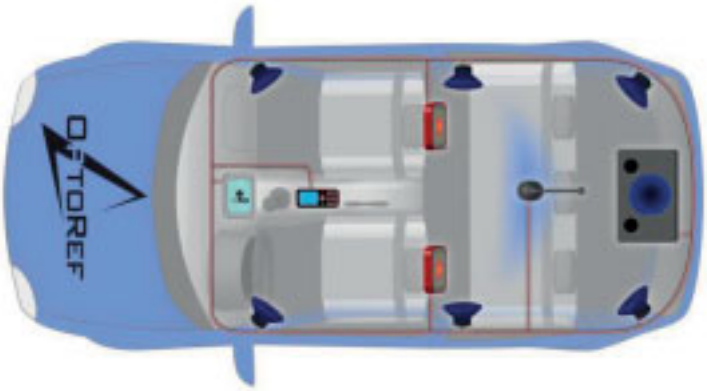

Fig. 2 Mulitmedia Bus System (MOST-Bus) with POF

1.3 POF in the in house communication sector

Another sector where POF displaces the traditional communication medium is in-house communication [6, 7], although the possibilities of application are not confined to the inside of the house itself. In the future, POF will most likely displace copper cables for the so-called last mile between the last distribution box of the telecommunication company and the end-consumer. Today, copper cables are the most significant bottleneck for high-speed internet.

“Triple Play”, the combination of VoIP, IPTV and the classical internet, is being introduced to the market with force, therefore high-speed connections are essential. It is highly expensive to realize any VDSL system using copper components, thus the future will be FTTH, see figure 3.

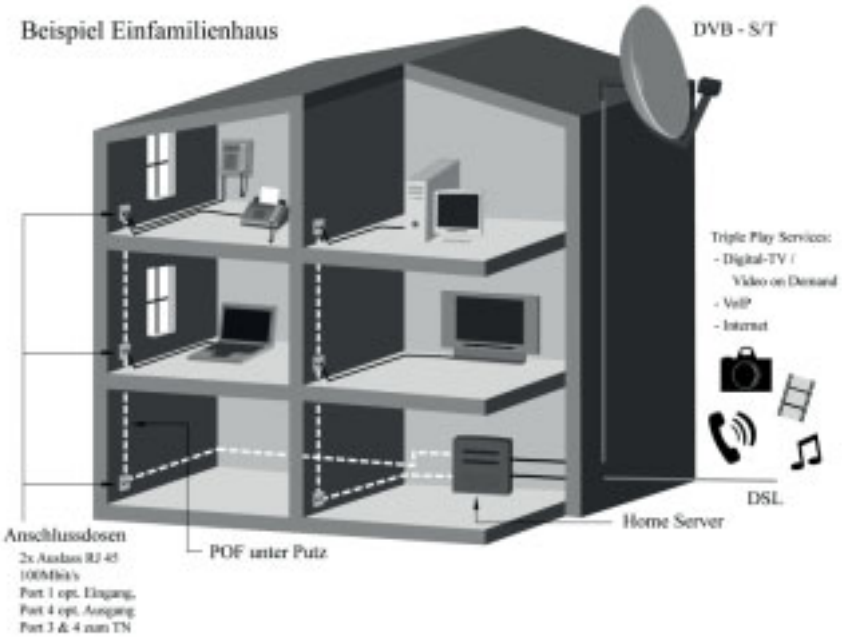

Fig. 3 In house Communication with POF

1.4 The Motivation for WDM over POF

Within the preceding paragraphs, several sectors where introduced, where POF offers advantages when compared to the established technologies. Other possible industrial sectors include the aviation or the medical sector. All these applications have one thing in common – they all need high-speed communications systems.

The standard communication over POF uses only one single channel [1,2]. To increase bandwidth for this technology the only possibility is to increase the data rate, which lowers the signal-to-noise ratio and therefore can only be improved in small limitations.

This paper presents a possibility to open up this bottleneck. In glass fiber technology, the use of the WDM (wavelength division multiplexing) in the infrared range at about 1550nm has long been established [8-10]. This multiplexing technology uses multiple wavelengths to carry information over a single fiber [11]. This basic concept can – in theory – also be assigned to POF. However POF shows different attenuation behavior, see fig. 1. For this reason, only the visible spectrum can be applied when using POF for communication.

For WDM, two key-elements are indispensable: a multiplexer and a demultiplexer. The multiplexer is placed before the single fiber to integrate every wavelength to a single waveguide. The second element, the demultiplexer, is placed behind the fiber to regain every discrete wavelength. Therefore, the polychromatic light must be split in its monochromatic parts to regain the information. These two components are well known for infrared telecom systems, but must be re-developed for POF, because of the different transmission windows.

One technical solution for this problem is available [12], but it cannot be efficiently utilized in the POF application scenario described here, mostly because this solution is afflicted with high costs and therefore not applicable for any mass production.

2. BASIC CONCEPT OF THE DEMULTIPLEXER

As mentioned before, a demultiplexer is essential for WDM. Several preconditions must be fulfilled to create a functional demultiplexer for POF. First of all, the divergent light beam, which escapes the POF, must be focused. This is done by an on-axis mirror. In the first attempt, a spherical mirror is used. To get perfect results without any spherical aberrations, an ellipsoid mirror should be used.

The second function is the separation of the different transmitted wavelengths. In figure 4, this principle is illustrated for three wavelengths (red, green, blue). This is not a limitation for possible future developments, but rather an experimental basis from where to run the various simulations described below. The diffraction is done by a diffraction grating. The diffraction is split into different orders of diffraction. The first order is the important one to regain all information. There a detector line can be installed to detect the signals.

Because the grating is attached to a bended basement only one element can cover both functions, the focusing and the diffracting. The higher the grating constant g of the diffraction grating is the sharper the maxima of the different diffraction orders. The diffracted light interfere positively on the detection layer for:

$$z\lambda = g(\sin\alpha + \sin\beta) \tag{1}$$

The resolution of the diffraction grating follows the Rayleigh Criterion and depends on the complete number of grating steps N and not on the grating constant:

$$\frac{\lambda}{\Delta\lambda} \leq zN \tag{2}$$

The light is also not afflicted with any aberrations or attenuations of a focusing lens or other refractive elements, which are necessary for any other setup [13,14].

One other characteristic of key elements for POF communication is the three dimensional approach. Key elements of glass fiber communication are usually designed planar. This simplification cannot be adopted for POF communication, because of the large Numerical Aperture and therefore large opening angle of the POF.

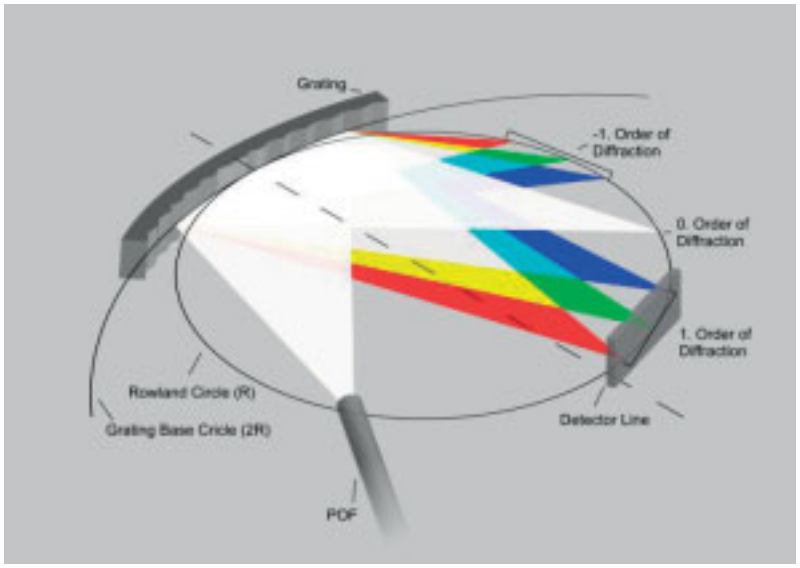

Fig. 4 Principle sketch of a Rowland Spectrometer

3. RESULTS OF THE SIMULATION

In the following steps, a software program is used to design a demultiplexer based on the general concept outlined above. For the current task, the software OpTaLiX provides all needed functionalities [15]. This approach offers different advantages, it is easy to design, analyze and evaluate the simulated results. Also, effective improvements of the configuration can be simulated fast.

3.1 Results of the Simulation for different line densities

In figure 5, the 2D plot for the reference wavelength (520nm) of the demultiplexer with an ellipsoid mirror and grating is shown. The multicolored light is emitted by a polymeric fiber. It hits the mirror, where it is focused and diffracted in its monochromatic parts. The light is focused onto a POF- or detector-array.

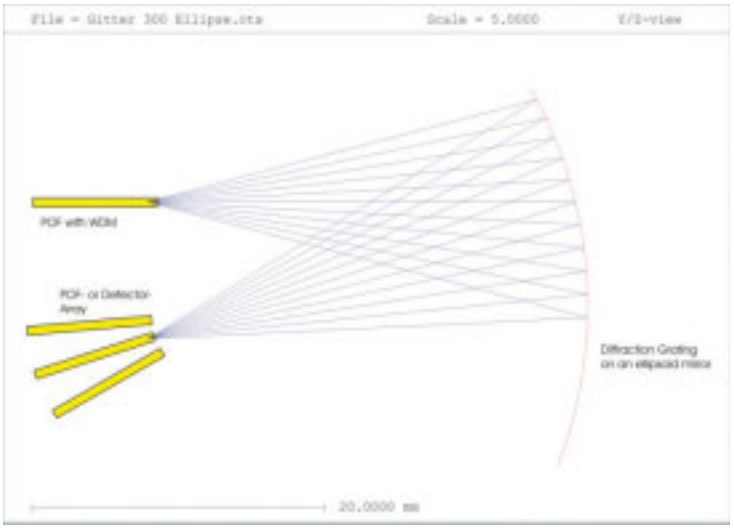

Fig. 5 2D plot of the demultiplexer

Without a grating, a perfect point to point mapping (without any aberrations) is possible with an ellipsoid mirror because of the two foci, but there is no separation of the different channels. With a grating stamped on the mirror, the separation of the multicolored light in its monochromatic parts is possible. But this grating distorts the optical path of light dramatically.

The first change is the gap of the different colors in the image layer (here the POF- or Detector Array) increases with the line density of the grating, see figure 6 and 7. This can be noticed for an ellipsoid mirror (figure 5) and for a spherical mirror (figure 6) as well. The spherical mirror has the advantage, that the shape can be produced for injection molding easier.

The second changes are the great aberrations especially for the demultiplexer high line density. To underline this result and to analyze the aberrations in detail, the transverse ray aberration (TRA) and the optical path difference (OPD) in spectrometer mode are shown in figure 8 for the demultiplexer with an ellipsoid mirror and 1200 lines/mm. The chief ray coordinates are irrespective for the TRA and OPD to overlap the different colors.

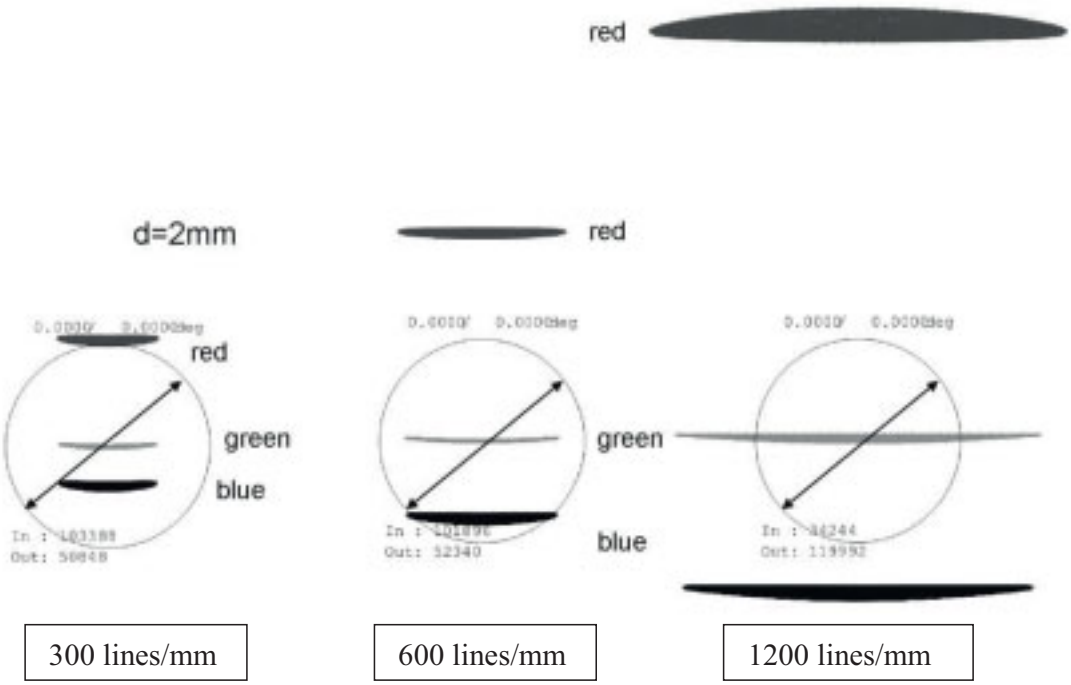

Fig. 6 2D Plot of the demultiplexer with an ellipsoid mirror

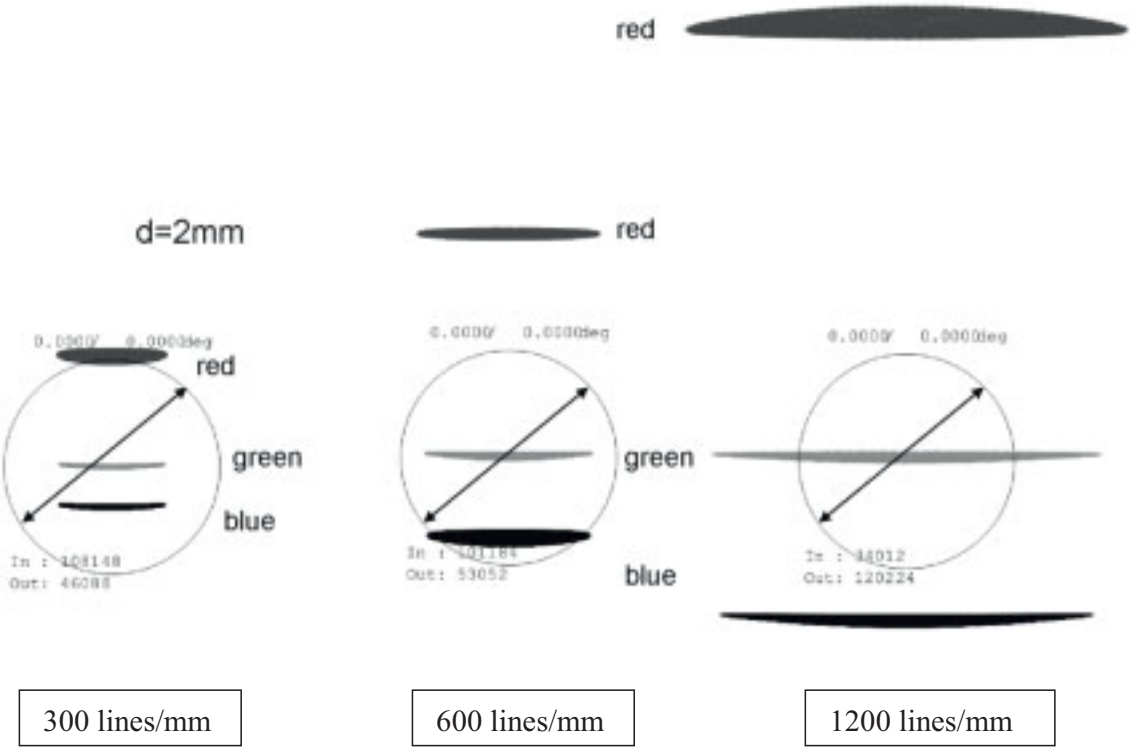

Fig. 7 2D Plot of the demultiplexer with a spherical mirror

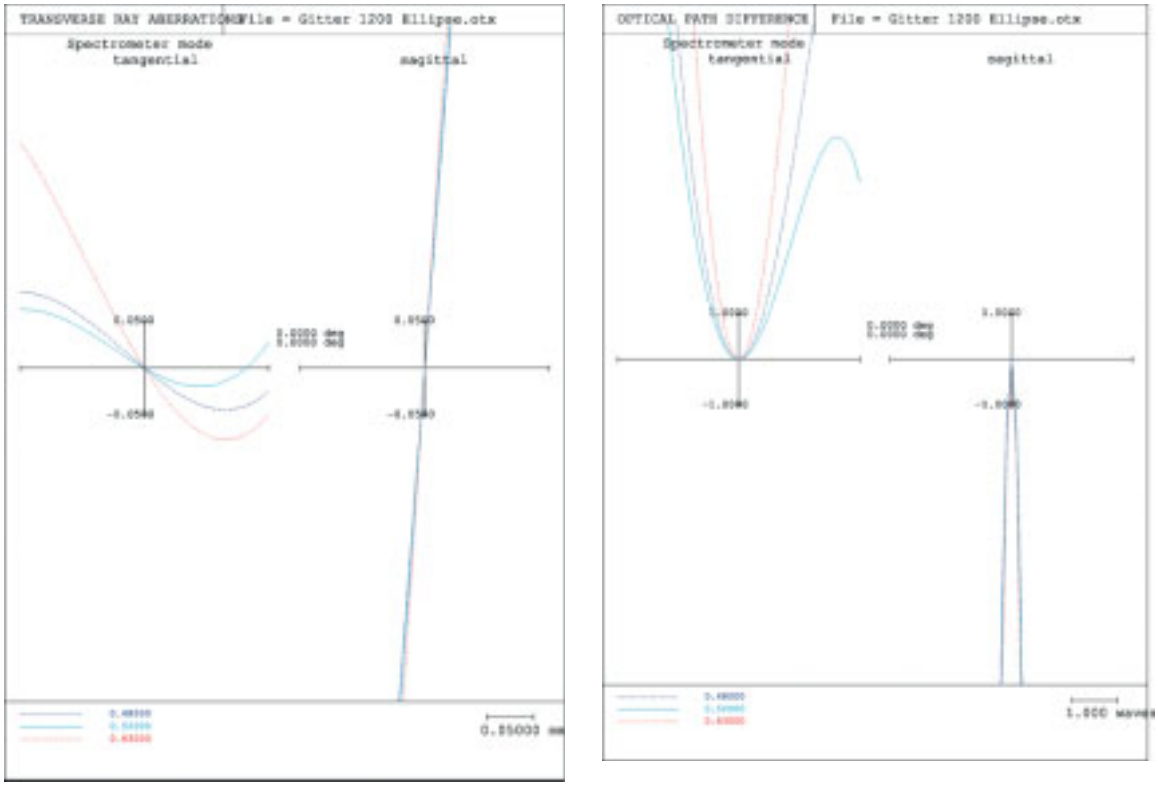

Fig. 8 TRA and OPD for the ellipsoid demultiplexer with 1200 lines/mm

The TRA shows a slight defocusing for the meridional section, but a very strong defocusing for the sagittal section. The graph of the function in the meridional section exhibits a predominant third order Seidel coefficient. Therefore the slight defocusing in the meridional section compensates the astigmatism. The OPD shows as expected strong deviation from the ideal waveform especially in the sagittal section. This defocusing leads to high losses for the coupling efficiency for the POF- or detector- array in the image layer.

3.2 Results of the Simulation with improved mirror shape

It is obvious that the grating changes the focal length especially of the sagittal section; therefore the shape of the mirror must be improved. It is necessary to change the radius of curvature notable in the sagittal section. Hence the basic shape of the mirror is not longer a sphere or ellipsoid. To meet the demands a higher order shape, which is nearly cylindrical, is used.

The change of the mirror shape improves the imaging quality substantial. The Spot Diagram and the TRA for the improved demultiplexer are shown in figure 9.

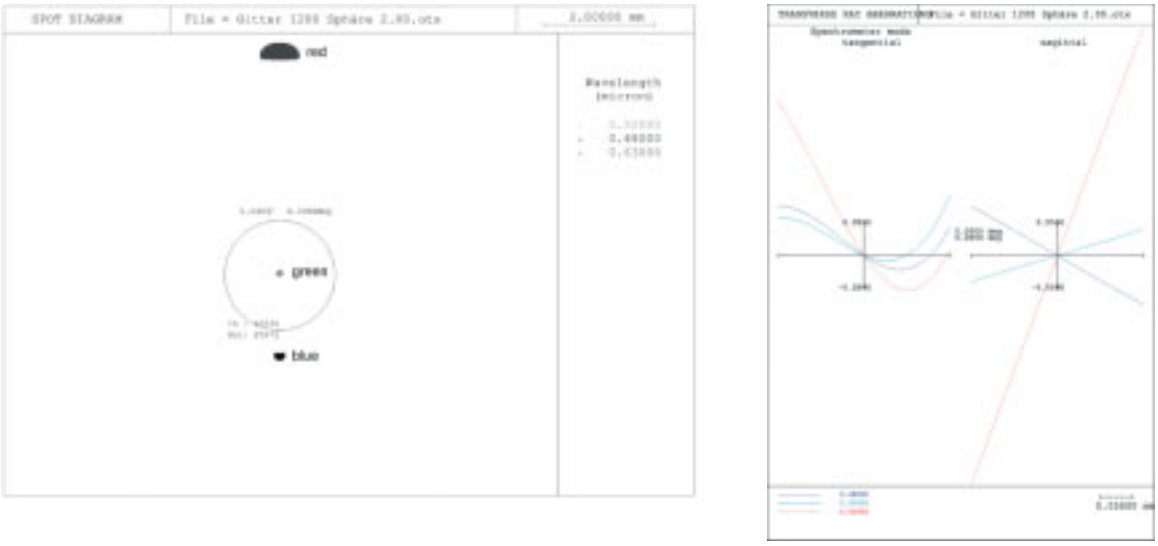

Fig. 9 Spot Diagram (circle diameter 2mm) and TRA for the improved demultiplexer

The Spot Diagram shows three dividable colors. The gap between every color is larger than 2mm. The TRA shows a marginal shift of the focus of all wavelengths to offset the astigmatism in the meridional section. Because of the spectrometric function of the demultiplexer it is not possible to focus all three colors simultaneously. There is always a combination of over and under correction for the different colors. Hence the radius of the mirror in the sagittal section is optimized to focus the colors completely as much as possible.

This improved demultiplexer can separate three colors with enough space between them to regain the information with a POF- or detector-array. The shapes of the foci feature low coupling losses and the shape of the mirror is easy to produce in injection molding.

3.3 Illumination Model for the improved mirror shape

The results shown in the previous paragraph are based on a simple ideal light source, see fig. 10. The bonding light rays emerging the POF are extrapolated into the fiber. The intersection point of these rays is the starting point of the light source.

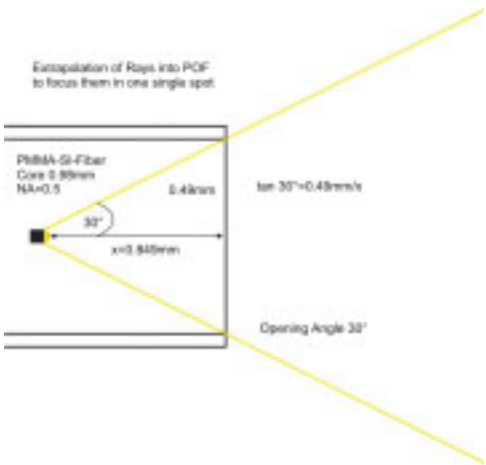

Fig. 10 Configuration of simple light source

This model works well in the far field range for $r \geq 2\lambda$. To achieve more realistic spot sizes on the detection layer five point source where used. One is situated as before and four are situated equal distant on the boundary circle. The spot diagram for these 5 sources is illustrated in fig. 11. The shape of the different focus points of the different light sources is similar to shape of the single light foucs point, see fig. 9. Only the position of the foucs points changes sligthly due to the position of the light sources.

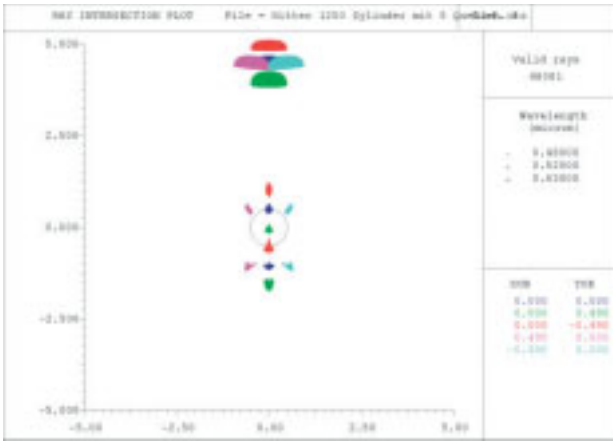

Fig. 10 Illustration of image layer with five sources (different color means different light source)

The next step is to use a surface source with a diameter equal the core diameter of POF (d=0.98mm). The result can be seen in fig. 11. This analysis shows, thas the diffraction of light overlap the typical shapes shown in fig. 10. only a round shape for each foucs point is left, whith a diameter of about 1mm.

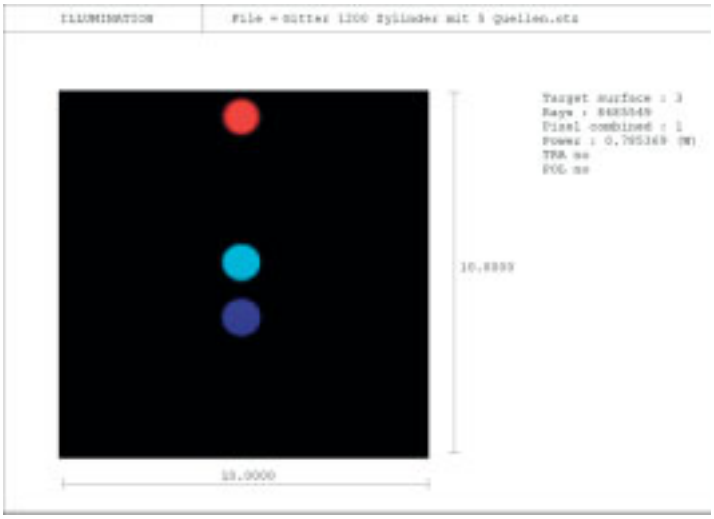

Fig. 11 Image layer illuminated by a surface source

3.4 Injection Molding

The demultiplexer should be produced by means of the injection molding technology. This technology is a very inexpensive way to produce a high amount of devices with low costs.

In injection molding it is possible to process polymer materials. The improved configuration is simulated with PMMA for complete body. The POF consists of PMMA as well. Hence the complete configuration can be produced by means of injection molding.

In this manufacturing technique molten plastic is injected at high pressure into a mold, which is the inverse of the product's shape. The mold is made by a moldmaker (or toolmaker) from metal, usually either steel or aluminum, and precision-machined to form the features of the desired part.

To get first results of this technique to assure that it is possible to fabricate optics, a first waveguide has been manufactured, fig 12.

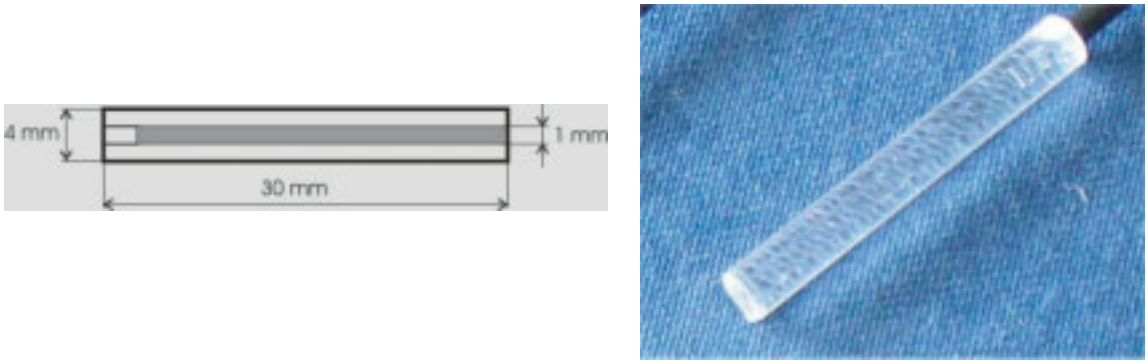

Fig. 12 Sketch and Photo of first injection molded device

The core of the fabricated waveguide consists of PMMA and the cladding is made of PC. The average value of the attenuation of the fabricated waveguides at different wavelengths used for the demultiplexer is measured and is shown in table 1.

Table 1 Attenuation of the molded device at different wavelengths

Attenuation [dB] /per piece		
660nm (red)	530nm (green)	480nm (blue)
1,80	2,17	2,52

4. CONCLUSION

The Polymer Optical Fiber exhibits many advantages in comparison to glass fiber and copper as the medium for communication. The mentioned applications show different sectors where POF is already applied.

State of the art for POF communication is the use of only one single channel. This means a limitation of bandwidth. The solution for this bottleneck is WDM over POF, there not only one channel is used to transmit information over a single fiber. To use this technique two key elements have to be designed completely new: a multiplexer and a demultiplexer, because the key elements of the established WDM for glass fibers in the IR cannot be applied.

The simulation results show, that it is possible to build up a demultiplexer by means of a diffraction grating. A special shape of the mirror is needed to suppress most of the aberrations which results of the grating. The improved demultiplexer can separate all three colors with a gap of 2mm and crosstalk lower than 30dB. Even the more complex models show a gap between the different colors, hence it is possible to regain all transmitted information without any channel overlap.

The next step will be the assembly of the prototype made in injection molding.

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Access Networks for 10 Gbps everywhere

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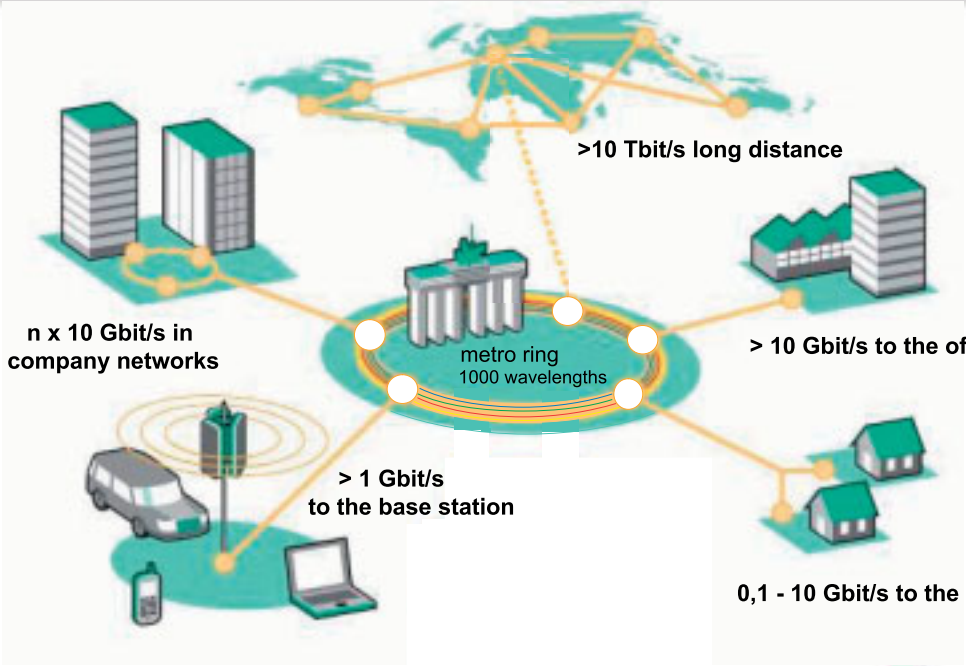
Future Global Network



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Outline

- Introduction
- Bandwidth requirements
- FTTH requirements and network structures
- In-house and home networks
- Conclusion

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Bandwidth Requirements

Bandwidth requirements mainly defined by:

- Information content to be transmitted per time unit (image, video, voice, text, ...)
- Response time (interactive services: human – human, human – machine)

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New Services

- **Peer to peer transmission of high resolution pictures and movies**
- **Web-TV**
- **Super-HDTV**
- **3D-HDTV**
- **High-quality immersive video conferencing**
- **….**

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High-quality Immersive Video Conferencing

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HDTV vs Super-Hi-Vision

	HDTV	Super-Hi-Vision (NHK)
• Resolution	1080 x 1920	4320 x 7680
• Data rate uncomp.	1,5 Gbps	24 Gbps
• Data rate compressed	10 Mbps	160 Mbps

- Europe premiere of Super-Hi-Vision at Olympia 2012
- Super-Hi-Vision will reach private homes in 10 years

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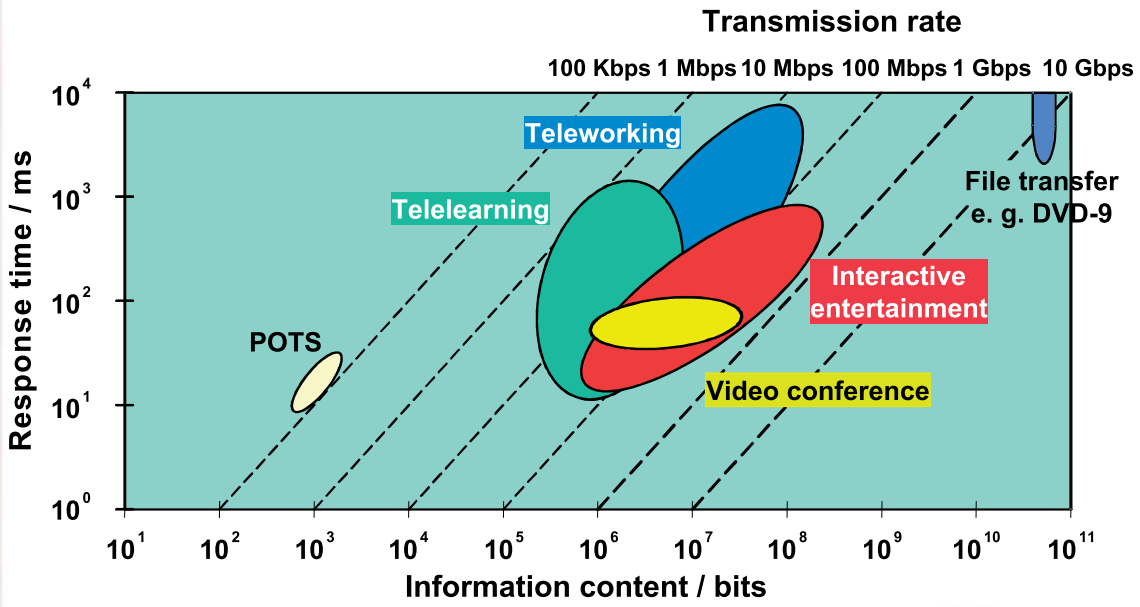
Response Time and Transmission Rate



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1 Gbps up to 10 Gbps everywhere

- Future data rates for broadband access
  - private: 100 Mbps → 1 Gbps → 10 Gbps (long term)
  - business: n x 1 Gbps up to n x 10 Gbps
    → Fiber to the Home, Fiber to the Office
    → Fiber in the Home, Fiber in the Office
- Symmetrical access (downstream – upstream)
- Broadband access for everybody

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FTTH Requirements and Network Structures

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Key Requirements for FTTH

- Long lifetime of fibre plant, > 30 years up to 100 years
- Open access
- Scalability and flexibility
- Zero touch of fibre pant
- Uniform components and sub-systems
- Easy installation
- Low operation and maintenance
- High security and reliability
- High energy efficiency, low power consumption
- Low cost

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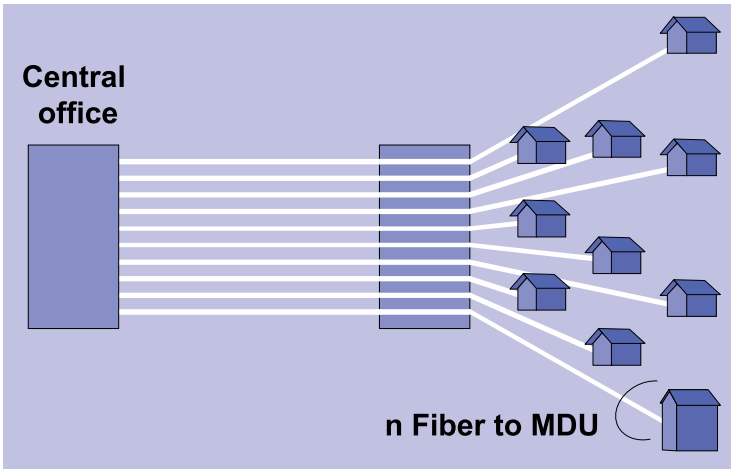
Home Run, Point to Point



- Unlimited bandwidth
- Simple structure
- Uniform components
- Easy open access by fiber

MDU: Multi dwelling unit

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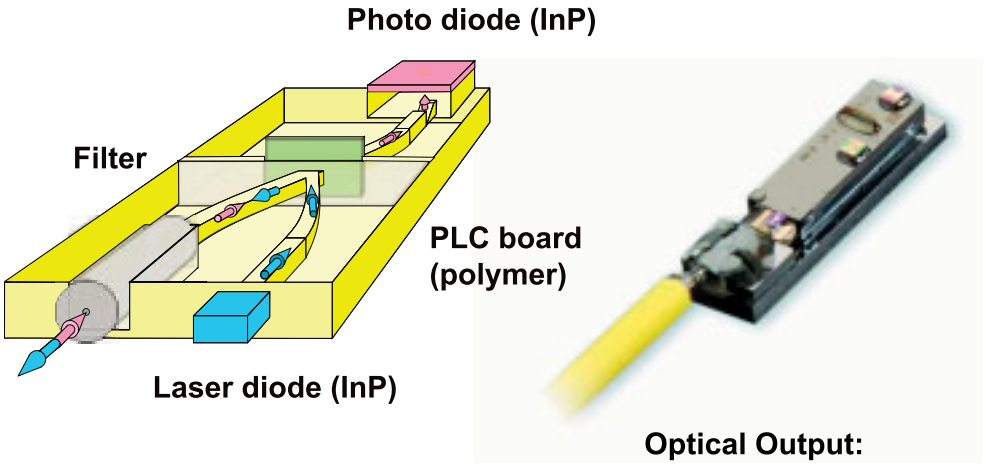
Low Cost Transceiver on Polymer Basis



Optical Output:

+2dBm (@ 50mA / 1310nm)
+5dBm (@ 50mA / 1490nm)

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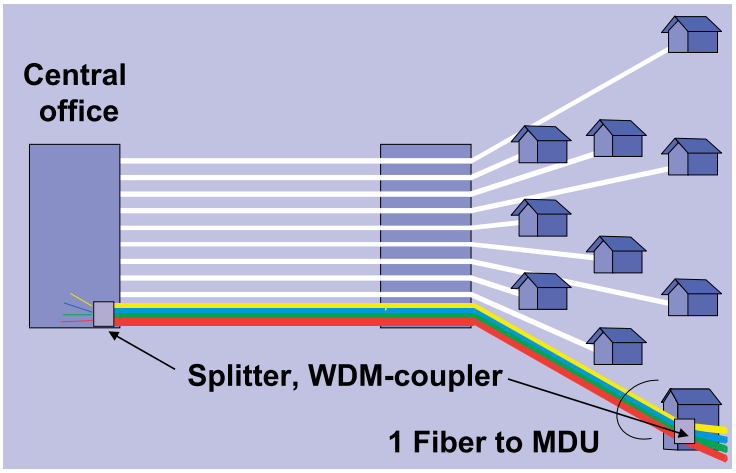
Virtual Home Run with CWDM or DWDM



MDU: Multi dwelling unit

- **Fiber sharing**
- **High bandwidth**
- **Open Access by wavelength channel**

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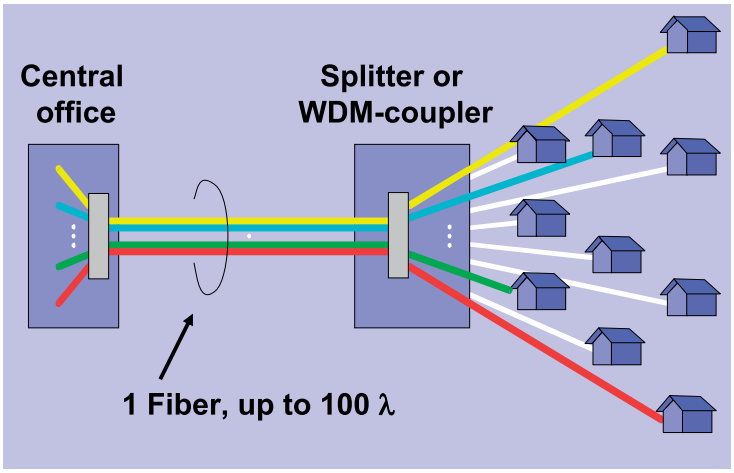
Virtual Home Run with DWDM



- Single fiber star topology, classical PON structure
- Fiber sharing in the feeder
- High bandwidth
- Open Access by wavelength channel

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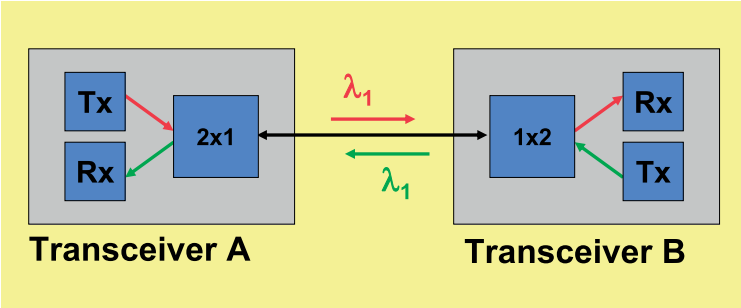
Full-Duplex Transmission Using Same λ



- Full-duplex transmission using same wavelengths for both directions
- Reach crosstalk limited → 40 km
- Coupling of Tx and Rx
  - Power splitter → low cost
  - Directional coupler (circulator) → low insertion loss

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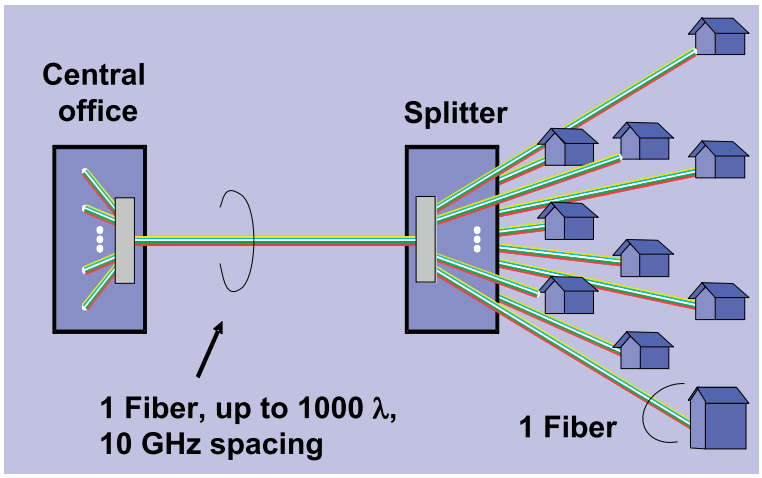
Virtual Home Run with UDWDM, Coherent TRx



- Fiber sharing in the feeder and last meters
- Bandwidth limited by channel spacing
- Open access by wavelength channel
- Experiments by DTAG and HHI in 1993

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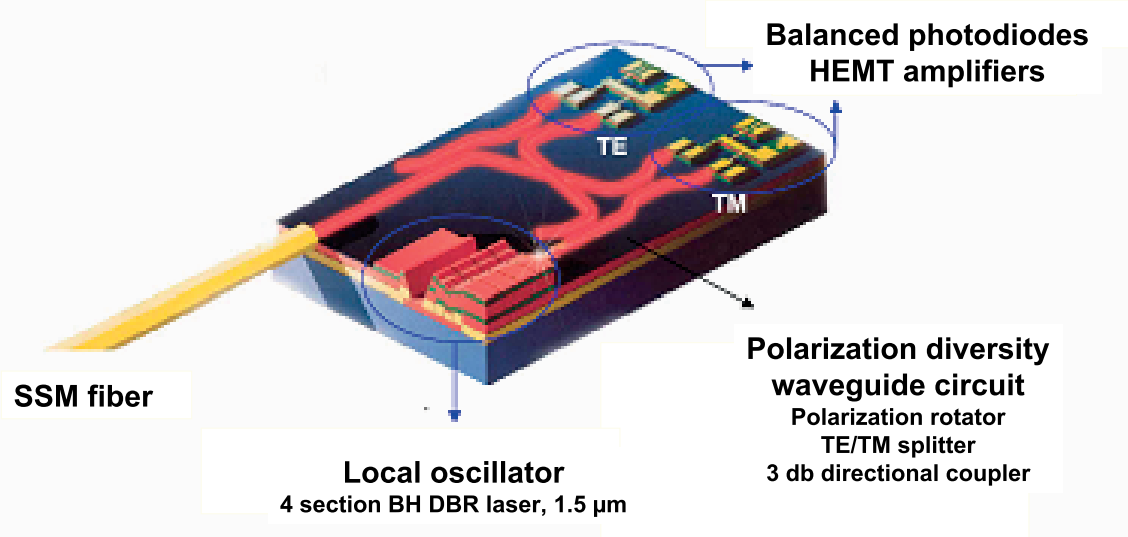
Integrated Coherent Receiver



World's first integration by HHI in 1995

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In-House and Home Networks

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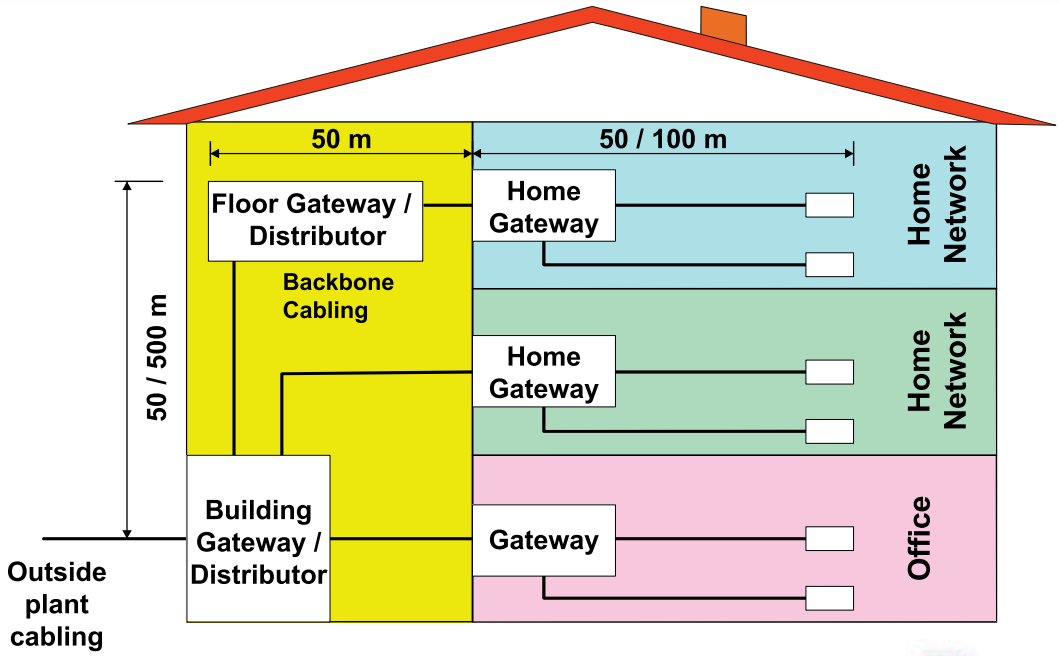
In-House and Home Network Topology



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In-House and Home Network Requirements

- High bandwidth up to 10 Gbps
- Future-proof solution, scalability
- Long lifetime of installation, up to 30 years
- Distance > 50 m
- Robust and cheap network elements
- Simple & flexible network installation (Do It Yourself, DIY)
- Plug&Play solutions
- High energy efficiency, low power consumption
- Standards

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Broadband In-House & Home Network Media

- Copper wires*
  - CAT7 cable (> 10 Gbps)
  - Coaxial cable (several Gbps)
- Optical fibers*
  - Plastic optical fiber (SI, up to 1 Gbps)
  - Glass optical fiber, SMF (unlimited), GIF (> 40 Gbps)
- Wireless, only concentrated of a room
  - Radio (several Gbps)
  - Light (several 100 Mbps)

*Bit rates for approx. 100 m

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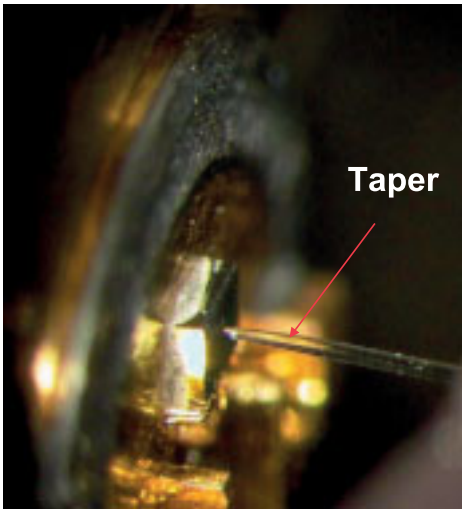
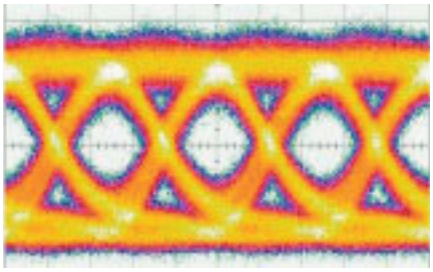
40 Gbps Transmission over 600 m GI-Fiber





Eye diagram
40 Gbps @ 600 m GI-fiber

Photodiode
Spot Diameter: 10 µm
Working Distance: 15 µm

Draka

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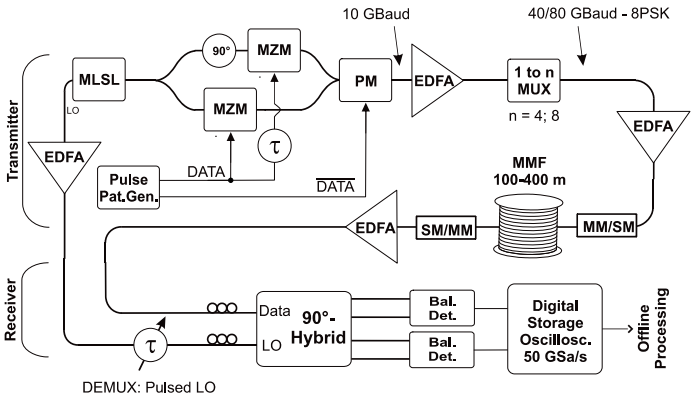
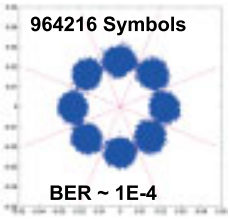
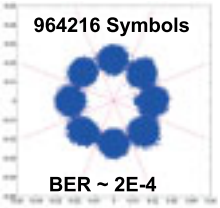
240 Gbps over 200 m MMF



80 Gbaud RZ-8PSK @ 200 m OM4



40 Gbaud RZ-8PSK @ 400 m OM4



- **Higher-order modulation format, OTDM, SSMF/MMF and MMF/SSMF coupling, pulsed LO for de-multiplexing**
- **120 Gbps (40 Gbaud) RZ-8PSK over 400 m @ BER ~$2\cdot10^{-4}$**
- **240 Gbps (80 Gbaud) RZ-8PSK over 200 m @ BER ~ $2\cdot10^{-4}$**
- **Highest serial bitrate on 50 µm MMF so far!**

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Conclusion

- Future data rates for broadband access
  - private: 100 Mbps → 1 Gbps → 10 Gbps (long term)
  - business: n x 1 Gbps up to n x 10 Gbps
  → Fiber to/in the Home, Fiber to/in the Office
- Long lifetime of fiber plant of > 30 up to 100 years
  → FTTH fiber plant must be future-proof
- PtP fiber system fulfill technical requirements best
- WDM technologies are very suitable for fiber sharing and upgrade of PON-systems, but more complex → OAM
- Optical in-house and home networks become the same significance like FTTH-systems
- Low cost components, automatic mounting technologies

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Modulare Systemkomponenten
auf Basis planar-optischer Polymer-Chips
(POLYPLANAR)

"PolyPlanar"

FOC

FOC – fibre optical components GmbH
Justus-von-Liebig-Str. 7 · D-12489 Berlin
Tel. +49 30 5655 07-0 · Fax +49 30 5655 07-39
info@foc-fo.de · www.foc-fo.de

Freitag, 8. Mai 2009

Faseroptischer Systembaukasten

Grundlagen

- Technologie für Polymermotherboard
- TFF-Technologie
- RC-Faser (9/80) für alle Wellenlängen verfügbar

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Faseroptischer Systembaukasten

Konzept

- angepasste Wellenleiter realisieren Funktion von Kollimatoren
- TFF-Technologie auf dünnen Schichten (Glas, Polymer) zur Integration in Gräben von Polymermotherboards
- Ankopplung der Fasern an Wellenleiter über U-Profilgräben
- Integration von Aktivkomponenten über Spiegel
- Kaskadierfähige Detaillösungen erlauben hochintegrierte Funktionsmodule

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Faseroptischer Systembaukasten

Aufgaben

1. Realisierung des Polymermotherboards
2. Entwicklung der TFF-Technologie auf dünnen Schichten zur schnellen Ablösung der derzeitigen Zukaufteile
3. Pick-and-Place-Automat für Einsetzen der TFF-Filter, alternativ Verwendung zweiteiliger Substrate
4. Realisierung maßhaltiger U-Profilgräben, Voraussetzung für Ablösung der Ankopplung mit aktiver Ausrichtung durch passive Ausrichtung
5. Pick-and-Place-Automat für automatisierte Ankopplung mit passiver Ausrichtung
6. Realisierung hocheffizienter Spiegel
7. Realisierung von Aktivkomponenten mit geringer Verlustleistung
8. kostengünstige Gehäusetechnologie

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Faseroptischer Systembaukasten

Produktideen und Applikationsmöglichkeiten

Produkte:

- leistungsteilende Koppler auf Basis teildurchlässiger Filter
- wellenlängenselektive Koppler (WWDM, CWDM, DWDM) auf Basis wellenlängenabhängiger Filter
- Sende- und Empfangsbaugruppen auf Basis von Filtern und Aktivkomponenten
- passive Module (z.B. 16-Kanal CWDM-Modul)

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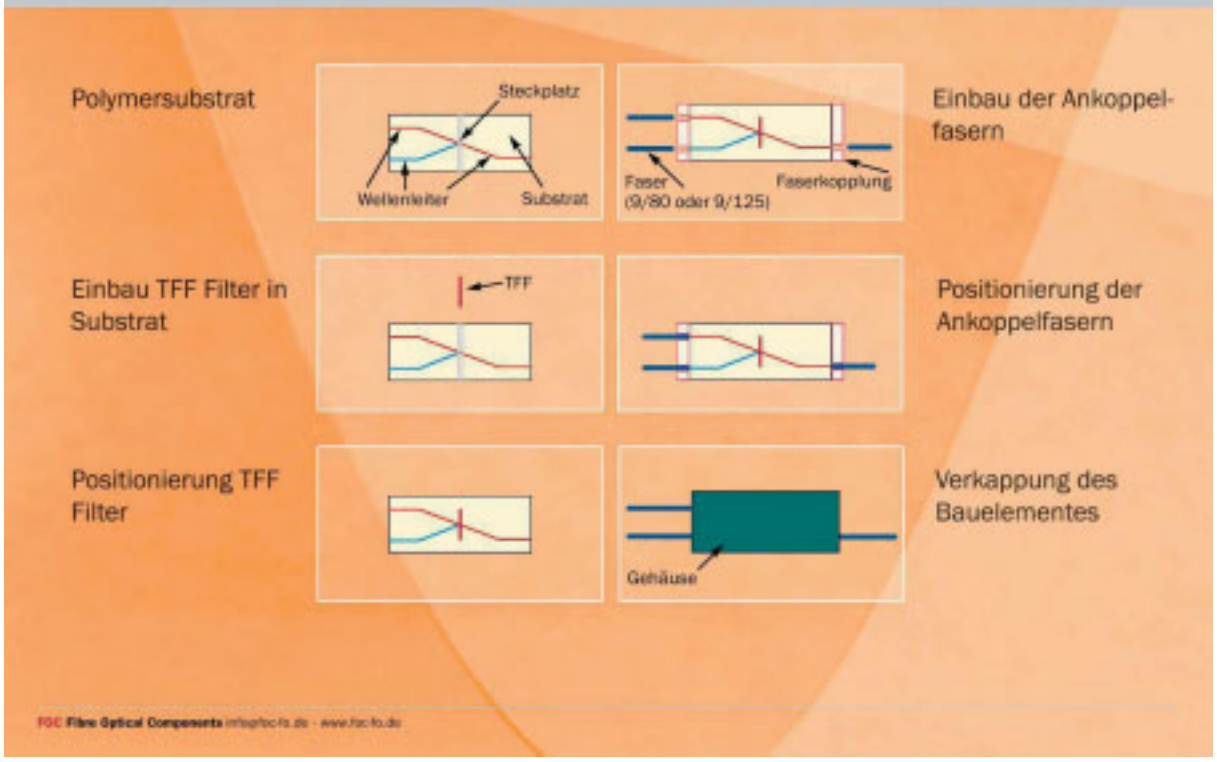
Polyboard – Arbeitsschritte und Herstellung eines Grundbauelements



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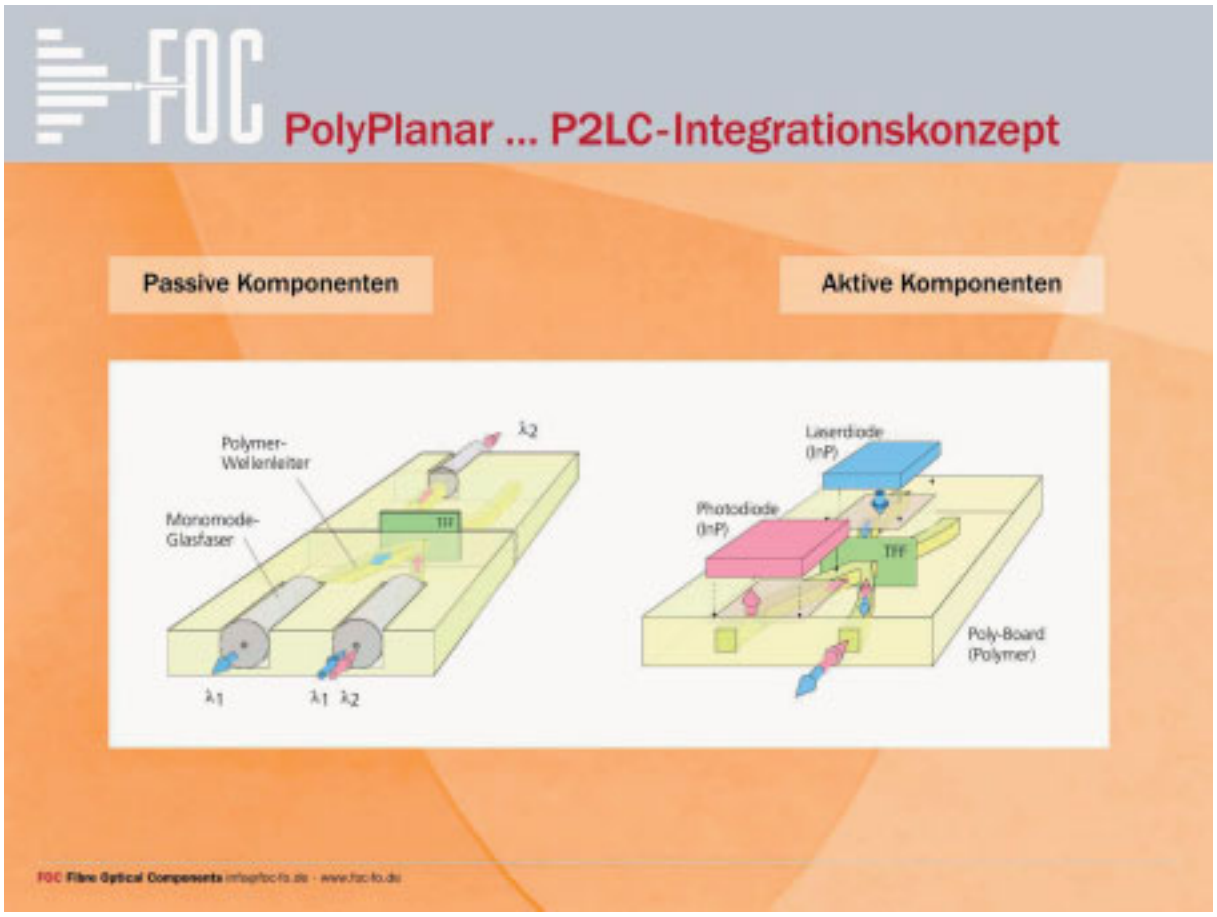
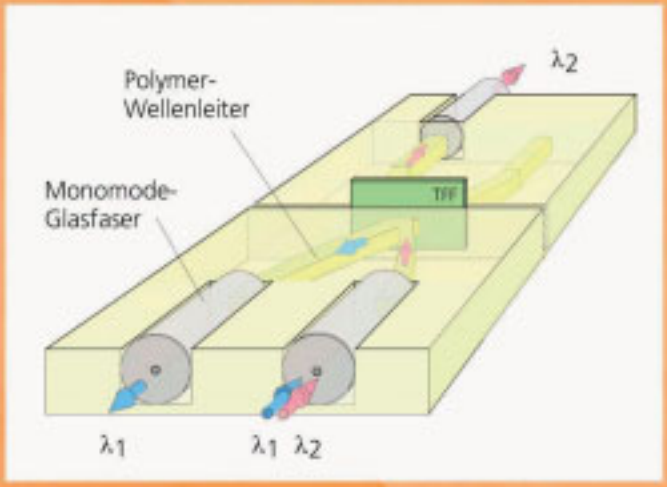
Polyboard – Faseroptischer Systembaukasten
FOC Fibre Optical Components


FOC
PolyPlanar ... P2LC-Integrationskonzept
Passive Komponenten
Aktive Komponenten
Polymer-
Wellenleiter
Monomode-
Glasfaser
TIF
λ2
λ1
λ1 λ2
Laserdiode
(InP)
Photodiode
(InP)
TIF
Poly-Board
(Polymer)
FOC Fibre Optical Components

P2LC-Integrationskonzept „Passive Komponenten“



Technologieentwicklung

- Chipentwicklung
- Entwicklung TFF-Nuten
- Entwicklung U-Nuten (Faser/Chip)

Komponentenentwicklung

P2LC-Boards mit integrierten TFF-/ U-Nuten

- [1x2] CWDM-Modul
- [4+1] CWDM-Modul

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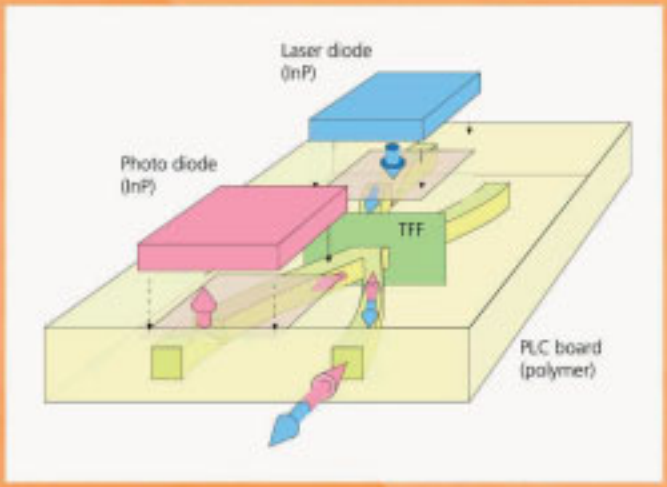
P2LC-Integrationskonzept „Aktive Komponenten“



Technologieentwicklung

- Chipentwicklung
- Entwicklung 45°-Spiegel

Komponentenentwicklung

P2LC-Boards mit integrierten TFF-/ U-Nuten und integrierten 45°-Spiegeln

- 4-Kanal Sender
- 4-Kanal Empfänger
- CWDM Transceiver

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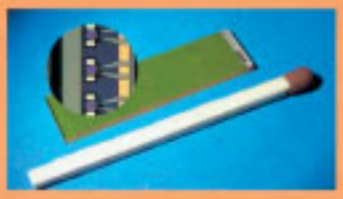
Tool Box based on Polymer PLC Technology

Polymer PLC + Thin Film Filter (TFF) → Polymer PLC + Photo Diodes → Polymer PLC + Photo/ Laser Diodes



Passive optical chips
- Splitter, coupler, AWGs
- Add/Drop MUX (OADM/ROADM)
- C/L Band filter
- Optical adapter

Integrated receiver chips
- CWDM/ DWDM receiver
- Channel monitor
- D(Q)PSK receiver
- Spectrometer
- Detector units for OCT

Passive optical chips
- CWDM/ DWDM transmitter
- Duplexer
- Triplexer
- Optical interconnect (active cable)
- USB 3.0 extender

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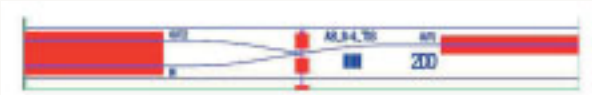
Faseroptischer Systembaukasten

TFF-MUX mit gesägtem Schlitz, Chipgröße: 12,5 x 3 mm



TFF-MUX mit geätzten U-Nuten und TFF-Schlitz, Chipgröße: 12 x 1,5 mm

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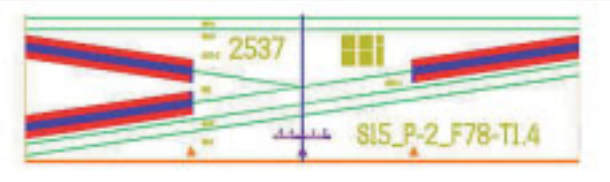
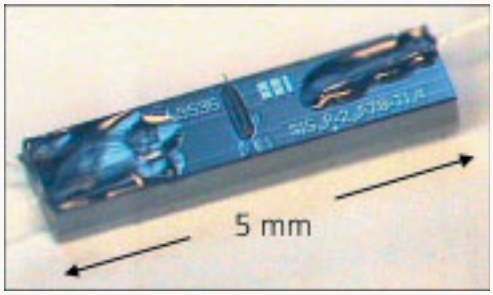
Faseroptischer Systembaukasten



TFF-MUX, Chipgröße: 5 x 1,3 mm, inkl. U-Nut



Konfektionierter 1 x 2 MUX mit TFF und RC-Fasern

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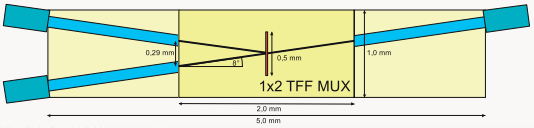
Faseroptischer Systembaukasten

Dämpfungs-Anteil	Theoretischer Wert [dB]	Bestwerte HHI [dB]			Bestwert AIFOTEC [dB]
		1260-1360nm	1460-1520nm	1530-1565nm	
WL (2mm)*	0,14*	0,26	0,32	0,14	0,??
TFF Gap (20µm)	0,12	0,15	0,15	0,15	0,??
TFF Absorption	0,10*	0,10	>1,00	0,20	0,??
TFF Position	0,00	0,05	0,05	0,05	0,??
TFF Winkel	0,00	0,05	0,05	0,05	0,??
F/C-Kopplung Feld (2x)	0,15	0,15	0,15	0,15	0,??
F/C-Kopplung Position (2x)	0,00	0,14	0,26	0,26	0,??
Stecker (2x)	0,20	0,20	0,20	0,20	0,??
Summe	**0,71**	**1,10**	**>2,00**	**1,20**	**0,??**

Verlustanteile optischer Pfad



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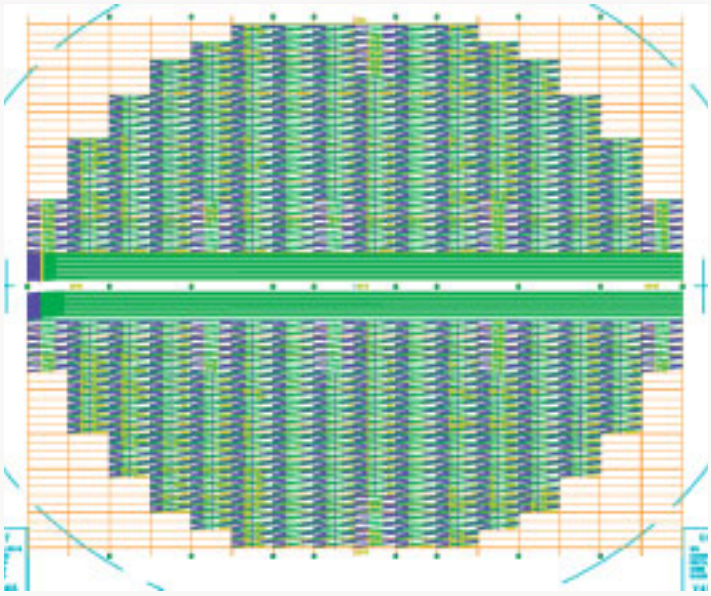
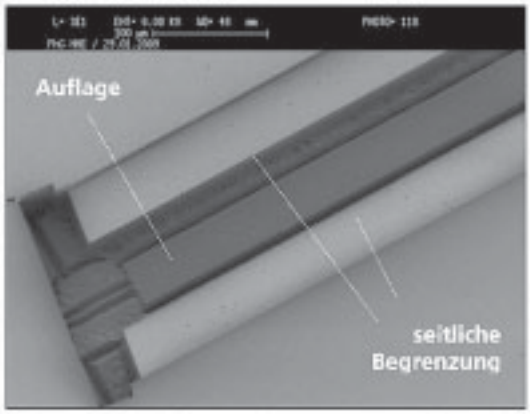
Faseroptischer Systembaukasten

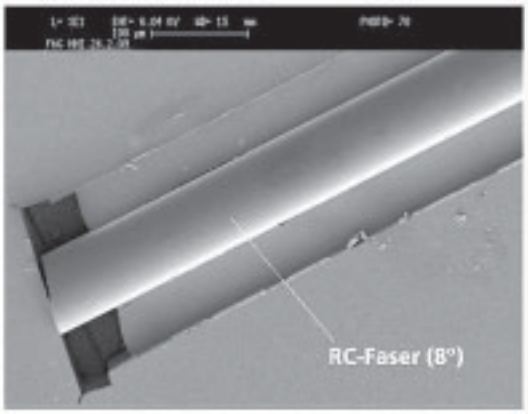


5“-Maske für 4“-Wafer, 1x2 TFF-MUX, 644 Elemente integriert (3. Design-Generation, 4“-Wafer).

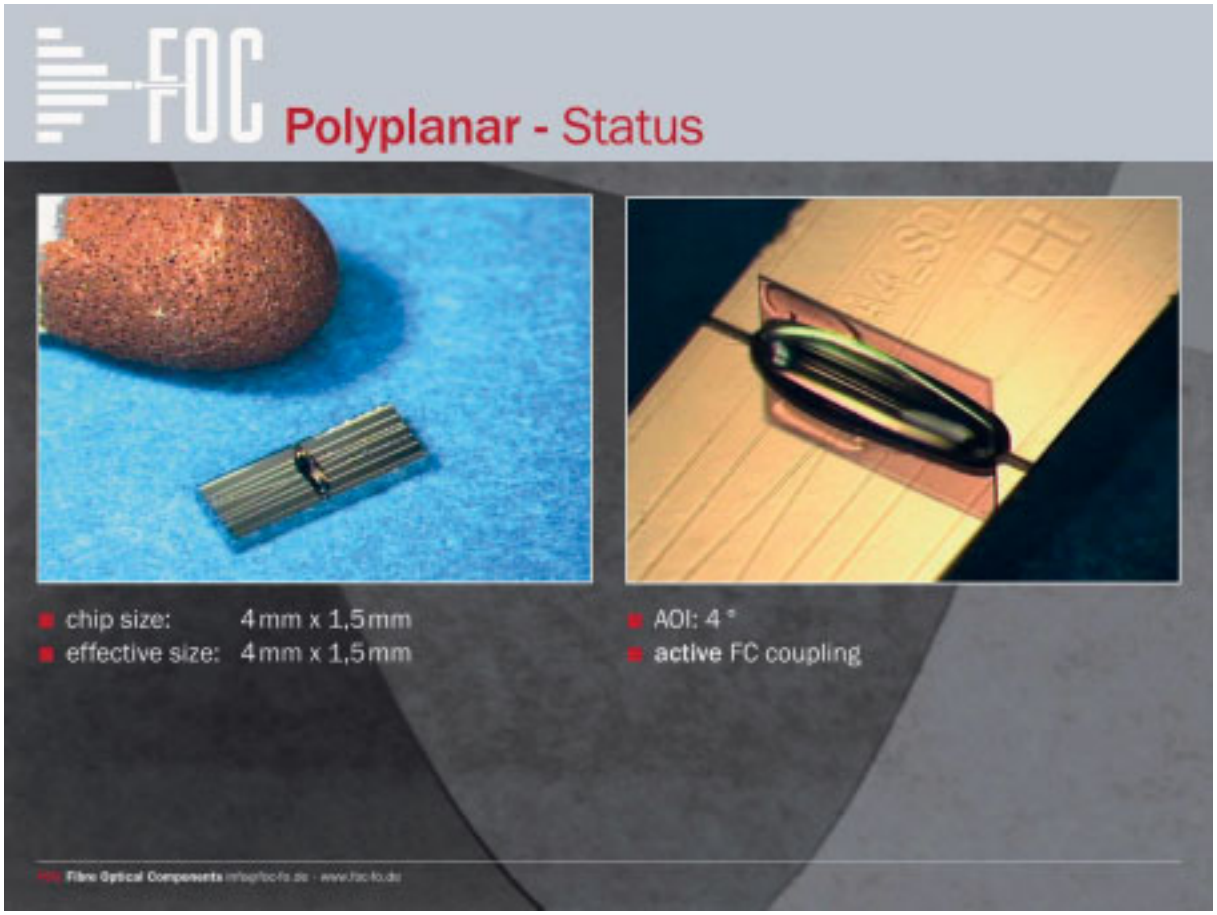
Faseroptischer Systembaukasten



SEM-Bild einer geätzten U-Nut.



SEM-Bild einer geätzten U-Nut mit RC-Faser (8°)


FOC
Polyplanar - Status
chip size: 4mm x 1,5mm
effective size: 4mm x 1,5mm
AOI: 4 °
active FC coupling
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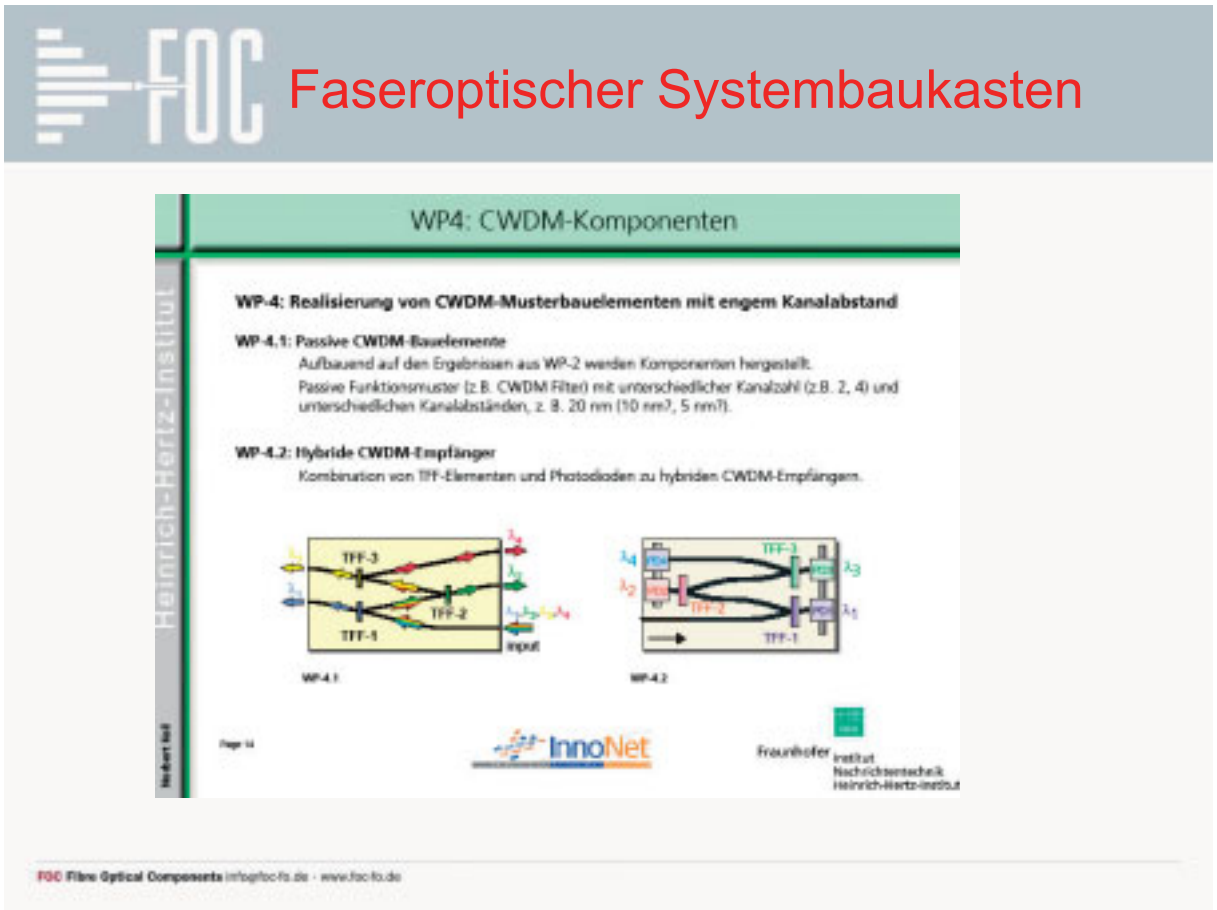
FOC
Faseroptischer Systembaukasten
WP4: CWDM-Komponenten
WP-4: Realisierung von CWDM-Musterbauelementen mit engem Kanalabstand
WP-4.1: Passive CWDM-Bauelemente
Aufbauend auf den Ergebnissen aus WP-2 werden Komponenten hergestellt.
Passive Funktionsmuster (z.B. CWDM Filter) mit unterschiedlicher Kanalzahl (z.B. 2, 4) und unterschiedlichen Kanalabständen, z. B. 20 nm (10 nm?, 5 nm?).
WP-4.2: Hybride CWDM-Empfänger
Kombination von TFF-Elementen und Photodioden zu hybriden CWDM-Empfängern.
TFF-3
TFF-2
TFF-1
Input
WP-4.1
WP-4.2
InnoNet
Fraunhofer Institut Nachrichtentechnik Heinrich-Hertz-Institut
Heinrich-Hertz-Institut
FOC Fibre Optical Components info@foc-fo.de · www.foc-fo.de

Vielen Dank
für Ihre Aufmerksamkeit
Fragen, Anregungen, Kommentare?

Modul Bauformen

und

Bauformen von ROSA und TOSA

Klaus.schulz@mergeoptics.com
Klaus.schulz@sodaja.com

Outline

- Bandwidth Demand
- Telecom vs. Datacom
- Module History
- Modules < 10 G
- Modules > 10 G
- Market Trends
- New Formfactors
- Summary

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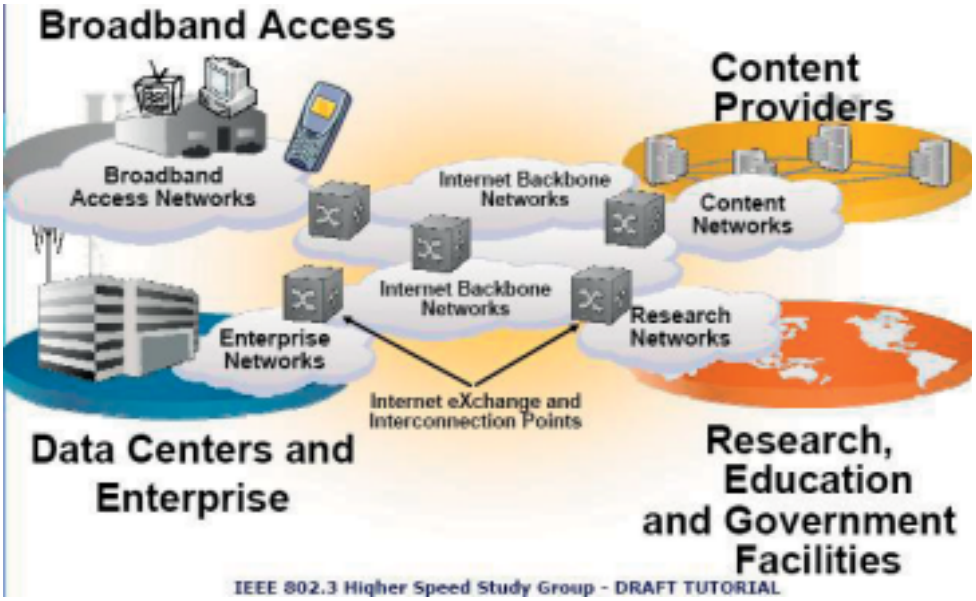
Bandwidth Demand – Bottle Necks



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Telecom vs. Datacom

Telecom – Discrete

- Laser → Butterfly
- Receiver → Butterfly
- EDFA → spec. Housing
- AWG → spec. Housing
- Add-Drop → spec. Housing

ROSA/TOSA → XLMD-MSA
Module → 300 pins MSA

WAN; MAN; LAN
L >> 40 km

Datacom – Integrated

Transmitter
Receiver } Transceiver
serial I/O
+
additional functions
parallel In/serial Out

Transponder

LAN; SAN; CO; Server Farms
2 m < L < 40 km

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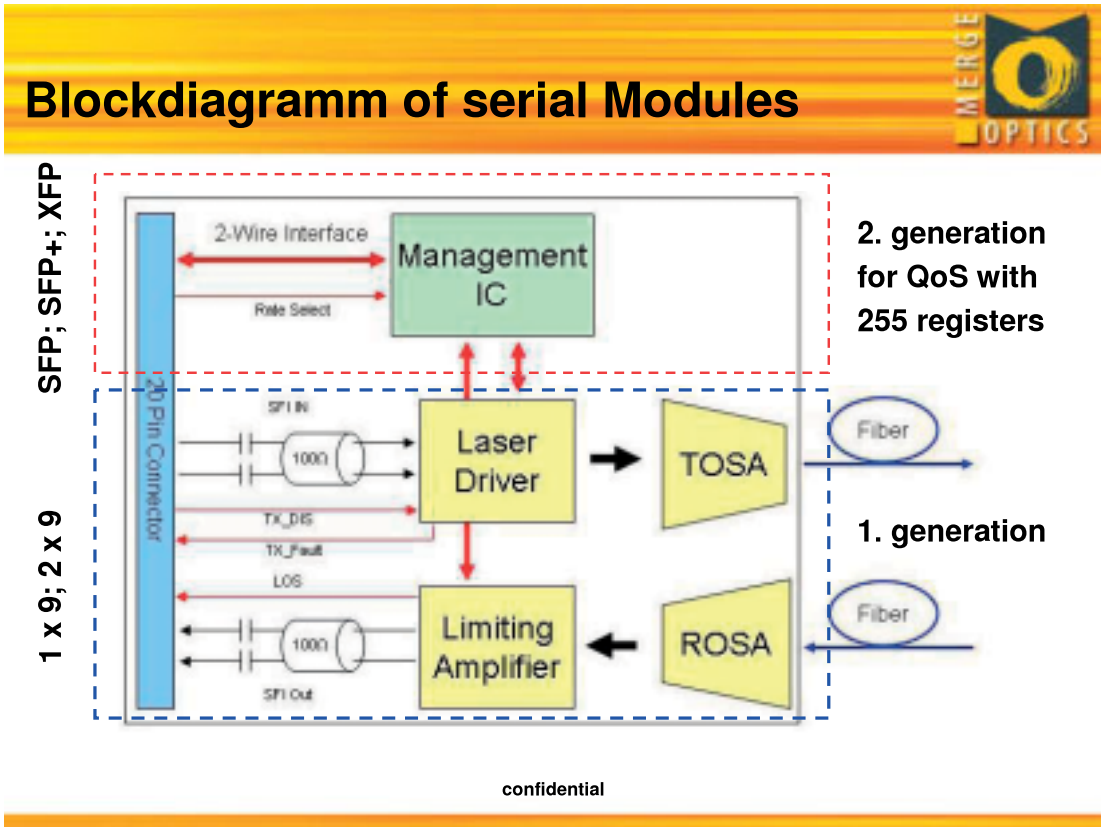
Blockdiagramm of serial Modules
MERGE OPTICS
SFP; SFP+; XFP
1 x 9; 2 x 9
2-Wire Interface
Rate Select
Management IC
20 Pin Connector
SFI IN
100Ω
Laser Driver
TOSA
Fiber
TX_DIS
TX_Fault
LOS
Limiting Amplifier
ROSA
Fiber
100Ω
SFI Out
2. generation for QoS with 255 registers
1. generation
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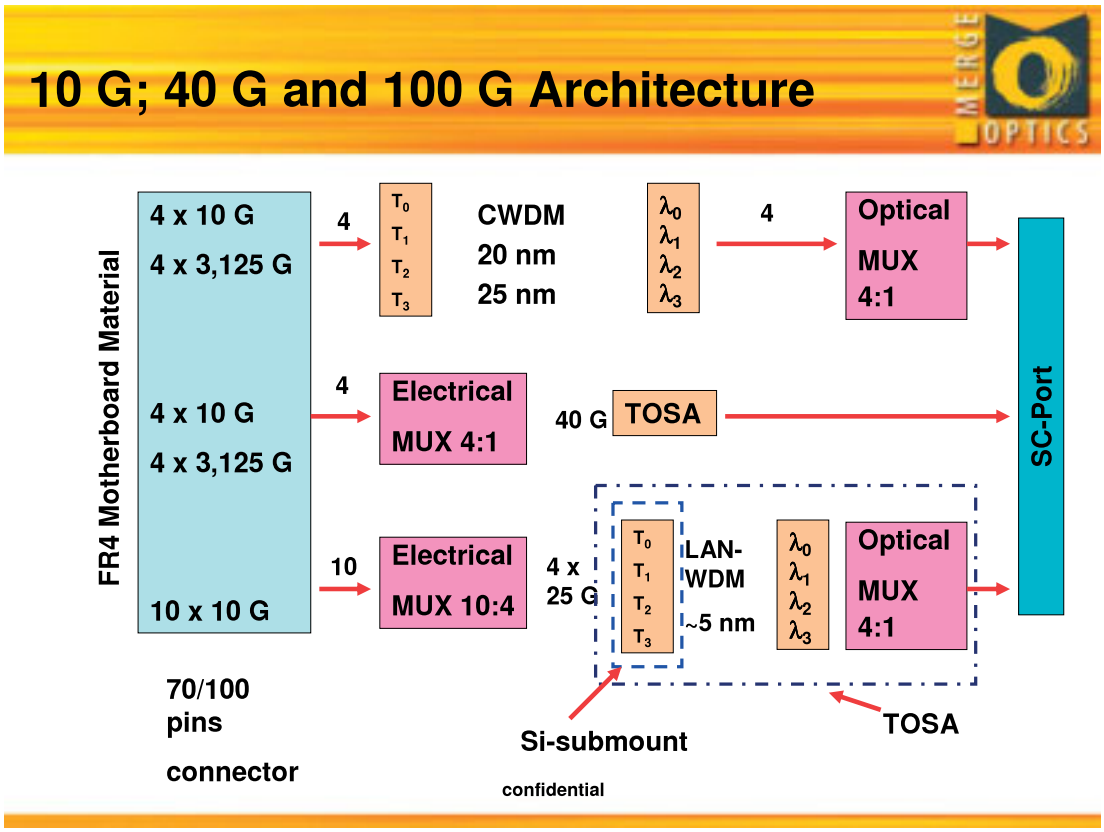
10 G; 40 G and 100 G Architecture
MERGE OPTICS
FR4 Motherboard Material
4 x 10 G
4 x 3,125 G
4 x 10 G
4 x 3,125 G
10 x 10 G
4
4
10
T0 T1 T2 T3
CWDM
20 nm
25 nm
λ0 λ1 λ2 λ3
4
Optical MUX 4:1
Electrical MUX 4:1
40 G
TOSA
Electrical MUX 10:4
4 x 25 G
T0 T1 T2 T3
LAN-WDM
~5 nm
λ0 λ1 λ2 λ3
Optical MUX 4:1
SC-Port
70/100 pins connector
Si-submount
TOSA
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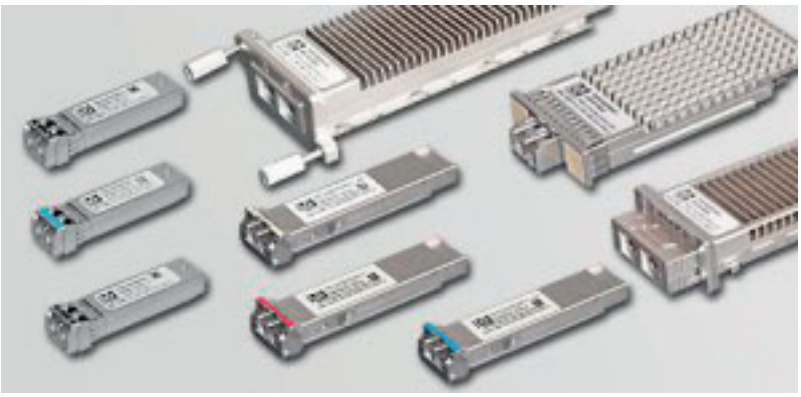
10 Gbit/s pluggable Modules



SFP+	XFP	X2/XPAK/XENPAK
20 pins	30 pins	70 pins
serial I/O	serial I/O	parallel In/serial Out
LC-Duplex	LC-Duplex	SC-Duplex
13 mm	17 mm	45 mm

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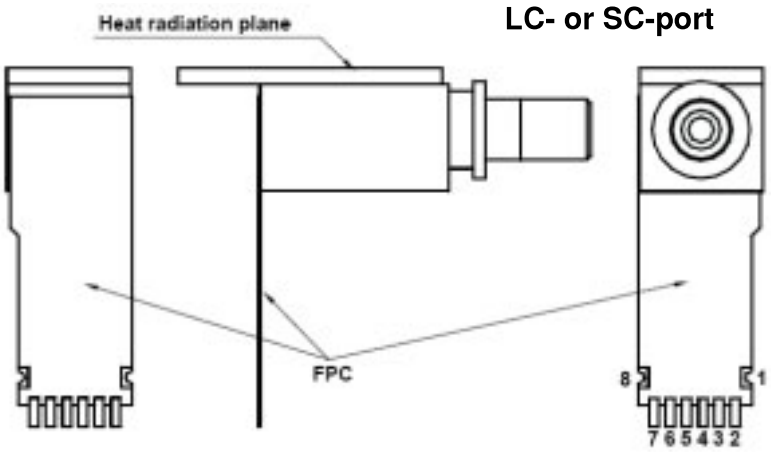
XMD-MSA TOSA w.ith TEC



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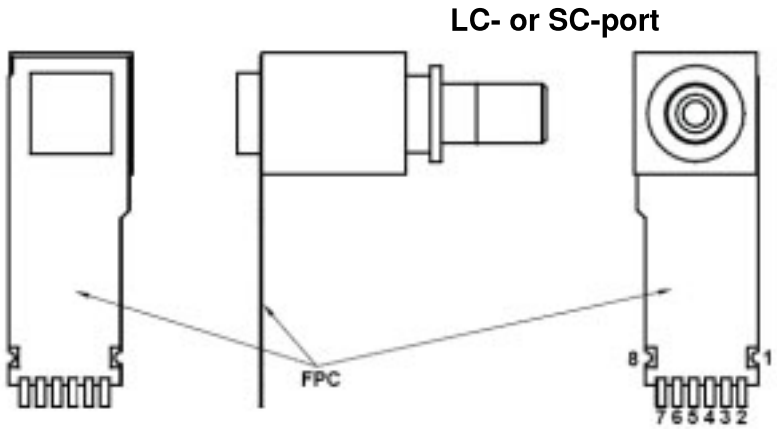
XMD-MSA ROSA (APD; PIN PD)



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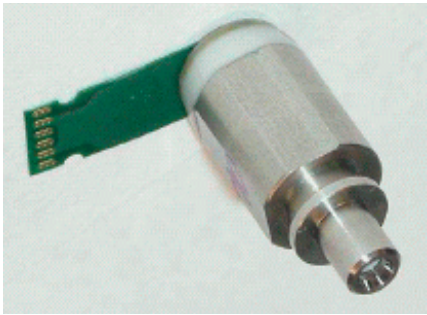
XMD-MSA ROSA/TOSA



Cubicle Housing

Cylindrical based on TO-can

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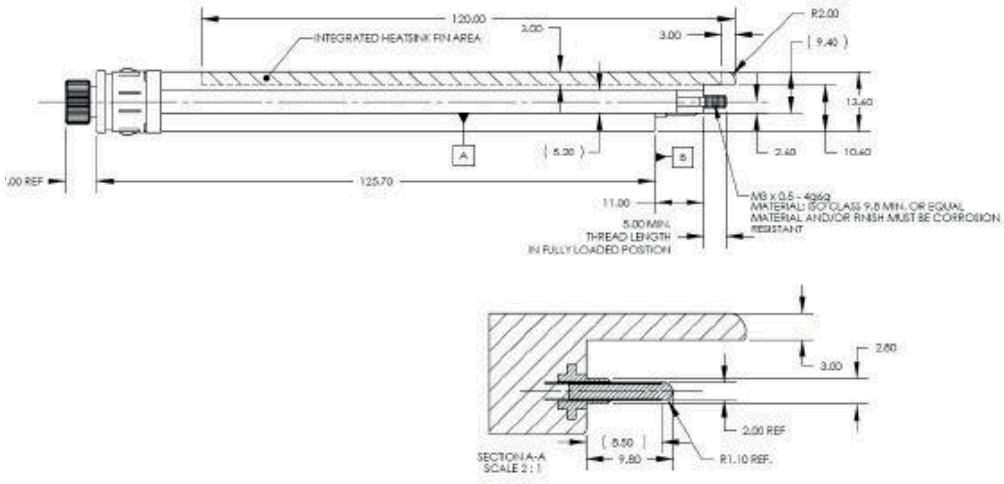
100GBASE-LR4
CFP-Module side view (1)



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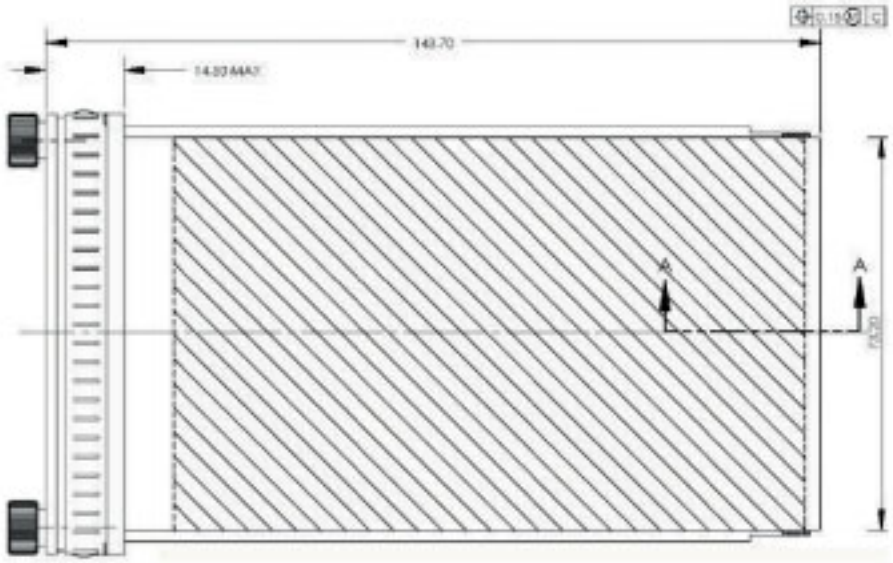
100GBASE-LR4
CFP-Module top view (2)



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Packaging TOSA - ROSA

100GBASE-LR4

- OptoPack → single transmitter with optical MUX
- XMD-MSA → single transmitter with optical MUX
- SOI → 4 EEL on substrate withTEC, MUX integrated

40 Gbit/s-Module

- OptoPack → single transmitter (new HTCC)
- XLMD-MSA → single transmitter

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Target Specifications

Optical multiplexed

- 4 x 25 Gbit/s 100GBASE-LR4; O-band Datacom → 10 km
- 4 x 25 Gbit/s 100GBASE-ER4; O-band Datacom→ 30 km, 40 km

Electrical multiplexed, optical serial

- 40 Gbit/s O-band; Datacom 2 km

Optical multiplexed

- 4 x 25 Gbit/s C-band; Data-/Telecom → 10 km

Electrical multiplexed, optical serial

- 40 Gbit/s C-band; Data-/Telecom → 2 km

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100GBASE-LR4 EML Requirements

- Highly integrated devices
- Reliable components (temperature, humidity and time; Harsh Tests)
  - Hermetic packaging
  - Devices should be flip-chip able and bondable
  - Large and reliable bond pads
  - Mountable on a micro TEC
- Sufficient laser output power to compensate optical MUX and DEMUX insertion loss (~4-5 dB)
- Optical isolator
- TOSA packaging connected with flex-circuit or BGA to module board

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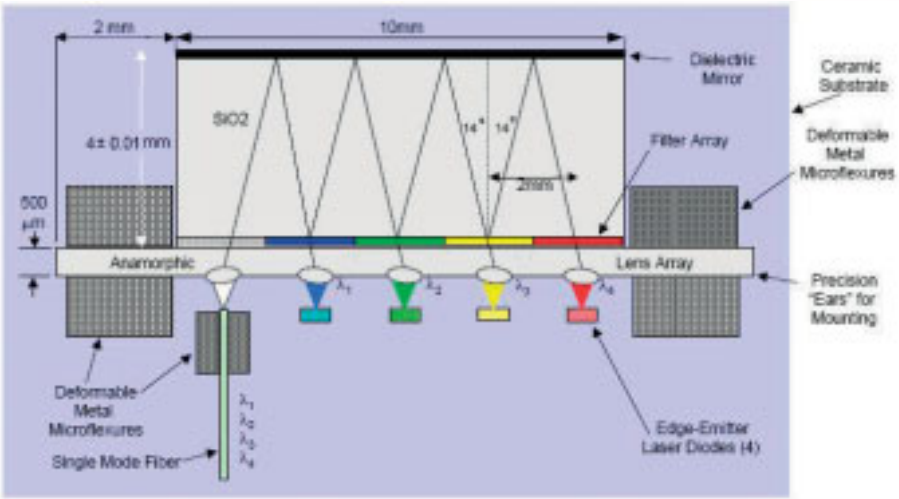
Quad-MUX TOSA (schematic)



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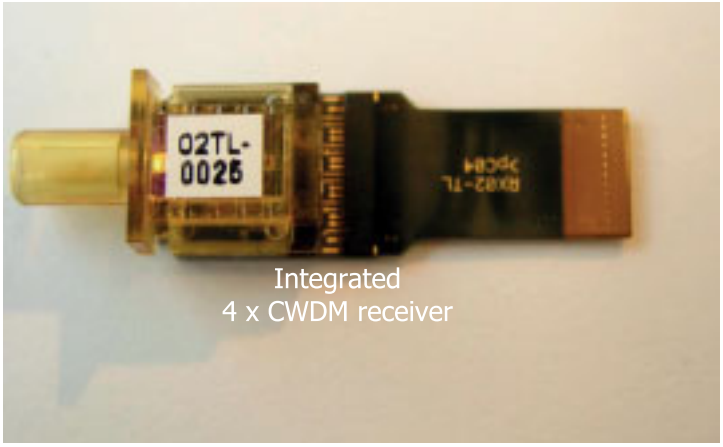
Quad-DEMUX ROSA



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Market Trends

- Compact Transceiver
- Short Interconnects ~10 Gbit/s
  - Server Farms/Cluster
  - Office Network
- MM-Technology
- SM-Technology → 40 Gbit/s (4 x 10 Gbit/s)
- Active optical cable
  - Multifiber Systeme(10 x 10 Gbit/s; 12 x 10 Gbit/s)
  - Multiwavelengths → MUX/DEMUX
- FTTx

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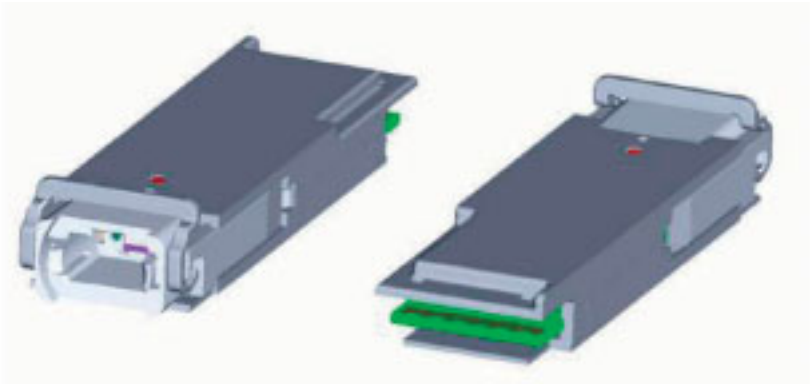
QSFP 4 x 10 G; 850 nm
CXP 10 x 10 G; 850 nm
AOC 12 x 10 G; 850 nm

QSFP-Module



Optical I/O 1 x 12 MPO

Width 19mm

Electrical I/O 38 pins

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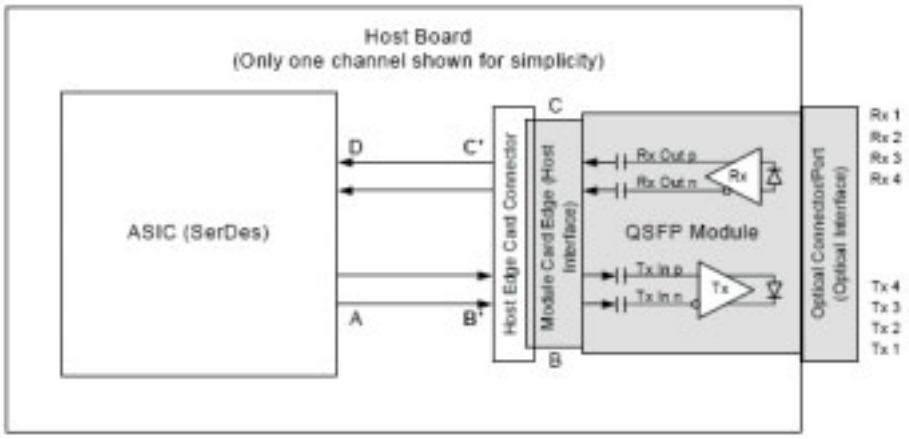
QSFP - Blockdiagramm



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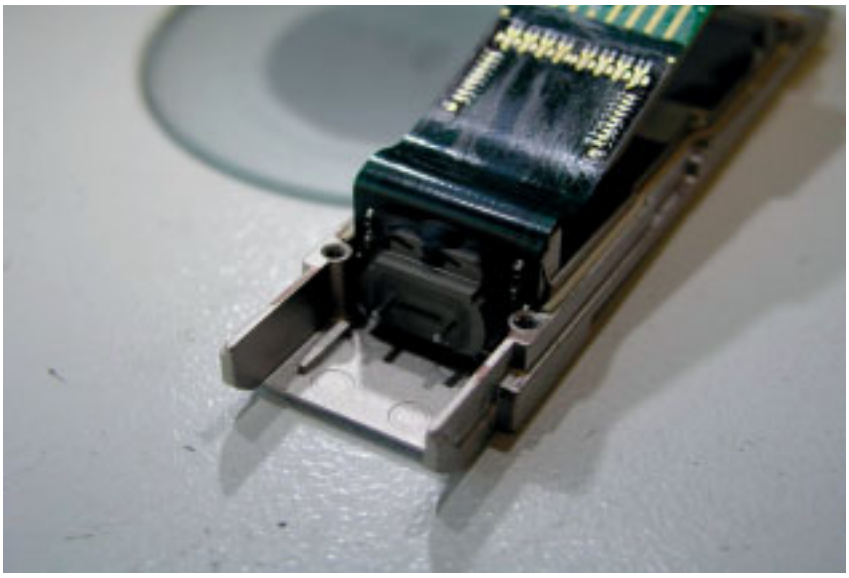
QSFP view of optical Port



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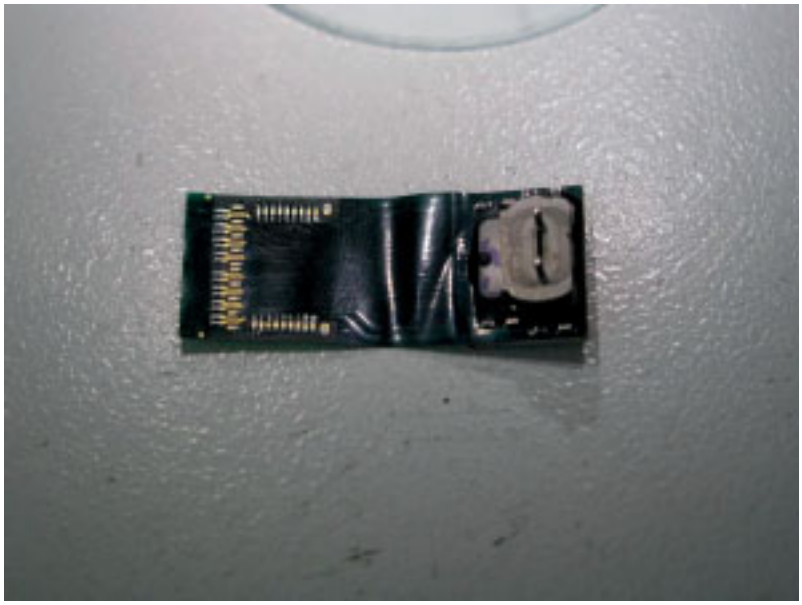
QSFP ROSA/TOSA w. FPC



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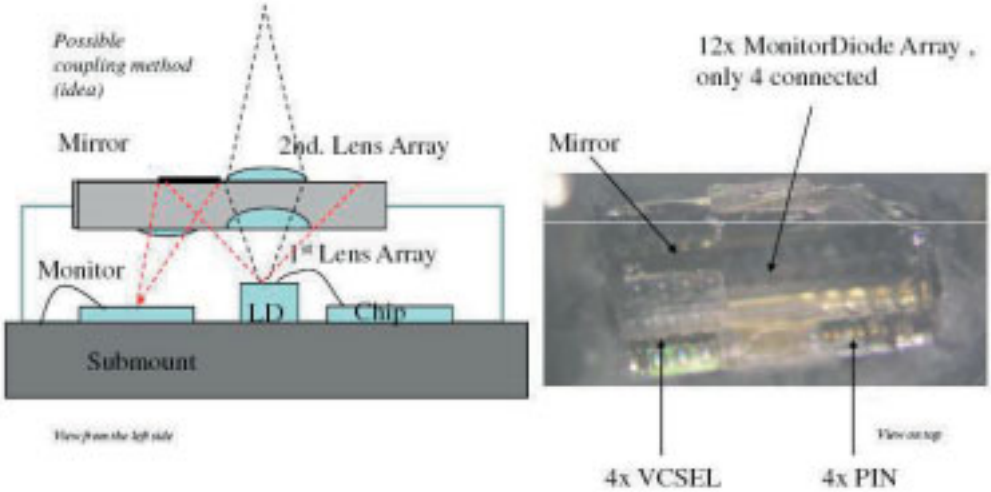
QSFP ROSA/TOSA Microoptics



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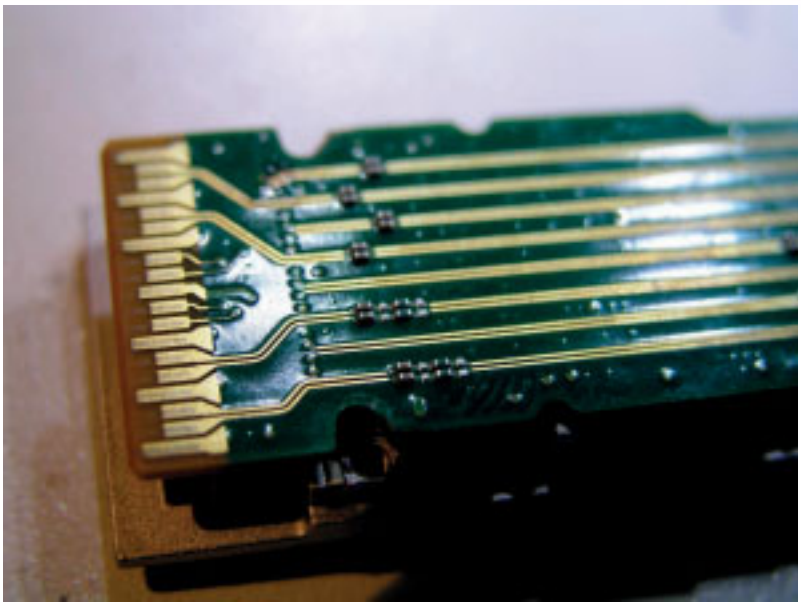
QSFP electrical I/O



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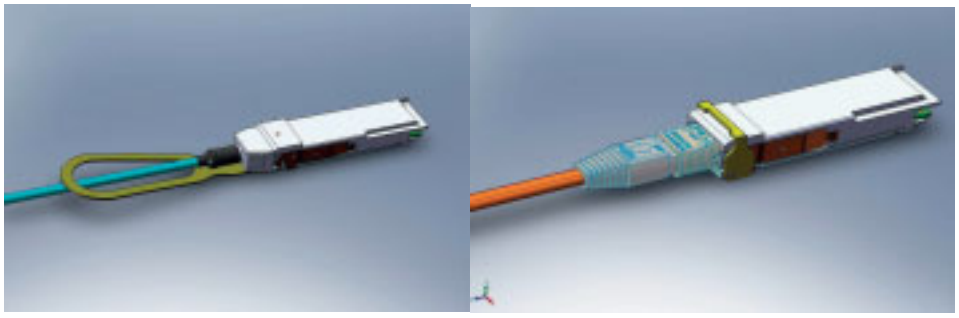
AOC – QSFP 4 x 10 Gbit/s



QSFP w. integrated Cable QSFP w. plugged Cable

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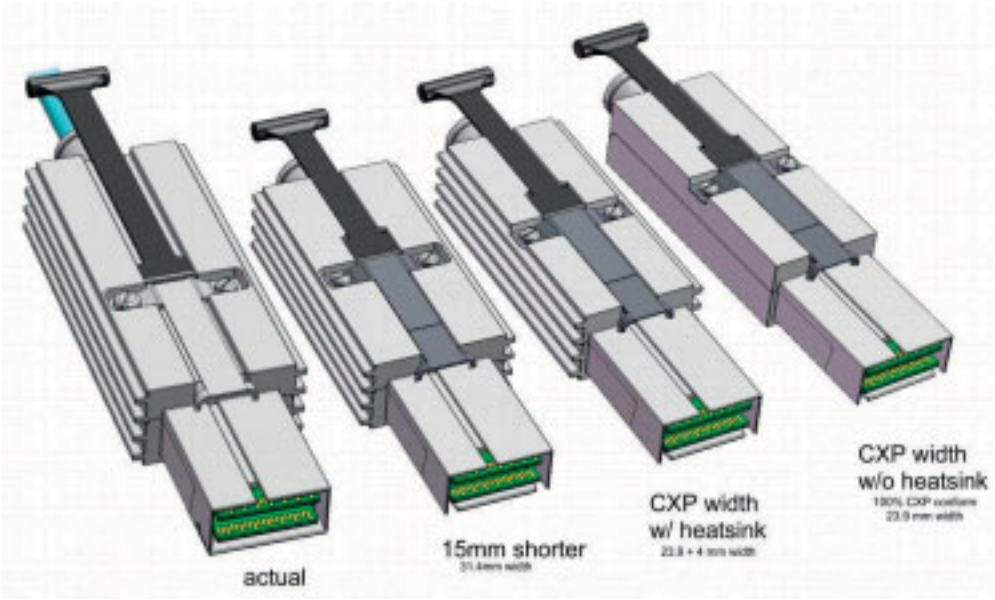
Evaluation of CXP-Modules



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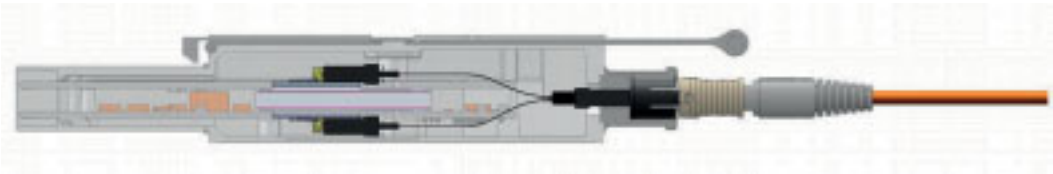
CXP-Module (cross section)

1 x 12 MT-Ferrule **2 x 12 MPO**



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Fan Out Cable – 12x10G → 3x4x10G

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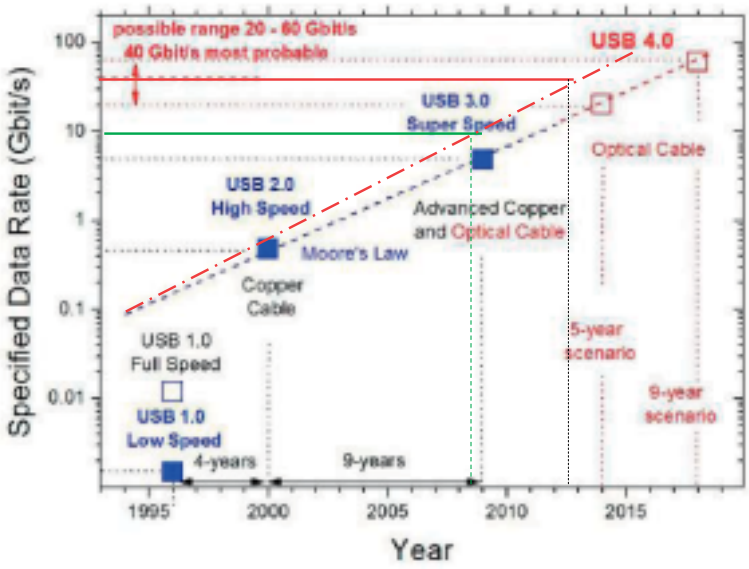
Optical Interconnects
Office Networks
Electrical USB → Optical USB

Short Interconnects



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Converged I/O Interface (1)

- Architecture Specification
- Revision 0.8
- September 2008
- The information in this document is subject to change

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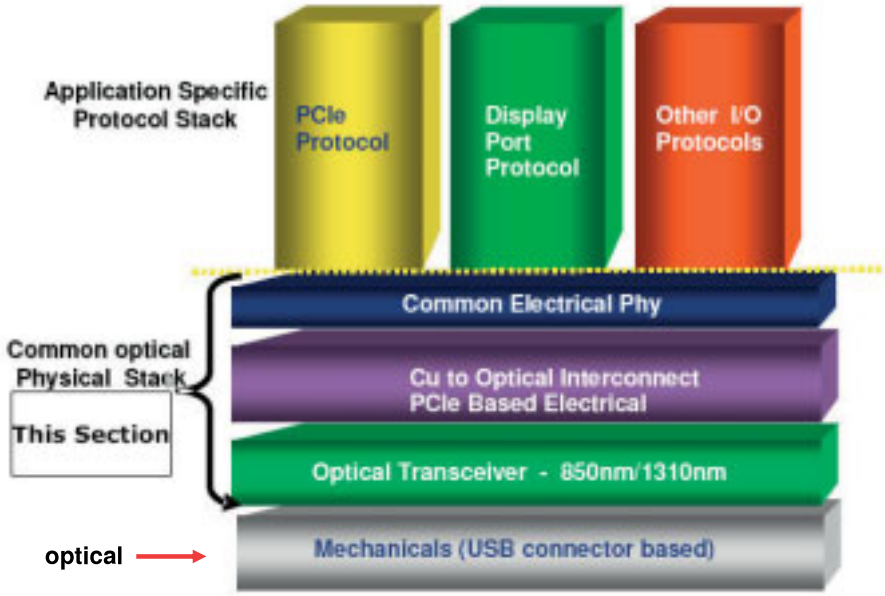
Converged I/O Interface (2)



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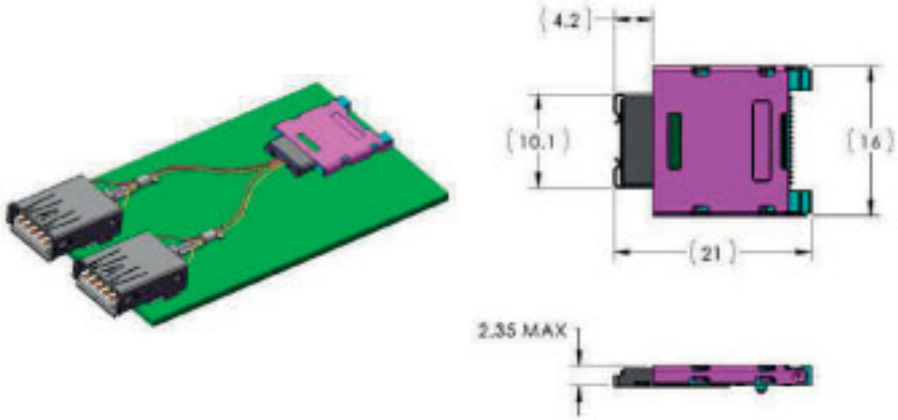
Converged I/O Interface (3)



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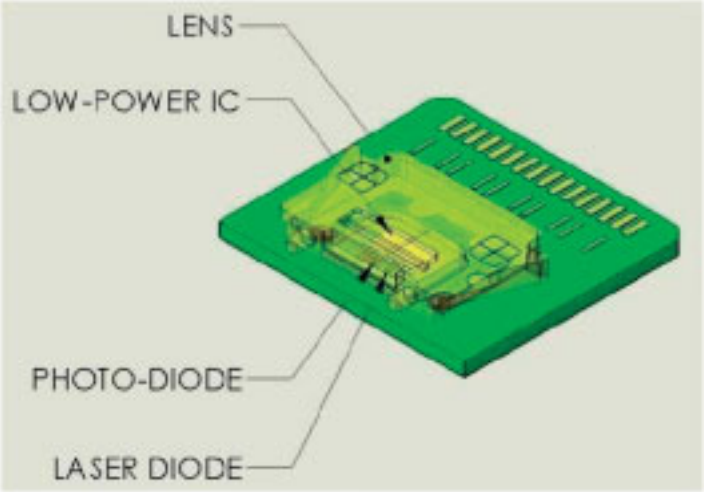
Optical Transceiver 2 Channels



2 x 10 G; 850 nm; <10 m; MT connector; SMD

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Summary

- 40 G and 100 G in progress
  - 40 G → 4 x 10 G electrical mux, optical serial
  - Next generation of QSFP w. SC-Duplex port
  - 100 G → 4 x 25 G electrical mux & optical mux
- Short Interconnects dominated by 850 nm
  - QSFP 4 x 10 G
  - CXP 10 x 10 G
  - AOC 12 x 10 G
  - Converged I/O 2 x 10 G

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Optical coupling using planar thin glass based waveguide components

H. Schröder[a)], L. Brusberg[a)], N. Arndt-Staufenbiel[b)], T. Tekin[b)]

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[b)]Technische Universität Berlin, Germany
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phone: +49 30 46403 277 fax: +49 30 46403 271
email: henning.schroeder@izm.fraunhofer.de

ABSTRACT

We introduce new optical coupling elements for electrical-optical circuit boards, sensors and to bridge the growing field of nano-photonics to the micro-photonic periphery. It is a photonic packaging technology using thin glass foils. Novel innovative features are added to this technique to leverage its generic usage.
Keywords: thin glass, ion exchange, optical interconnects, sensor, electrical –optical circuit boards

1. INTRODUCTION

Nano-photonics and electrical-optical integration are rapidly growing fields with a strong potential for applications in a wide spectrum covering optical sensors, data & telecom, respectively. Its merit of ultra compactness becoming also a challenge since the periphery remained micro-level.

New packaging and integration technologies are a key issue for innovative products. The *glass*Pack concept combines common technologies of printed circuit board (PCB), silicon integrated circuit (IC), micro-electro-mechanical-system (MEMS), and integrated optic (IO) industries to a novel packaging concept to realize electronic, optical, and optoelectronic multifunctional packages. The growth rates of the flat panel display (FPD) market lead to a mass production of borosilicate thin glass substrates such as Schott D263T™ having a thickness of 0.03 to 1.1 mm and constantly high quality. These thin glass substrates are available in different formats have excellent optical, electric, thermal, mechanical, and chemical properties, which make it suitable for harsh and hazardous environments or applications in the field of optical sensing and data communication. The *glass*Pack is based on using thin glass substrates of different brands as substrate material.

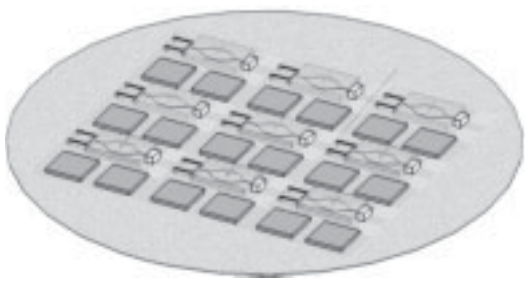

Figure 1: glassPack technologies processed on wafer level.

The choice of appropriate glass depends on the application. Optical waveguides and fluidic channels will be implemented inside the thin glass substrates. Electrical feed troughs' and wires on the surface form electrical circuits. Integrated waveguides, fluidic channels, or electrical wires implemented in various thin glass substrates can be stacked at wafer level (Figure 1), resulting in 3D-packages [1]. This paper focuses on the possible optical coupling schemes which are addressed within the *glass*Pack concept: Butt coupling and out of plane coupling in different ways and for different application areas.

2. *GLASS*PACK TECHNOLOGY

The technology of the *glass*Pack concept relies on the realization of the passive optical waveguides within the thin glass substrates. Our technology for planar integration of optical waveguides below the surface of thin glass substrates is the silver ion-exchange technology. The resulting single- or multi-mode waveguide are characterized by a graded refractive index profile. The waveguide manufacturing consists of two processes in a molten salt at a temperature of 350°C. A structured alloy mask deposited on the surface of the thin glass substrates supports the local confined diffusion process between the glass and the salt melt [2]. The ion-exchange technology is suitable for optical circuits containing straight or curved waveguides, tapers, splitters, Mach-Zehnder interferometers, and further integrated planar optical structures below the surface of the thin glass substrates [3].

One further benefit of using thin glass substrates is the possibility of direct fusion bonding to silica fibers. The fiber end face is positioned in front of the polished end face of the integrated waveguide. A CO_2-Laser beam focused on the bonding zone melts both bond partners about the annealing point and fuses them together. A reliable bond without intermediate layer results [4].

3. OPTICAL COUPLING

3.1 In plane coupling

In the sensor demonstrator realized recently [1] the photo diodes and the laser chips are butt coupled to the waveguide chip. This approach is quite common and the coupling efficiency depends on the beam properties of the laser as well as the waveguide profile which can be adopted by controlling the diffusion parameters. In Figure 2 the position of the butt coupled components are shown. Most critical is the active alignment of the Mach-Zehnder-waveguide plate to the very little already assembled laser dies (left inset).

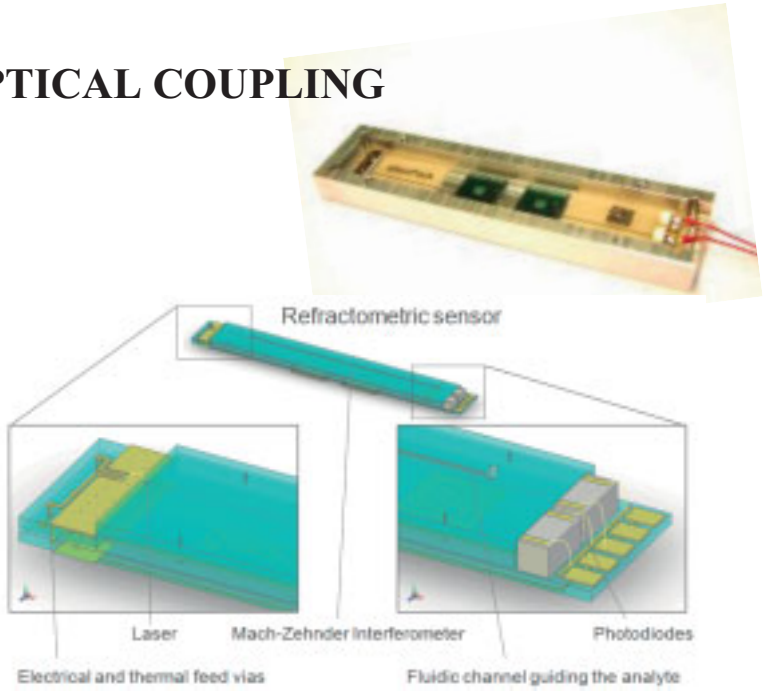

Figure 2: Design and photograph of the realized refractometric sensor with integrated MZI and fluidic channels, and optoelectronic components. The sensor has a length of 80 mm and a width of 10 mm

3.2 Out of plane coupling

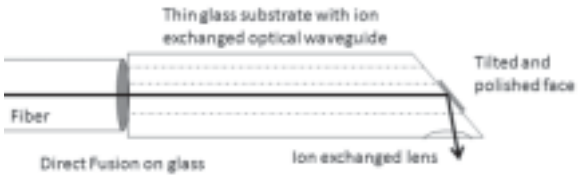

Figure 3: Schematic drawing of optical coupling element using the glassPack technology with beam deflection.

As it can be seen from Figure 3 the main features of the concept are the very thin glassy substrate with integrated optical waveguides and lenses made by ion exchange. At one end of the waveguide integrated thin glass a micro-machined optical surface can be used as optical mirror for beam deflection. For improvement of beam reflectivity the surface can be covered by high reflecting materials. The angle of deflection can be well defined related to the field of application. On the other end of the waveguide integrated thin glass, fiber and fiber array connectors are be possible.

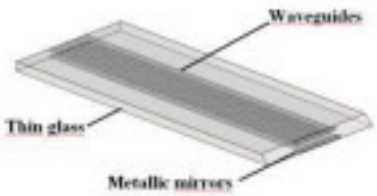

Figure 4: 90 degree beam deflection element with planar waveguide arrays on top and bottom side and metallic coated 45 degree mirror plane

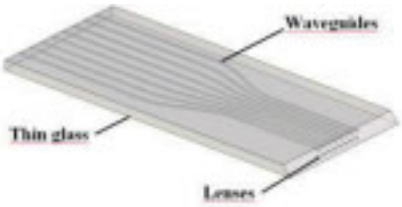

Figure 5: Out-of-plane coupling element with planar fan-out waveguide structures on top and planar integrated GRIN lenses on bottom side

The coupling element itself can be realized as single layer element or as a stacked sandwich of thin glasses to realize more complex optical functions and mechanical properties. But even in single layer glass foils more optical functionality can be integrated by means of a double side ion exchange process. Waveguides are well aligned vertically and the 45 degree mirror plane is polished very precisely in order to achieve a 90 degree beam deflection element for double layer waveguide arrays (Figure 4). Moreover as depicted in Figure 3 and Figure 5 an ion exchanged lens array in the bottom layer can be integrated to focus the out coming light to a small PD or vertical grating structure of silicon photonics chips.

Of course the mirror plane can be polished in arbitrary angles to achieve other design compliant deflection angles. Furthermore the fiber interconnection with appropriate pitch (e.g. 250 µm) is crucial. The high potential of the novel concept is based on scope for design of planar integrated waveguide arrangements like fan-out, fin-in and splitting structures. Different waveguide arrangements are caused by the application target.

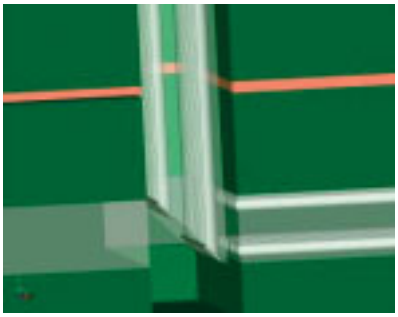

Figure 6: Schematic drawing of optical out-of-plane coupling to embedded optical layers like thin glass foils with ion-exchanged waveguides which are laminated together with prepreg and copper layers.

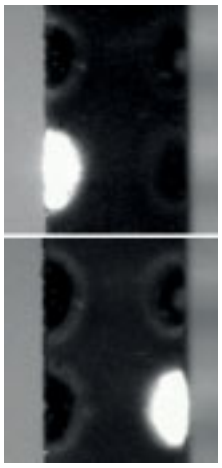

Figure 8: (upper) Light coming out of the position A (Figure 7) and (lower) light coming out of the position B

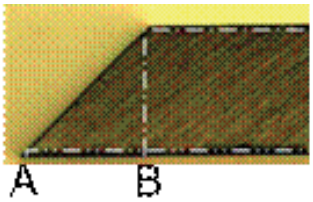

Figure 7: 45 degree polished thin glass substrate with double layer ion exchanged optical waveguides. Dashed lines indicate both of the waveguides. A and B indicate the position of the out of plane coupled beams.

Furthermore as shown in Figure 6 thin glass elements with double waveguide layers can be used for EOCB out-of-plane coupling as well. This approach takes advantage from two major points: First the coupling element is made of waveguides and do not suffer from variations in height to the daughter card or backplane caused by PCB thickness variations. Secondly the coupling element is made from the same material by ion-exchange like the board layer waveguides itself as introduced in [2]. So a very good mode field adoption can be realized. The coupling element fits into connector elements as introduced in [5] for PCB integration. In Figure 7 and Figure 7 the deflection and the out coupling is demonstrated.

4. SUMMARY

We have demonstrated coupling concepts as part of our generic *glass*Pack technology using thin glass foils. The benefit of glass results in excellent optical, electric, chemical, and thermal properties. Suitable technologies like ion-exchange, laser drilling, electro-plating, and fusion bonding and direct optical butt coupling are used for the refractometric sensor and show high potential to realize integrated wafer level packages in glass. Furthermore waveguide array coupling elements of very flexible design are demonstrated to realize out of plane coupling. So such kind of coupling elements can be applied for multimode and multilayer optical coupling of electrical-optical circuit boards (EOCB) and to interconnect single mode silicon photonic wires through high-index contrast vertical gratings to the micro optical periphery.

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Optical link for high-speed board-level parallel interconnections

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ABSTRACT

This paper demonstrates a complete short-distance parallel optical interconnection on PCB-level basing on ceramic transmitter/receiver modules for high-speed signal conversion, integrated polymeric waveguides and the optical coupling elements. The novel technology for the structuring of PCB-compatible high density parallel optical interconnects will be described in detail. The solution for the optical coupling into the integrated waveguides is based on a micro-optical indirect coupling element with wave guiding structures. The demonstrated optoelectronic modules are 4-channel BGA ceramic multi-chip modules with 4 x 10 Gbps transmission capacity

Keywords: short-distance optical interconnects, PCB-level interconnects, integrated optics, optical coupling, polymeric waveguides, MCM

1. INTRODUCTION

Further advances in bandwidth of data and telecommunication systems will need to take advantages of optical packaging technologies. The challenge for optical interconnections at board- and backplane-level is the cost competitive implementation in standard electrical substrates. Hybrid electro-optical printed circuit boards with integrated optical waveguides allow for maximum interconnect density and more functionality in the opposition to available solutions for short-distance interconnects, which are using fibers or fiber-ribbons. There are several waveguide fabrication techniques, which are promising for the integration of an optical layer into the hybrid PCB as a light-guiding media [1-5]. The used materials have to meet several requirements, which are related to conditions during waveguide processing, as well as during the integration in printed circuit boards. Essentially polymer materials have established themselves, because of theirs advantages in compatibility with current printed circuit board fabrication. Further development of copper based signal transmission shifts the implementation requirements towards higher data rates. Commercially viable technologies already enable electrical transmission with a bandwidth-length-product of more than 10Gbit/s*m [6]. These are, however, much more space and power consuming at given data rates than the optical technologies. This growing bandwidth demand calls for the development of novel optical transmitters and receivers that combine high performance and low packaging complexity at low-cost. Another challenge remains in the effective light coupling from the optoelectronic device (laser or photodiode) into the integrated waveguide.

2. INTERCONNECT CONCEPT

The concept for the optical link shown in Fig. 1 bases on the requirements for short-distance parallel interconnects on the PCB-level. The optical interconnect consists of three main parts: transmitter/receiver module, optical coupling element and the PCB-integrated waveguide.

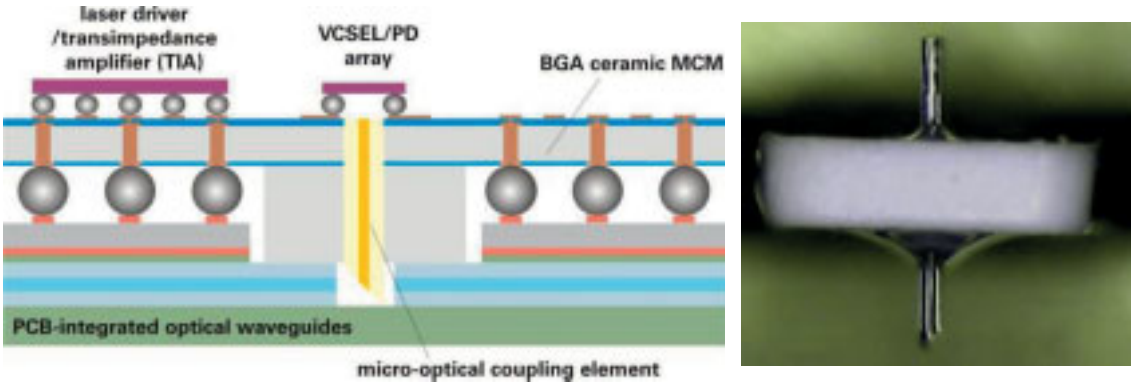

Fig. 1. Concept of printed circuit board integrated optical interconnect (left) and the side view of 1x12 array of coupling fibers mounted in ceramic carrier (right)

The transmitter/receiver module integrates the function of electrical-to-optical signal conversion (and reverse) with the high frequency modulation (goal 10 Gbps). The solder-bumped flip chip (FC) bonding technology used for the assembly of optoelectronic array devices takes advantage of the self alignment feature. Furthermore, the package is a ceramic ball-grid array (BGA) package, which is characterized by its cost effectiveness and compatibility with the standard SMT process. The concept assumes indirect optical coupling between the OE devices and the PCB-integrated waveguides, which are implemented by a separate micro-optical coupling element. It consists of a 45° mirror surface (total internal reflector) for light deflection. The element was fabricated using standard fiber ribbon – up to 12 multimode silica fibers with core and coating diameters of 50 µm and 125 µm respectively, and pitch of 250 µm. The 45° mirror surface was realized by a wet grinding and polishing process. The fibers are fixed into the ceramic carrier, which has a mechanical function enabling a passive alignment in three dimensions (Fig. 1). The alignment in the plane parallel to the PCB surface is realized by using metal pins, similar to the alignment pins in the commercial multi-fiber MT-connectors. The ceramic carrier for the micro-optics acts as a spacer allowing for an adjustment in z-direction. The used concept for coupling element fabricated using wave-guiding structure (fiber) features no beam widening for different axial distances between the active device and waveguide.

3. POLYMER OPTICAL WAVEGUIDES

Following the trends for the optical interconnects on the printed circuit board level (including requirements regarding the structural dimensions, fabrication process demands and optical performance) an novel method for the structuring of integrated waveguides has been developed. This galvanic build-up approach of “waveguide-in-copper” technology includes electroplated copper channels coated with sol-gel SiO_2-TiO_2 under cladding layer and optical adhesives as core and upper cladding material. This technology features a pitch of 250 µm and structural dimensions of < 100 µm. The respective technology is highly compatible with standard PCB processes. The Fig. 2 shows the cross section of processed

waveguides with the core dimensions of approx. 90 µm x 60 µm and the pitch of 250 µm. Because of use of materials with different refractive index, the waveguides features asymmetric optical structure with the numerical aperture (NA) of 0.17 for core - under cladding interface and NA = 0.29 for core - upper cladding interface.

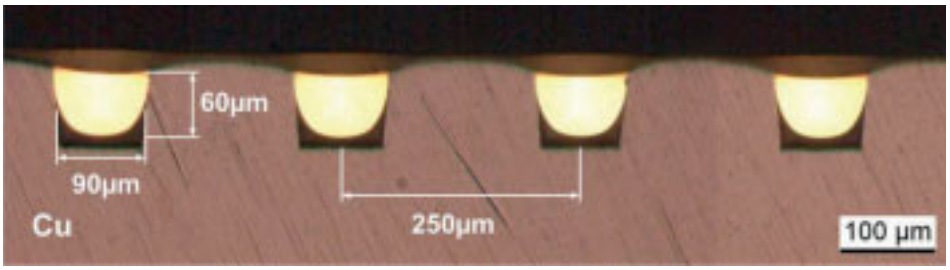

Fig. 2. Endfaces of a backlit waveguides with 250 µm pitch and 90 µm x 60 µm core areas in the galvanic build -up approach of "waveguide-in-copper" technology

The minimal waveguide attenuation of 1.03 dB / cm was determined on the basis of the so-called cut-back method. The comparably large attenuation of the waveguides can be mainly ascribed to the geometrical imperfections of waveguide core. Optimization of fabrication process should decrease the insertion losses of the waveguides.

4. OPTICAL INTERCONNECT DEMONSTRATOR

4.1 Ceramic optoelectronic multi-chip module

This SMT-compatible optical multi-chip module integrates active optoelectronic devices and as well as control electronics (laser driver and receiver amplifier) for transmitting and detecting of high-speed signals (up to 10 Gbit/s). The used optoelectronic devices are bare die 1x12 arrays of VCSELs and the p-i-n PDs with device pitch of 250 µm. The GaAs VCSEL array features lasing at 850 nm wavelength, beam divergence of 18° (full width at $1/e^2$), nominal optical power of 1 mW and 10 Gbps modulation (reported in [7]). The GaAs p-i-n PD arrays have an active area diameter of 70 µm and responsivity of 0.5 A/W around 850 nm. The electronics (LDD and TIA) are SiGe devices designed for data rates up to 10.7 Gbps. The VCSEL driver features CSP (chip size package) solder-bumped package (figure 6 - left), conformal to SMT process. In order to minimize the parasitics by shortening of interconnection length flip chip connection using Au stud bumps was chosen for the TIA ICs, which was available only with pad metallization suited for wire bonding. Both ICs are single channel devices. In order to demonstrate a feasibility of the proposed concept a 4-channel transmitter/receiver module was designed. The assembly of OE devices requires fluxless process to avoid the contamination of sensitive optical interfaces. The proposed approach for a flip chip bumping/assembly process implies the application of cylindrical solder preforms using lead free solder alloy (SnAgCu) as a bump material and the use of plasma treatment in order to remove oxide films from the preforms and activating the pad surface to achieve sufficient wetting. The soldering is performed in an inert gas atmosphere (nitrogen N_2) enabling the flux free flip chip assembly process of the optoelectronic components. As interposer material a 96% alumina ceramic (Al_2O_3) with the thickness of 635 µm was used. This material provides excellent mechanical and thermo-mechanical properties. Its coefficient of thermal expansion (CTE) of 6.7 is almost matched to the CTE of OE devices substrate material ($CTE_{GaAs} = 5.7$), which reduces the thermo-mechanical stress.

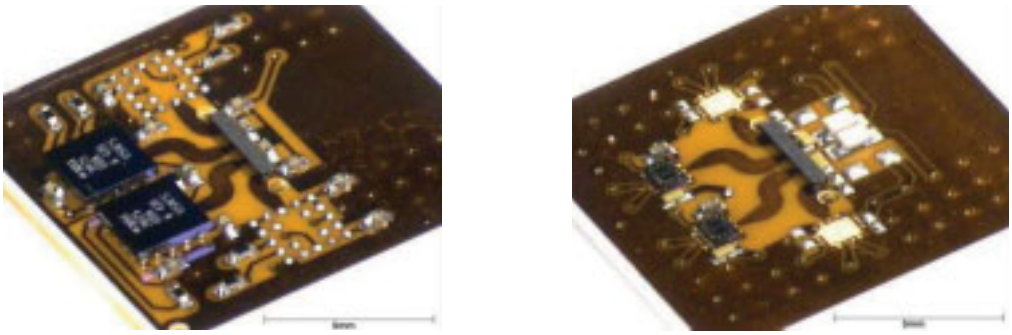

Fig. 3. Top view of assembled transmitter (left) and receiver (right) demonstrator

This mismatch et al. determines the reliability of the interconnection. Furthermore the high thermal conductivity of alumina promotes the effective heat transport of the dissipated power. The resulting transmitter and receiver demonstrators are 4-channel BGA ceramic MCMs with 4 x 10 Gbps transmission capacity and 96 BGA balls with a pitch of 1 mm placed on ceramic interposer with dimensions of 13 mm x 13 mm (Fig. 3).

4.2 Electro-optical printed circuit board

In order to supply the OE transmitter (Tx) and receiver (Rx) MCMs with electrical (HF, supply and control) signals a hybrid (electro-optical) printed circuit board (EOPCB) with integrated optical waveguides has been designed and implemented. The target was the realization of 4-channel demonstrator board for the assembly of developed BGA ceramic multi-chip modules and embedded parallel short-distance optical interconnection. The BGA pad structure for the Tx (right) and the Rx (left) module can be seen in the central section of the PCB (Fig. 4). The high frequency signals are transported with microstrip lines from the SMA connectors to the Tx/ Rx modules. The glass reinforced ceramic low loss laminate was used as the base material. All assembly components are devices for SMD process. The optical layer includes straight parallel optical waveguides fabricated in the additive “waveguide-in-copper” technology. This layer is laminated with the electrical layer, which results in hybrid printed circuit board. In the Fig 4 the optical layer with holes for passive alignment of the micro-optical coupling element can be seen through the opening in the HF laminate. In this place the ceramic carrier/spacer with micro-optics will be inserted. It enables the mechanical decoupling between the optical and electrical connections, which are characterized by different tolerance requirements for the assembly.

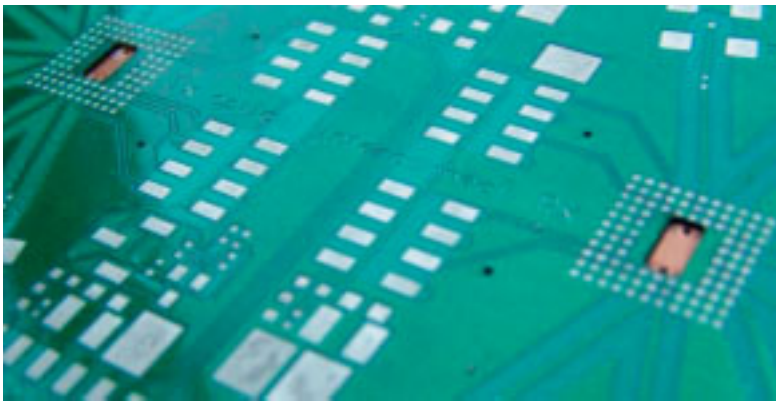

Fig. 4. Electro-optical printed circuit board demonstrator with the opening in the HF laminate showing integrated optical layer

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Multi channel coupling elements for optical printed circuit boards and optical backplanes

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ABSTRACT

We present multi channel optical interconnects, based on integrated glass fibers, with passively aligned in-plane and 90° out-of-plane couplers for printed circuit boards. The out-of-plane coupler features micro optics, mechanical alignment structures, and a snap-fit system to assemble the complex coupler out of several simple, self aligning parts. Further we present an optical printed circuit board for on-board transmitter and receiver electronics for four channels using 4×10 Gbit/s transmitter and receiver chips.

1. INTRODUCTION

Telecommunication and data acquisition systems are dealing with ever increasing data rates. At a certain point the integration of optical interconnects into printed circuit boards is getting a promising approach due to low signal distortion, low attenuation, no crosstalk, simple modulation schemes and easy demodulation. In addition optical interconnects provide signal transmission with reduced electromagnetic interference (EMI). This is important especially for mixed-signal systems, where high accuracy analog electronics for sensor applications meets high speed digital electronics for data acquisition and signal processing. Electrical isolation between transmitter and receiver might also be advantageous, especially in medical applications.

A common approach to enhance transmission capacity is to parallelize optical channels, but even if the data rate of a single channel would be sufficient, the use of multiple parallel channels might reduce the system complexity in the front and back end electronics when multiplexers and demultiplexers can be saved.

In this paper we present multi channel board level optical interconnects, based on integrated glass fibers, with passively aligned in-plane and out-of-plane couplers. The out-of-plane couplers are made of several simple prismatic parts, which are plugged together in a self aligning snap-fit system to form a complex optomechanical assembly.

Further we present an optical printed circuit board for on-board transmitter and receiver electronics for four channels using 4×10 Gbit/s transmitter and receiver chips.

2. OPTICAL PRINTED CIRCUIT BOARD

Glass fibers offer mechanical robustness and very low attenuation, which make them suitable for optical PCBs and optical backplane applications with transmission distances of a few meters. At these distances standard graded index multimode glass fibers with 62.5 µm core and 125 µm outer diameters can easily handle data rates of several tens of gigabits at a single wavelength using NRZ modulation. The achievable data rate is only limited by the transmitter laser diode and can be enhanced by parallelizing the optical paths. The very tight diameter tolerances of standard glass fibers enable a simple and effective passive coupling method, described later.

The integration of glass fibers is done by laminating the fibers into the layer stack of a multilayer PCB between two layers of FR4 with polyimide spacers for pressure relief and guidance (Fig. 1). To access the fibers, the FR4-layers have to be processed before lamination. Openings are milled, into which the fibers extend after lamination. To achieve optical quality end facets the fibers currently are mechanically cleaved before they are embedded. Furthermore we are working on a laser cutting process using a CO_2-laser to fabricate optical facets following the lamination process. This will keep the fibers more resistant to the PCB manufacturing process (lamination, drilling, plating, and printing) and provides optical facets for multiple parallel fibers in one plane.

The fibers are fixed on the bottom plane between the fiber guides. For single channel applications with single glass fibers, thick copper pads running along the fiber path can be used to guide the fiber and to protect it from pressure while laminating [1,2]. For multiple parallel channels at a standard 250 µm pitch with just a small intermediate gap the manufacturing tolerances for the copper pads are too large for guides between the fibers. Therefore a 125 µm thick polyimide layer is attached to the bottom FR4 sheet and grooves for the fibers are laser cut into the polyimide. Furthermore the use of polyimide instead of copper guides improves electrical isolation between transmitter and receiver.

Bottom and top layers are stacked together and laminated using only proven standard PCB manufacturing processes. Many polymers for optical waveguides show yellowing or even decomposition at these conditions or at still higher temperatures whilst soldering the electronic components at more than 250°C. Glass fibers withstand these temperatures without any damage or decline of their optical transmission properties.

Subsequently electrical tracks, bores, throughplatings, and solder stop will be fabricated. At these process steps care must be taken not to damage the fiber stubs in the openings.

The openings for the fiber ends are quite large (5 × 4 mm^2) for easy inspection of the placed coupling elements. Fig. 2 shows a close-up view of the openings with four parallel glass fiber stubs. In a final board the openings can be made much smaller.

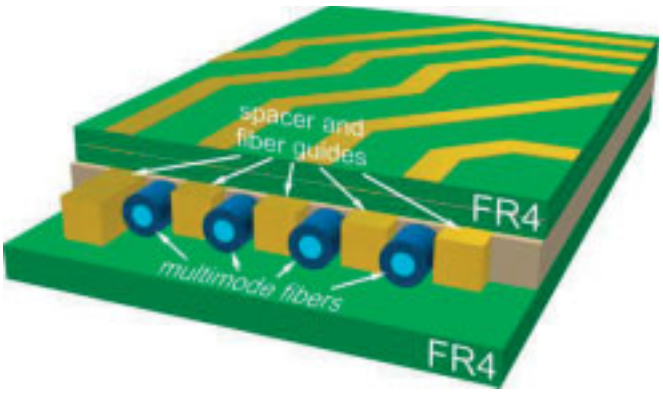

Fig. 1. Cross section of optical PCB with embedded glass fibers, spacers and fiber guides.

Fig. 3 shows a demonstration board with four parallel embedded glass fibers, throughplatings, and electrical tracks for the driver and receiver circuit. At the semicircular edges on both ends SMA connectors for differential electrical signals will be mounted.

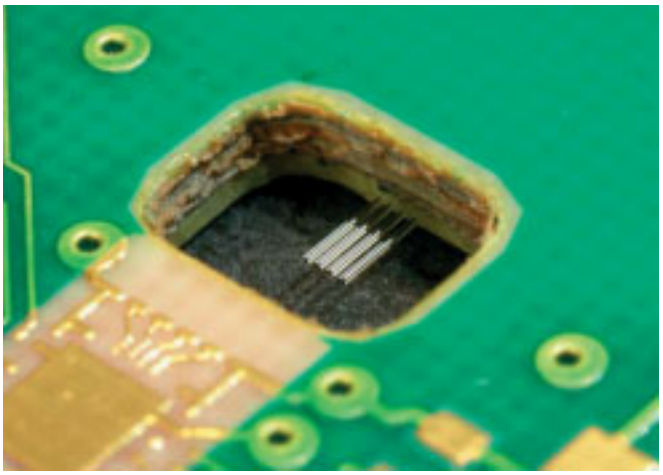

Fig. 2. Close-up view of opening with four parallel glass fiber stubs.

The driver electronics is based on a Helix HXT3104A 4×12.5 Gbit/s VCSEL-driver, the receiver electronics on a Helix HXR3104A 4×10 Gbit/s pin-diode-receiver. The ICs will be mounted in chip-on-board technique as bare dies and wire bonded onto gold plated bond pads on the PCB. Power and low speed control signals will be applied through 10-pole headers. The driver and receiver electronics as well as the VCSELs and photodiodes are the bandwidth limiting elements. The optical PCB uses glass fibers with a bandwidth-length product of 160 MHz·km. From this results a bandwidth of 80 GHz or approximately 115 Gbit/s at a wavelength of 850 nm for the intended length of up to 2 m. These speeds are beyond the capabilities of common electronics, VCSELs or pin-photodiodes.

Fig. 3. Demonstration board of an optical PCB (253 × 64 mm^2) with four parallel embedded multimode glass fibers.

3. IN-PLANE COUPLERS

To couple light into and out of the fibers specific optoelectronic coupling elements are used (Fig. 4). They are placed onto the fiber stubs and provide a low loss butt coupling without the need for focusing optics or mirrors. Fig. 5 shows a schematic diagram of the coupling element. It combines both the optoelectronic chip array (VCSELs or pin-photodiodes) and a tailored microstructure which supports the solely passive alignment of the optoelectronic chip array to the glass fibers, whereas the geometrical accuracy of the glass fibers is very

important. Both parts are attached to a substrate (1.89 × 3.00 × 0.81 mm^3) within a tolerance of 10 µm to each other.

The optoelectronic chip array is bonded onto one common electrode using conductive adhesive. The array size ranges between 1000 × 250 × 150 μm^3 and 1000 × 350 × 150 μm^3 with a standard channel pitch of 250 µm. The substrate is made of standard PCB material which provides electrical connections to a flex circuit.

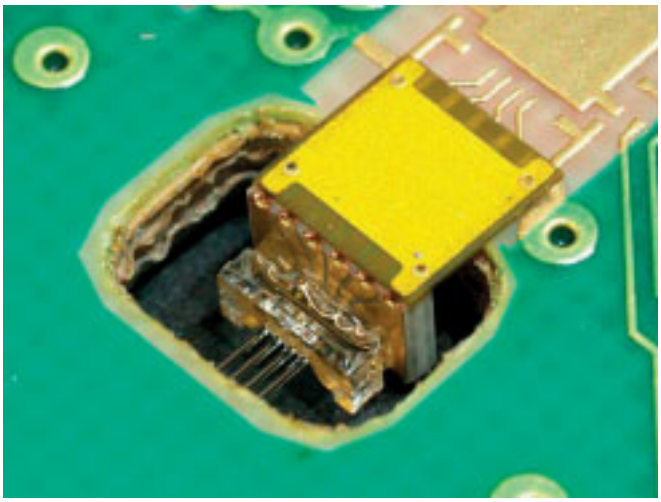

Fig. 4. Coupling element in optical PCB.

The optically clear alignment structure consists of an array of four precise V-grooves with large outer sides, an optical window, and spacers to obtain a proper fiber-chip distance and to clear a space for the bond wires. First prototypes were built from several PMMA parts made by deep X-ray lithography (LIGA) [3]. To achieve temperature resistant coupling elements, which withstand soldering temperatures the alignment structures were precision molded to one single part using a high temperature stable, optically clear, UV-reactive encapsulation polymer. The alignment structure covers the optoelectronic chip array and the gap between both is filled with UV-curable optical glue. Thus the chip is encapsulated and protected against environmental influences.

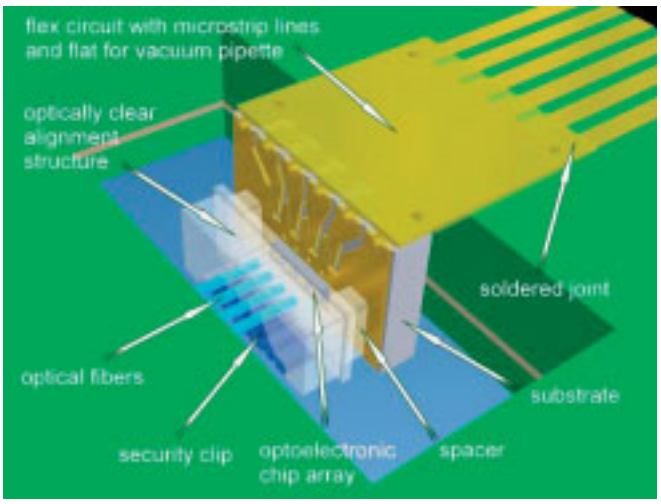

Fig. 5. Schematic view of coupling element in optical PCB.

To apply electrical contact to the coupling element, impedance matched microstrip lines on the flex circuit are used.

Mounting the coupling elements on the fiber stubs is done just by putting the element with its V-grooves onto the fiber array and sliding it up to the fiber endings. Soldering the contact pads and placing a security clip into the V-groove fixes the element onto the fiber. Further application of optical glue helps to improve the long term durability of the connection and to reduce reflections at the interfaces.

To achieve low coupling losses, the emitting area of the VCSEL or the sensitive area of the photodiode has to be placed with tight tolerances in the range of a few micrometers relative to the V-groove. Simulations of the coupling loss between a VCSEL and a step index multimode fiber were conducted. The VCSEL had a circular emitting area with a diameter of

10 µm and emitted a Gaussian beam with a beam divergence of 18° FWHM. The step index multimode fiber had a core diameter of 62.5 µm and a numerical aperture of 0.27. The simulations show a maximum coupling efficiency of 90% at a VCSEL to fiber distance of 225 µm with PMMA in the gap. The maximum coupling efficiency of the coupling between the described fiber and a photodetector with a diameter of the sensitive area of 70 µm in a distance of 225 µm is 50%. The minimum loss of the optical interconnect is therefore 3.45 dB [1].

Table 1. Insertion loss for two four-channel transmitter coupling elements.

Sample 1				
Channel	Measured power	Reference power	Coupling efficiency	Insertion loss
1	475 µW	1349 µW	35.2 %	4.53 dB
2	570 µW	1363 µW	41.8 %	3.79 dB
3	582 µW	1378 µW	42.2 %	3.74 dB
4	650 µW	1369 µW	47.5 %	3.23 dB
Sample 2				
Channel	Measured power	Reference power	Coupling efficiency	Insertion loss
1	1120 µW	1850 µW	60.5 %	2.18 dB
2	1125 µW	1848 µW	60.9 %	2.16 dB
3	1665 µW	1949 µW	85.4 %	0.68 dB
4	1405 µW	1732 µW	81.1 %	0.91 dB

We measured the coupling loss between a transmitter coupling element and a 50 µm core step index multimode fiber with 0.22 NA. Therefore the coupling loss is a little bit higher than with the 62.5 µm core fiber used in the optical PCB. The VCSELs were DC driven with 7 mA driving current to excite all emitting modes and the reference power was measured by a large area silicon detector (10 mm diameter) in front of the coupling element. Then the power coupled into the multimode fiber was measured and the coupling efficiency and the insertion loss were calculated. Table 1 shows the results for two transmitter coupling elements. Sample 1 shows a rather low coupling efficiency between 35.2 % and 47.5 %. The best alignment was achieved for channel 4 with a monotonic decrease to channel 1. Sample 2 has a better alignment between chip array and alignment structure and shows coupling efficiencies between 60.5 % and 85.4 % with channel 3 as best aligned channel.

A higher accuracy of the bonding process between the optoelectronic chip array and the alignment structure should minimize the losses and the channel variances. But for a detailed statistics we'll have to analyze a much higher number of coupling elements.

4. OUT-OF-PLANE COUPLERS

The aforementioned coupling elements are designed for intra-board interconnections. For space saving optical backplanes with plug-in cards optical connectors are required. A main component of these is an out-of-plane coupler with 90° beam deflection.

Out-of-plane coupling of optical signals is well known for polymer based optical PCBs. Most techniques employ planar mirrors and micro lenses as separate parts, which have to be aligned with respect to each other and to the waveguides in a complex process.

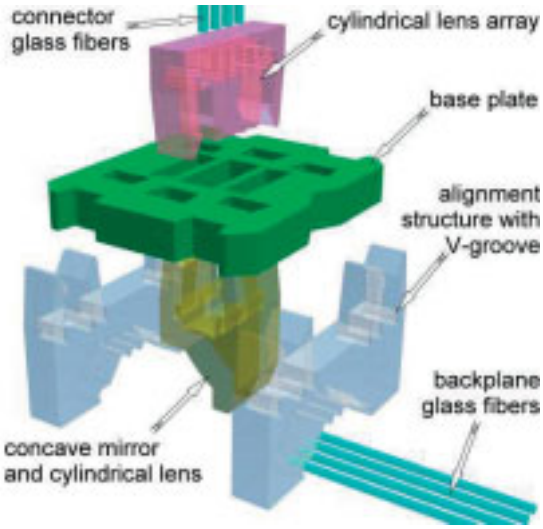

Fig. 6. Exploded view of 90° out-of-plane coupler with optical glass fibers.

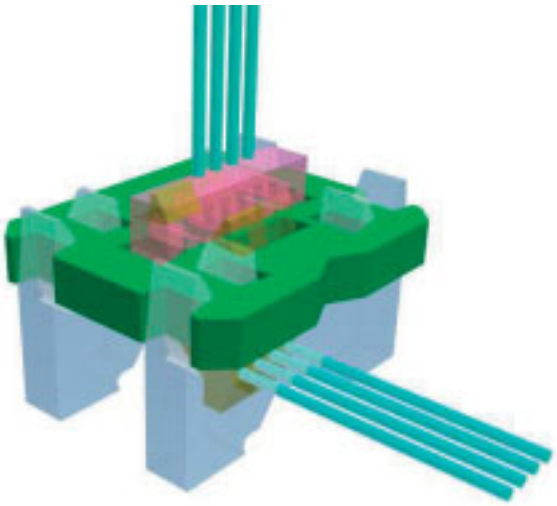

Fig. 7. 90° out-of-plane coupler plugged together with optical glass fibers.

In contrast our approach is aimed at a passive alignment of the required components to each other and to the optical fibers to fit into the presented optical PCB. Additionally the out-of-plane coupler should be a single component, which includes all optical and mechanical features, to align the component on a fiber array like the in-plane couplers and to deflect and focus the light to another perpendicular fiber array. The latter fiber array will be guided and aligned by another part of the optical connector, which still has to be developed.

A 90° beam deflection component with integrated micro optics for focusing is a complex part and difficult to fabricate in a single piece. For this reason we split the problem into several smaller ones with the condition that all parts are producible with LIGA as a very precise and available micro production technology. Without multiple exposures the LIGA process is constrained to flat prismatic parts, so that only cylindrical optics is practicable.

We designed a construction kit of several 500 µm thick prismatic parts (Fig. 6), which are plugged together with a snap-fit system to form the final out-of-plane coupler (Fig. 7). The snap arms are symmetric and designed to cancel tolerances. No gluing or welding is required. The horizontal fibers shown in Fig. 6 and Fig. 7 are the backplane fibers to which the out-of-plane coupler is aligned by the large V-groove-like structure and attached by the same security clip as used for the in-plane couplers. 90° deflection and focusing in one direction is done by two, side by side mounted concave total internal reflection mirrors and additional cylindrical lens. One

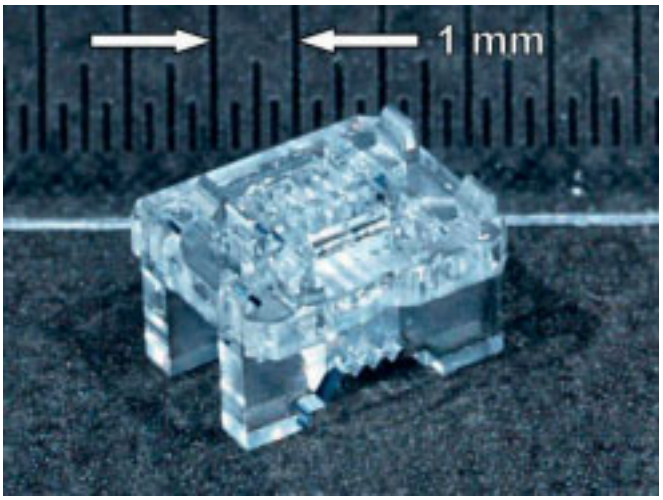

Fig. 8. 90° out-of-plane coupler.

piece with 500 µm width is wide enough to handle two optical channels with 250 µm pitch. By stacking the mirror-and-lens parts, any number of optical channels could be designed. V-groove and mirror parts are attached to the bottom of a base plate with snap arms. A cylindrical lens array perpendicular to the first focuses light in the other direction and is attached from top to the base plate. Thus light from a backplane fiber is focused to a spot 100 µm above the top surface of the cylindrical lens array part. The assembled out-of-plane is shown in Fig. 8.

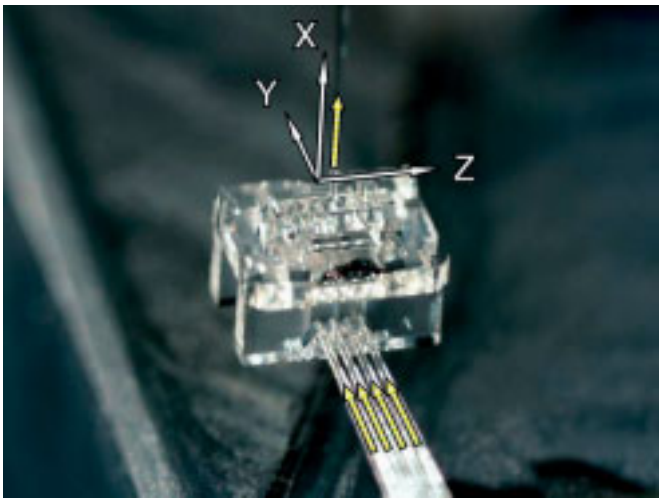

Fig. 9. Four-channel 90° out-of-plane coupler with optical glass fibers in coupling efficiency measurement setup. Also shown is the coordinate system for the coupling efficiency scans.

Simulations of the coupling efficiency of the element between two perfectly positioned step index multimode fibers with 62.5 µm core diameter show a coupling loss of 1.68 dB or 32%. Considering that none of the six surfaces in the light path are anti-reflection coated, this is a very good result.

Fig. 9 shows a 90° out-of-plane coupler mounted in a measurement setup for coupling efficiency measurements. The measurements were performed with an 850 nm laser source, a sensitive power meter and graded index multimode fibers with 62.5 µm core and 125 µm outer diameter. Prior to the measurements the output power of the laser source was calibrated without the coupler and with a fiber similar to the input fibers face to face to the output fiber so that the optical power of the incident light at the detector was 1.00 mW. The input fibers for the coupler were fixed in the V-groove of the coupler with a security clip while the output fiber (vertical) was attached to a three axis motorized linear stage. The used coordinate system for the coupling efficiency scans is also given in Fig. 10.

Measurements of the coupling efficiency on a finished four-channel 90° out-of-plane coupler show, that in practice the losses are higher. Table 2 lists the coupling efficiencies and the insertion losses for all four channels of the out-of-plane coupler. With 6.68 dB channel 1 shows the highest loss, channel 2 the lowest with 4.11 dB. This is a deviation to the simulation between 2.43 dB and 5.00 dB. It might be possible, that one or more of the involved surfaces were polluted, but we will have to do more extensive meas-

Table 2. Coupling efficiency, insertion loss, and FWHM for four-channel 90° out-of-plane coupler.

Channel	Coupling efficiency	Insertion loss	FWHM, Z-direction	FWHM, Y-direction
1	21.5 %	6.68 dB	53 µm	100 µm
2	38.8 %	4.11 dB	52 µm	92 µm
3	38.6 %	4.13 dB	53 µm	92 µm
4	34.1 %	4.67 dB	55 µm	86 µm

urements to resolve the reason for the mismatch.

To determine the position dependence of the output fiber and the channel cross talk, we measured the coupling efficiency in the YZ-plane in 100 µm distance to the coupler's top surface. This distance is defined by the focus plane for which the lenses and the mirrors were designed. The scan range was 760 µm in Y-direction and 1500 µm in Z-direction with a resolution of 10 µm. Fig. 10 shows details of the scans for each excited channel. The maximum coupling efficiencies and full widths at half maximum (FWHM) are also given in Table 2. The 250 µm channel spacing can clearly be seen. Also visible is the oval shape of the foci due to the cylindrical optics with a mean FWHM of 53 µm in Z-direction and of 93 µm in Y-direction. This was also shown by the simulations and could not be corrected with the simple optical system used. Therefore the position of the fibers can differ from the ideal position approximately 26 µm in Z-direction and 46 µm in Y-direction with less than 3 dB of additional loss.

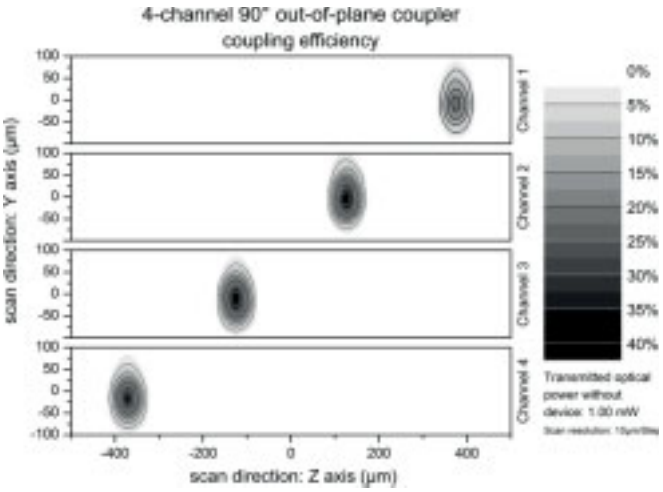

Fig. 10. Measured coupling efficiency of the 90° out-of-plane coupler in YZ-plane in 100 µm distance to the coupler's top surface.

Not visible in Fig. 10 is the cross talk between the channels. A more detailed analysis of the measured data shows a cross talk between adjacent channels of -23.5 dB (channel 1 to channel 2) or better.

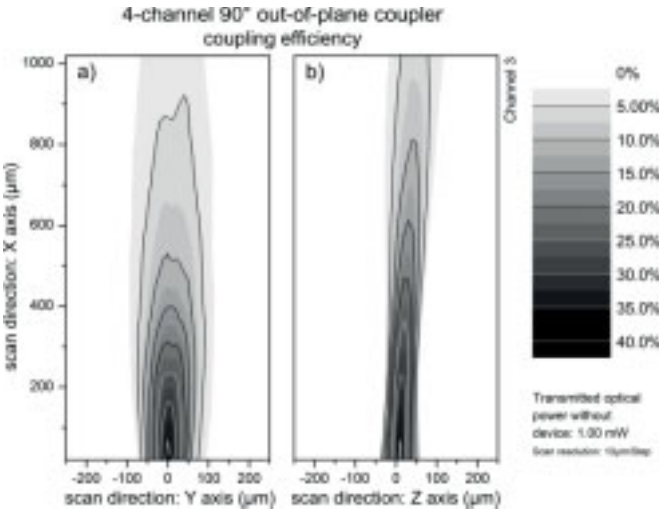

Fig. 11. Measured coupling efficiency of the 90° out-of-plane coupler a) in XY-plane and b) in XZ-plane for distances to the coupler's top surface from 20 µm to 1020 µm (X axis).

A scan of the coupling efficiency in the plane of the input and output fibers approximately through the focus point of channel 3 is shown in Fig. 11 a). The scan area is larger than that in Fig. 10 to measure the FWHM in X-direction. The bottom end of the diagram corresponds to a distance of the fiber's end facet to the coupler of 20 µm. Fig. 11 b) shows the coupling efficiency in a plane perpendicular to Fig. 11 a), again in output fiber axis. The differences in the images show the different focusing of the cylindrical optics. Also obvious is the fact that the angular adjustment of the coupling element to the scan directions was not optimal and the plane of Fig. 11 a), which is a cut through Fig. 11

b) at Z=0, is not fully aligned with the optical axis of the output beam. Due to this tilt the FWHM in X-direction can only be evaluated from Fig. 11 b) to 525 µm.

5. CONCLUSIONS

We presented a four channel optical printed circuit board with embedded glas fibers and appropriate in-plane and out-of-plane couplers. The optical PCB is made of a standard multilayer PCB with laminated glass fibers, openings to access the fiber ends, electrical tracks, and throughplatings. Special optoelectronic coupling elements align passively on the fiber ends and couple light efficiently in and out of the embedded fibers with an insertion loss of down to 0.68 dB. For the use in optical backplane connectors we presented a novel 90° out-of-plane coupler with integrated micro-optics. The coupler consists of several prismatic parts which are plugged together with a self aligning snap-fit system. Measurements show a fiber-to-fiber insertion loss between 4.11 dB and 6.68 dB.

6. ACKNOWLEDGMENTS

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Pluggable Connector Technologies for Polymeric Electro-Optical Backplanes

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Introduction

Over the past six years Xyratex has led optical research and development to identify and develop solutions for the integration of optical backplane technology into high density IT systems. The main achievement of this research programme has been the invention and real world demonstration of pluggable connectors for polymeric electro-optical backplanes.
The connection architecture adopted allows for electronic line cards with active optical edge connectors to be plugged into and unplugged from a passive electro-optical backplane.
The active connectors incorporate VCSELs emitting at 850 nm and PIN photodiodes sensitive to the same and are aligned directly to the waveguides in a butt-coupled arrangement thus eliminating the need for mirrors or other out-of-plane deflection structures.
In this talk, I will discuss the design, implementation and characterisation of an active parallel optical connector prototype, supporting a pluggable interconnection between line-cards and an electro-optical backplane.

Polymeric Electro-Optical Backplane

A passive backplane was designed, which incorporates 10 copper layers for ground, power, a Compact-PCI signal bus and one polymeric optical layer to carry high speed serial data of 10.3 Gb/s between line cards. The backplane is 4 mm thick and has four Compact PCI and optical slots devoted to optical communication.

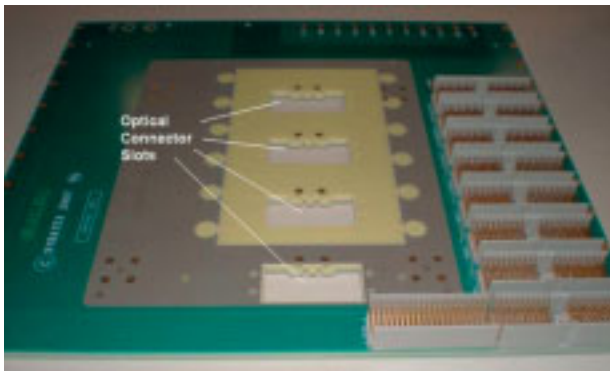

Figure 1: Electro-optical C-PCI Backplane

The optical waveguide layer is comprised of a polymer, which exhibits lowest optical loss at 850 nm. The waveguides are formed of a higher refractive index variant of the polymer (core) surrounded by a lower refractive index variant (cladding).
The optical waveguide interfaces are compliant with the MT standard for parallel optical connectors and thus enable stand alone testing with MT patchcords. The waveguide cross-section is 70 µm x 70 µm.

The optical interconnect layout allows for one waveguide link from each connector site to every other connector site. The waveguides incorporate bends of a radius of at least 17 mm and crossovers with varied intersect angles less than 90º.

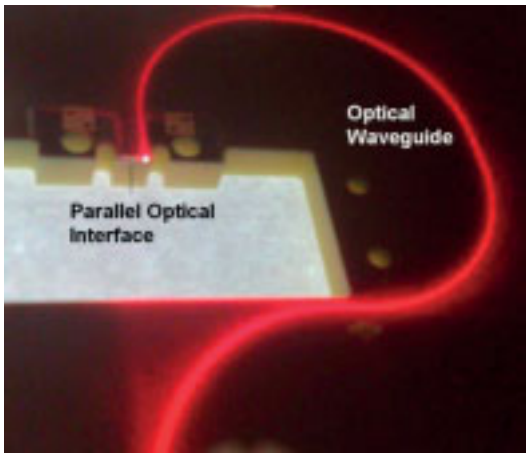

Figure 2: Illuminated Waveguide

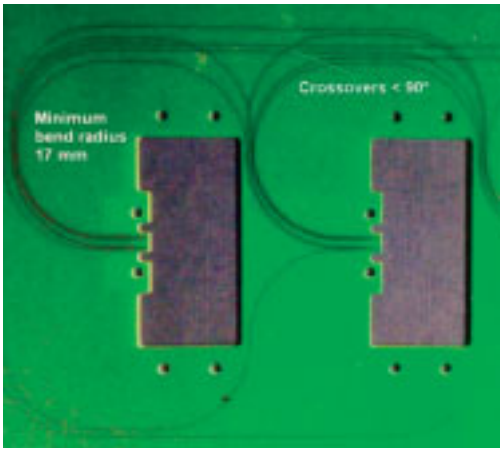

Figure 3: Waveguide Interconnect Design

Parallel Optical Connector

The method of connecting optical connectors to the electro-optical backplane in a pluggable way involves a two stage engagement process: a first stage of coarse alignment whereby the line card is inserted into the backplane providing the necessary electrical and mechanical connections, and a second stage of higher precision alignment whereby the optical connection is asserted.

A parallel optical transceiver circuit is constructed on a flexible laminate substrate. A microcontroller is present to regulate the photonic driver ICs and to maintain a 2-wire interface between the transceiver and the line card, whereby the transceiver is always in slave mode. The design allows multiple transceivers to be controlled by a single 2-wire bus.
The optical interface contains the active devices responsible for opto-electronic and electro-optic conversion. These devices are a 1 x 4 VCSEL array with VCSEL driver, and a 1 x 4 PIN array with TIA / LA. Each channel is capable of sustaining a data-rate of 10.3 Gb/s. In addition, the interface includes a collimating microlens array and a pair of registration pins to ensure precision alignment. Another focusing microlens array is attached to the waveguides on the backplane. The transceiver design allows the optical interface to float relative to the line card, thus ensuring that when coupled to the optical waveguides in the backplane it remains impervious to the transient motions within the system.

Prototype Demonstrator

A demonstration assembly has been constructed comprising a Compact-PCI chassis with single board computer and a hybrid electro-optical backplane. The chassis will accept up to four line cards each supporting an optical PCB connector.
Each line card includes four ports on the front end to support commercial XFP transceivers. These devices convert 10 GbE LAN (10.3 Gb/s) optical serial data into electronic XFI data and use a configurable crosspoint switch to map the XFI data between the XFPs and the prototype transceiver. The crosspoint switch also supports multicasting, allowing data on any of its inputs to be copied onto multiple outputs, providing flexibility for testing. A graphical user interface has been developed to provide user control over all line cards and optical connectors in the chassis via the C-PCI bus.

Conclusion

Xyratex in collaboration with American connector company Samtec have designed and constructed an active pluggable optical backplane connector and an electro-optical C-PCI system to demonstrate its functionality. A characterisation and test regime was implemented whereby 10.3 Gb/s test signals was sent between different line cards in the chassis via the optical connectors and waveguides either singularly or simultaneously. This has been successfully demonstrated with an acceptable level of signal recovery.

Xyratex is also leading collaborative research in the UK to explore various low-cost and industrially applicable methods of fabricating optical waveguides onto printed circuit boards with a view to driving the commercial proliferation and exploitation of hybrid optoelectronic PCB technology in the near future.

Figure 2: Electro-optical backplane Connector Demonstrator