



**lecture: *fundamentals of silicon photonics
packaging***

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Introduction

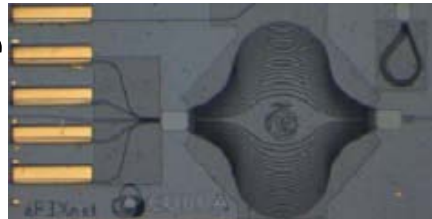
We shall consider the following questions

- Why do we need a photonic package?
- What are packaging and assembly?
- What are fundamental boundary conditions in silicon photonics packaging?
- What specific solutions do exist (examples)?

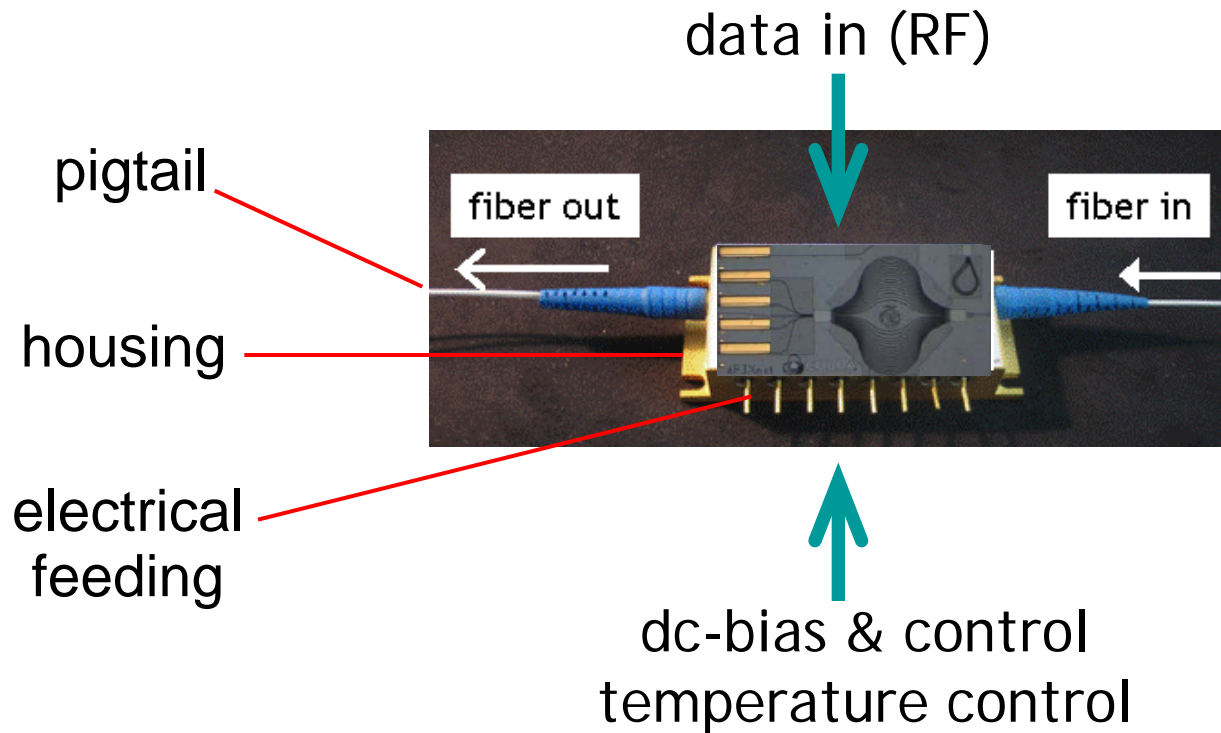


Packaging means...

Connect a photonic die



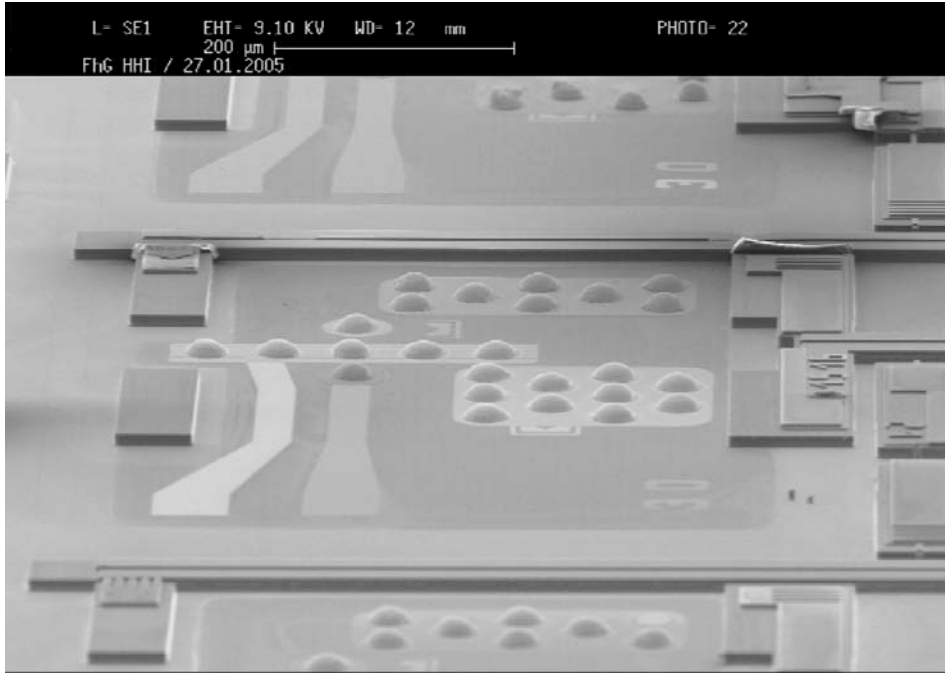
to the outside world



And assembly...

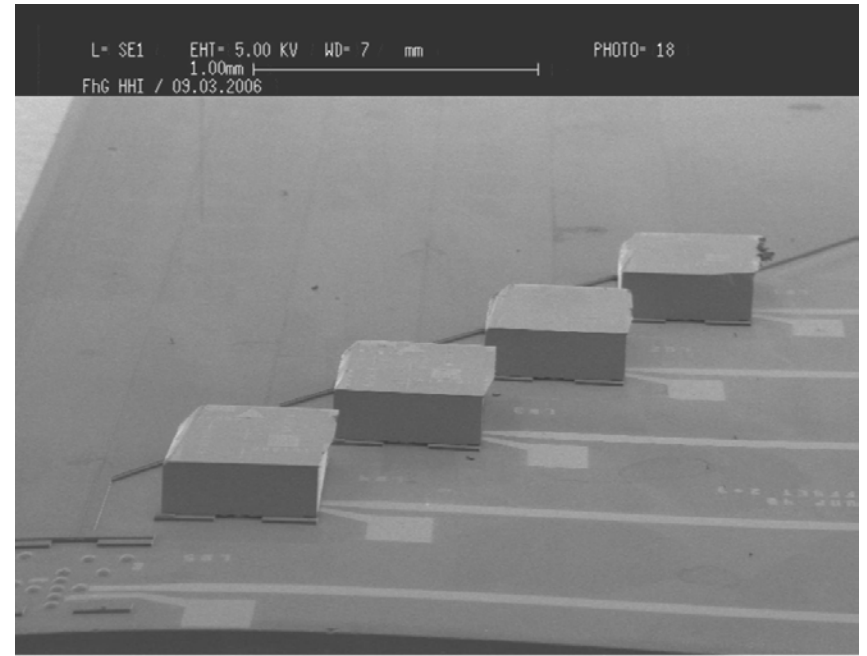


Take care that devices are assembled as needed.



bumping

soldering





Integrated photonics / silicon photonics
Complex devices, multiple sources, multiple I/O...

Packaging

Fiber pigtailing

Connect chip with single or multiple fibers

Housing, assembly

Implement chip housing
sub-assemblies
electric connections

- general consideration of the the whole packaging process does not make sense
- to much complexity in potential i/o schemes
- we limit us to fiber pigtailing here



Optical fibers

- high-speed and DWDM make single-mode fibers the preferred option
- typical dimensions

Mode-Field Diameter

Wavelength (nm)	MFD (μm)
1310	9.2 ± 0.5
1550	10.7 ± 0.5

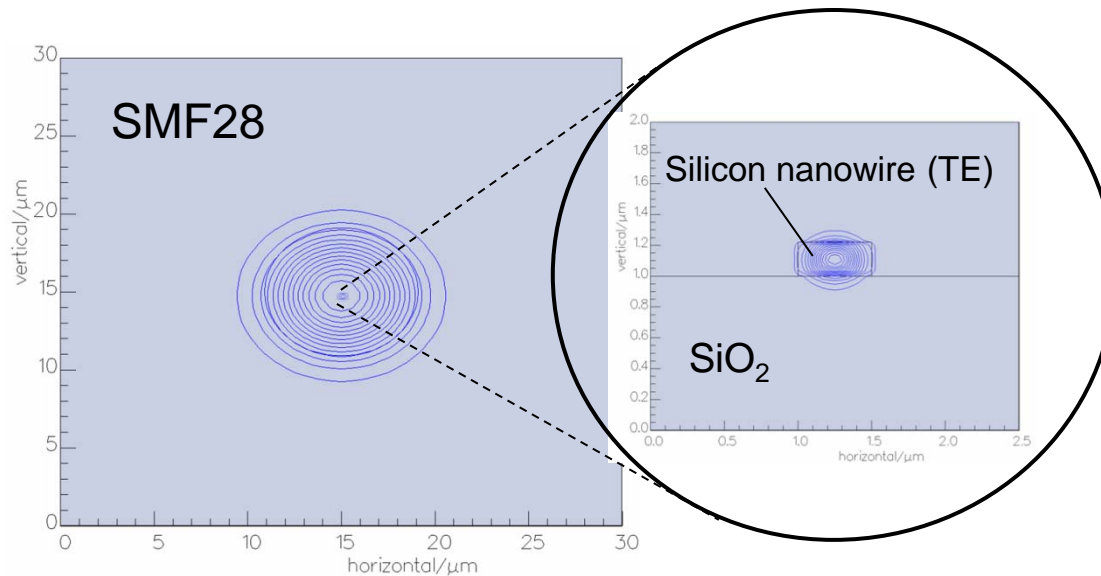
Glass Geometry

Fiber Curl	≥ 4.0 m radius of curvature
Cladding Diameter	125.0 ± 0.7 μm
Core-Clad Concentricity	≤ 0.5 μm
Cladding Non-Circularity	$\leq 0.7\%$

(Corning SMF28ULL specifications)

Major obstacle in silicon photonics

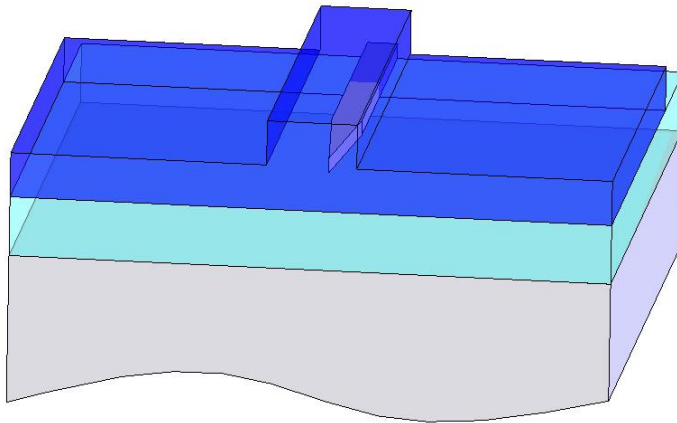
MFD of fiber and waveguides do not match



This requires

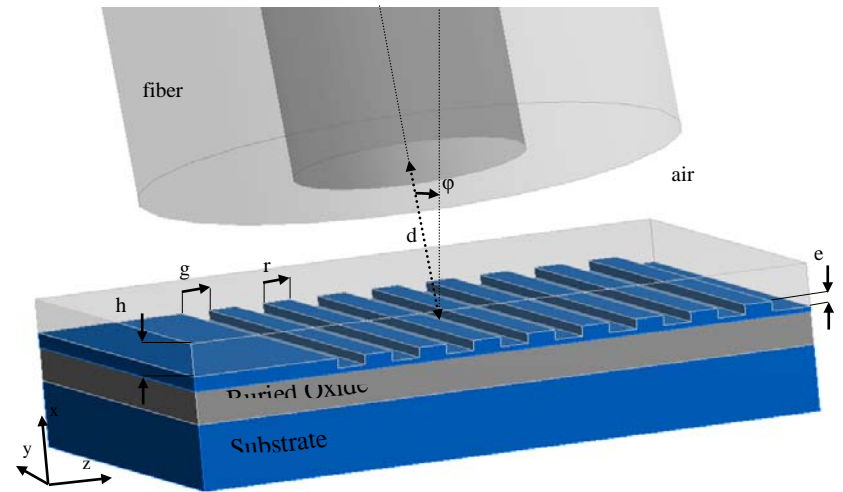
Spotsize conversion structures

Lateral coupling



- typically based on inverted tapers
- spotsizes: $\sim 3 \mu\text{m}$

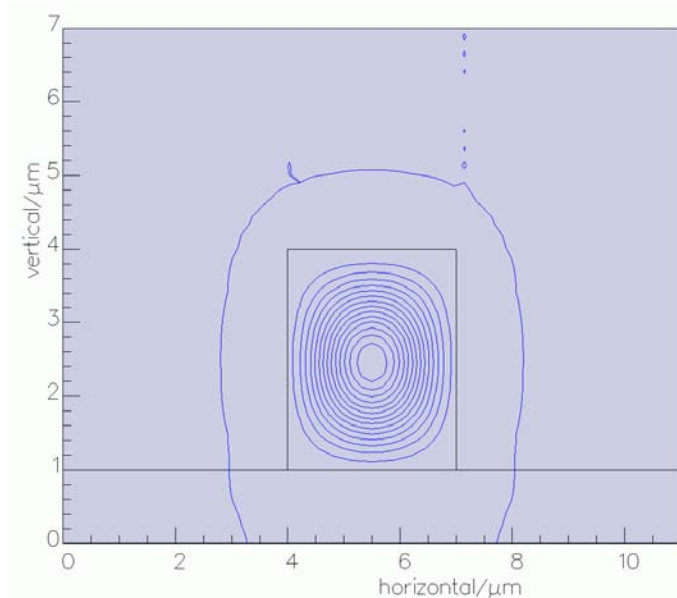
Vertical coupling



- typically based on gratings
- spotsizes: $\sim 10 \mu\text{m}$

Lateral - single fiber coupling issues

Inverted taper - example SiN waveguide geometry at end of taper
HxW=3 μ m x 3 μ m (SiNx), on SiO₂ (1 μ m)

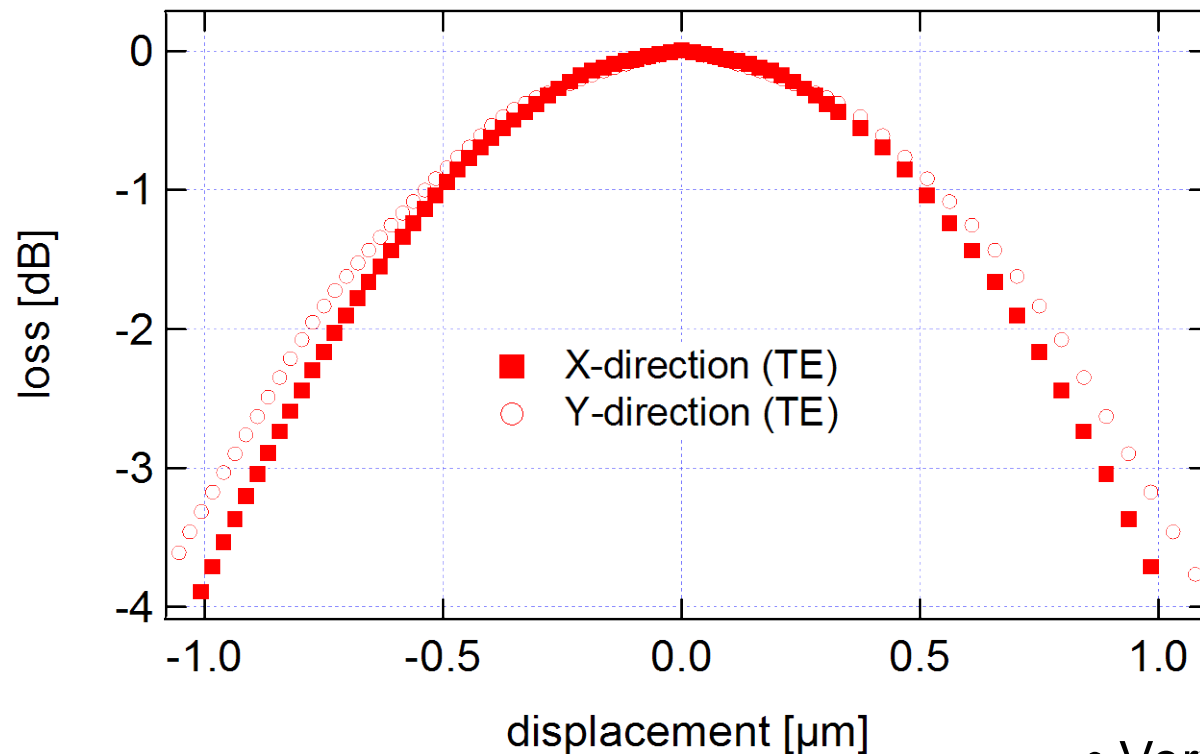


- MFD too small for standard fiber
- require lensed fiber
- what are alignment tolerances?



Lateral - single fiber coupling issues

XY alignment tolerances SiNx waveguide ($3\mu\text{m} \times 3\mu\text{m}$)
 $3\mu\text{m}$ fiber-spot



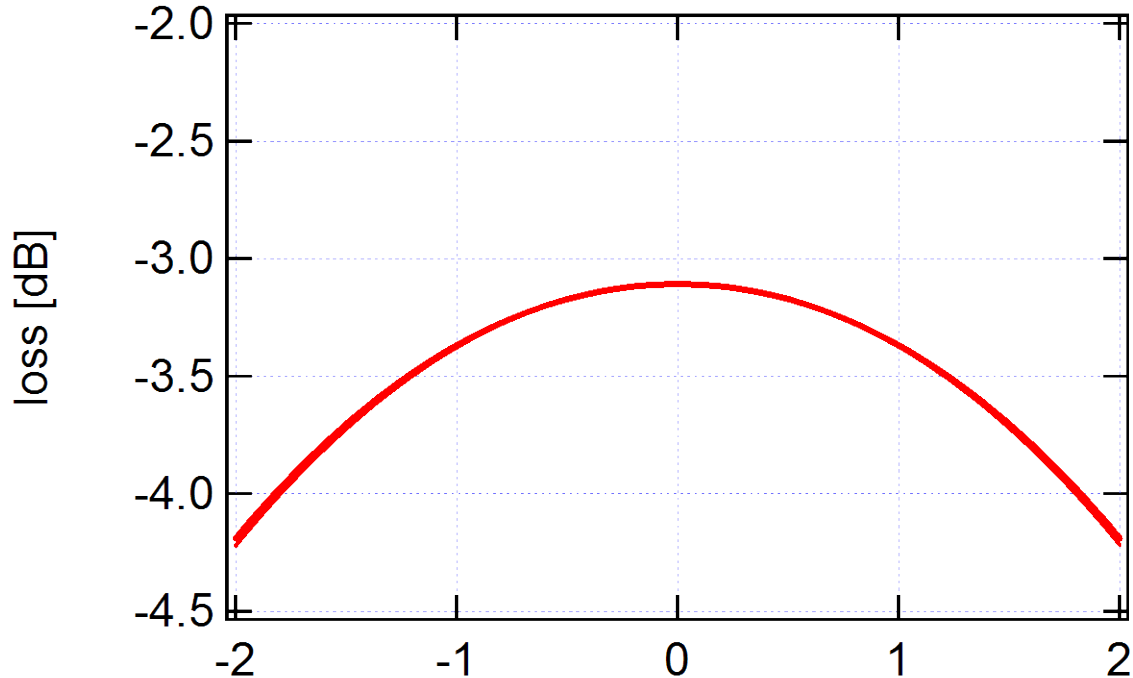
- Very small tolerances
- Can we improve?



Lateral - single fiber coupling issues

XY alignment tolerances

6 μm x 6 μm box waveguide vs standard fiber

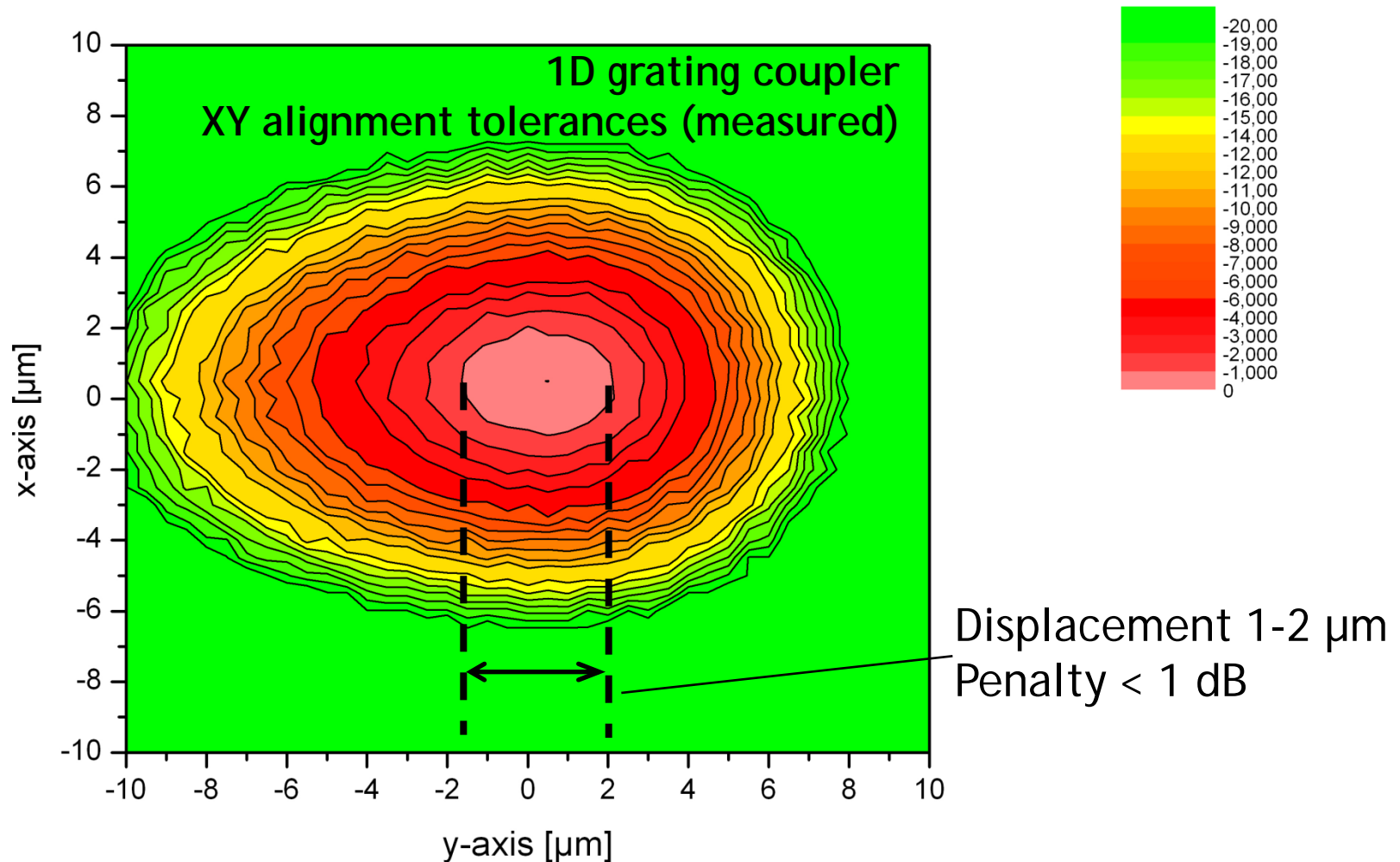


Compromise:

displacement [μm]

- Better tolerances but higher insertion loss
- Requires special, non-standard inverted taper

Vertical - single fiber coupling issues





How about z-dependency?

- approximation by Gaussian beam analysis
- lensed fibers deliver Gaussian beam
- most important parameter: spotsizes (beam width) w

$$w(z) = \overset{\text{beam waist}}{w_0} \cdot \sqrt{1 + \left(\frac{z}{z_R}\right)^2} \quad z_0 = \frac{\pi w_0^2}{\lambda} \quad \text{Rayleigh parameter}$$

Assuming that the beam intensity scales approximately $\propto w^2$

we would lose about 3dB at the Rayleigh distance

if the beam waist were exactly matched to the waveguide MFD.

Z-dependency is generally weaker than XY- dependency

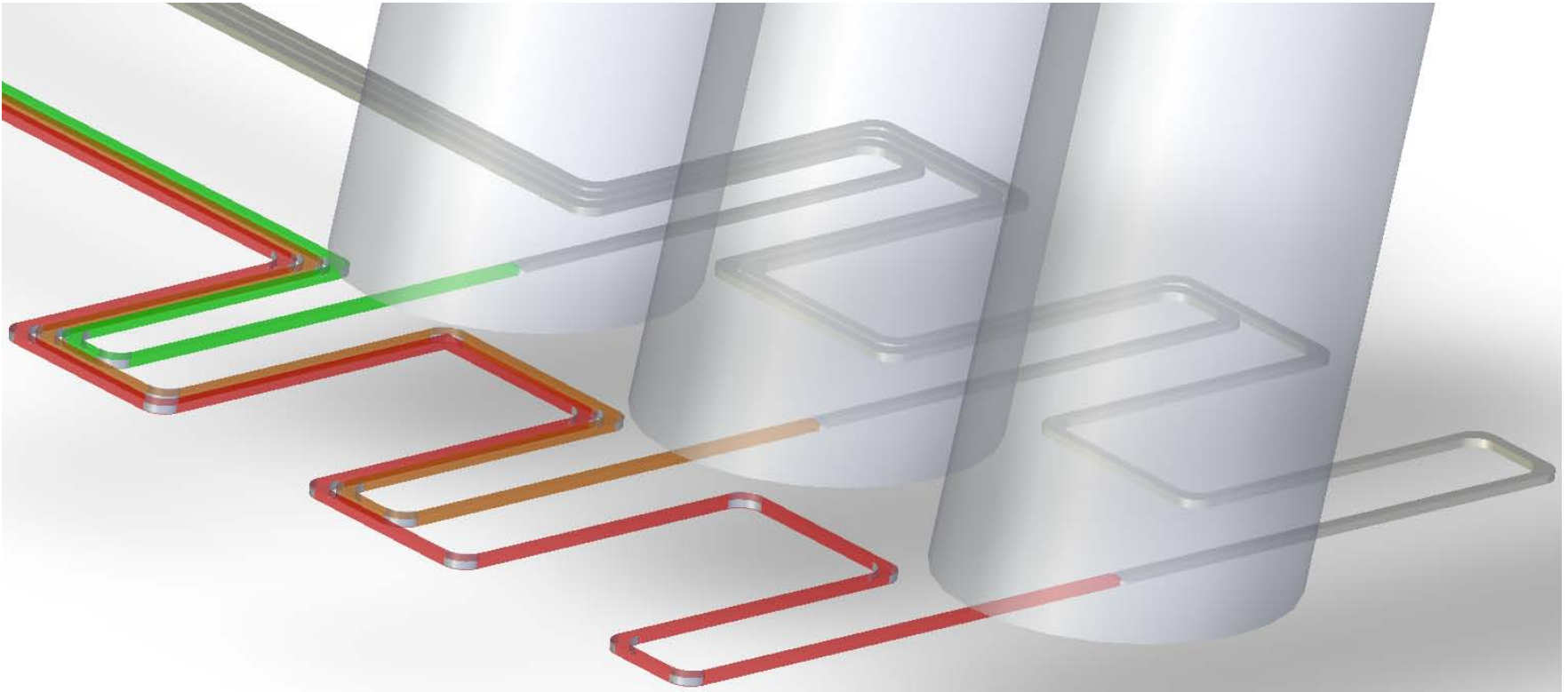


Single fiber coupling – intermediate summary

- lateral coupling with realistic XY-tolerances of $0.5\mu\text{m}/\text{dB}$
- vertical coupling with realistic XY-tolerances of $1.5\mu\text{m}/\text{dB}$
- lateral coupling requires lensed fibers for low loss
- vertical coupling can be done using standard fiber butts



Multiple fiber / fiber array coupling

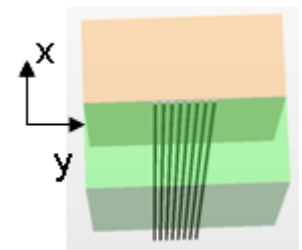
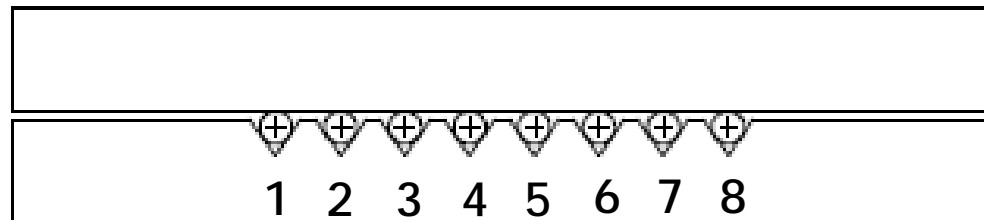
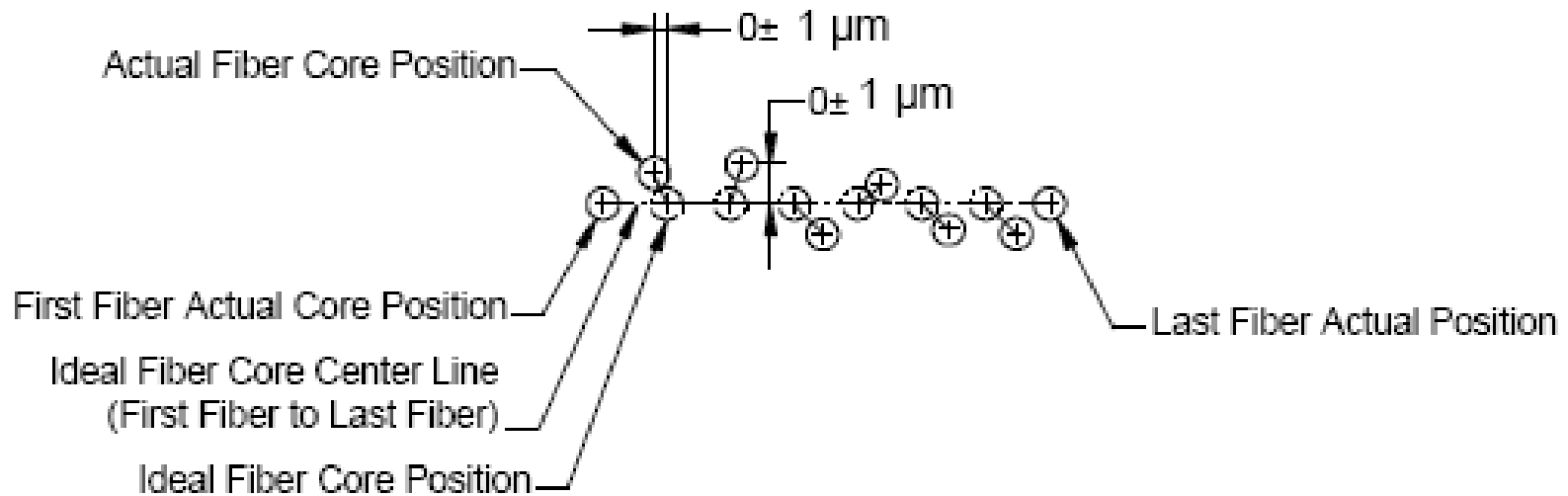




V-groove based 8 fiber array

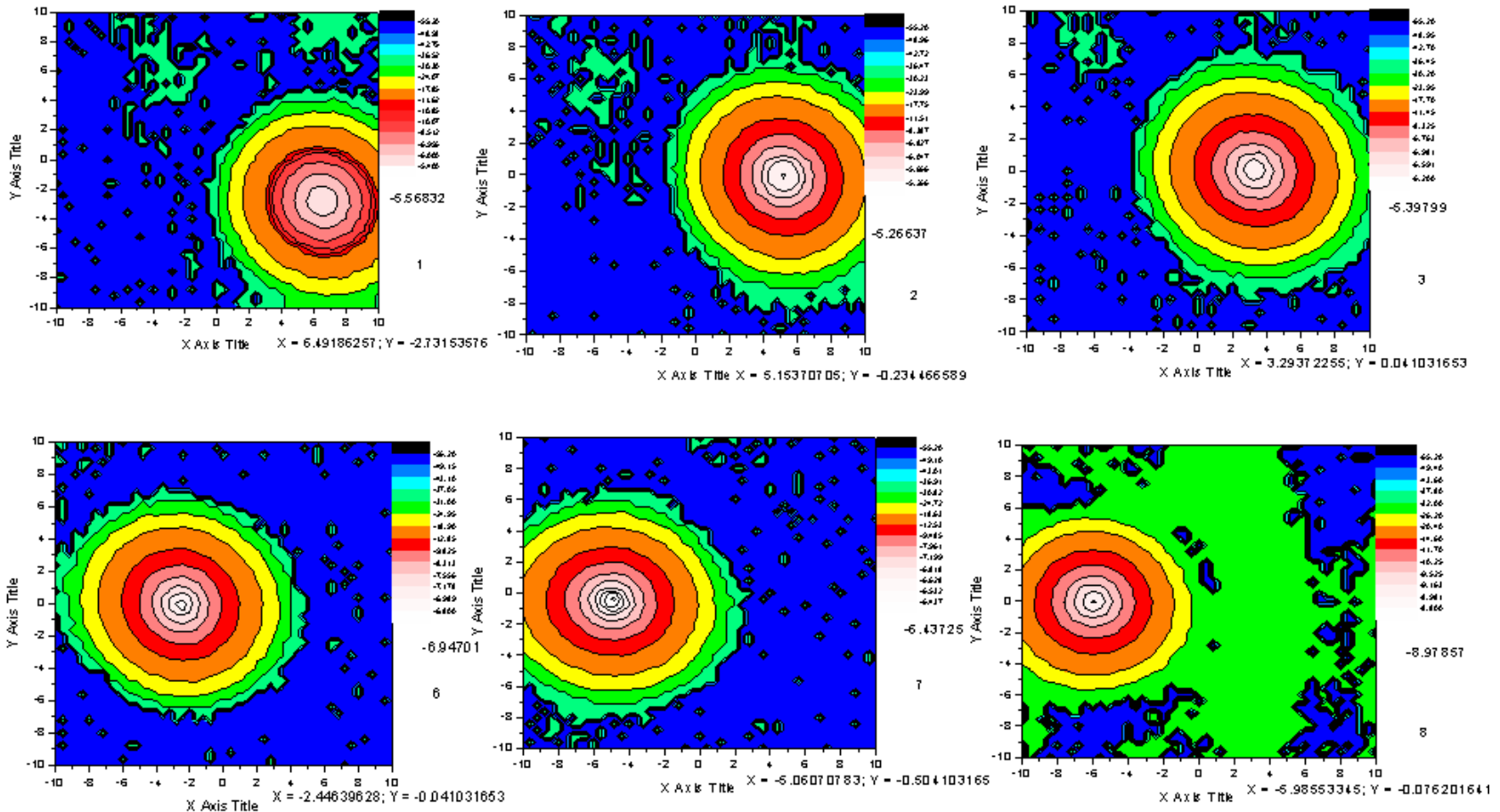
Specifications of the manufacturer

Fiber core positions are exaggerated for clarity





V-groove fiber array experiment

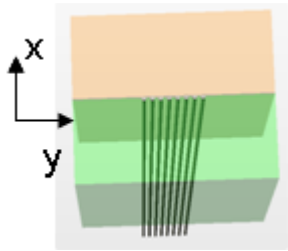


XY-Scanned Fiber Positions

Silicon Photonics – PhD course prepared within FP7-224312 Helios project

V-groove fiber array experiment

Measured misalignment of fibers in v-groove array



Fiber #	1	2	3	6	7	8
Mismatch in y [μm]	-2.2	0.8	0.3	0.1	0.0	2.0
Mismatch in x [μm]	0.0	4.0	1.7	-2.5	-4.3	0.0

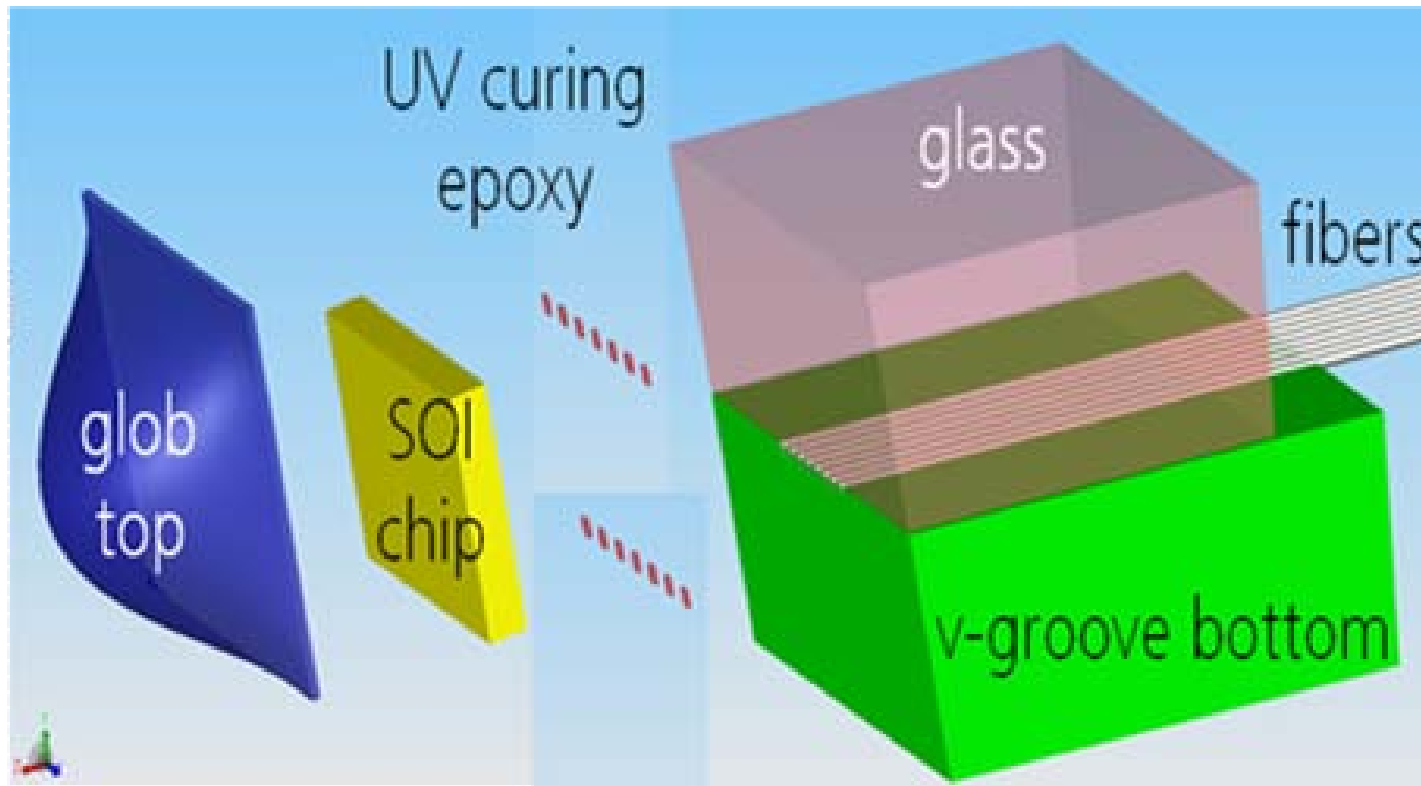
pitch

vertical

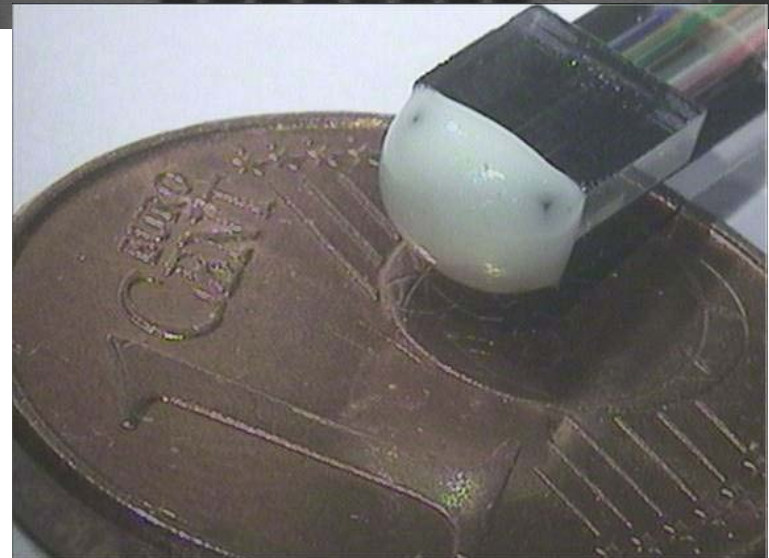
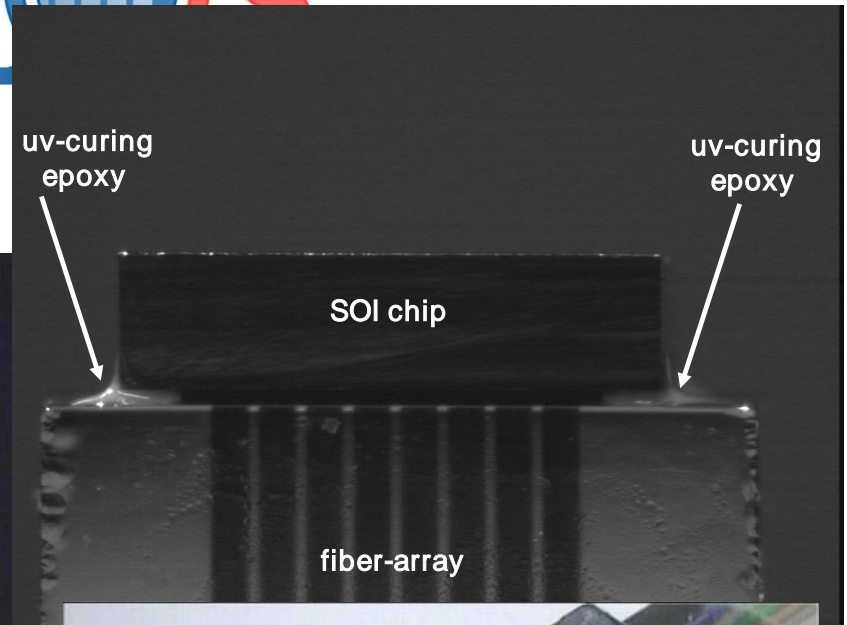
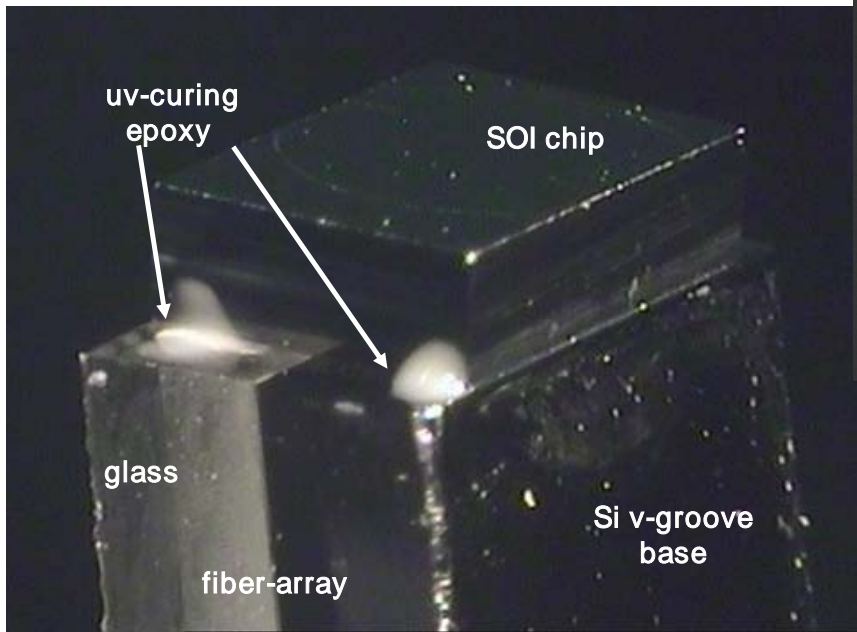
- measured tolerances are not the best possible, but typical
- fiber array tolerances too large for present lateral coupling structures
- tolerance-wise vertical couplers are favorable
- how can it be implemented?
- (not mentioned here other issues of grating such as polarization dependence etc)

Fiber array package - concept

- coupling to fully passive SOI chip



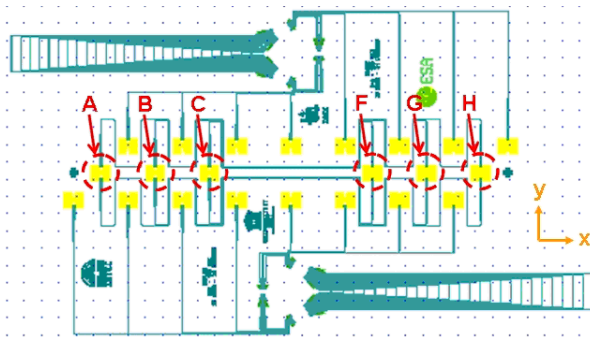
8 fiber array package realized



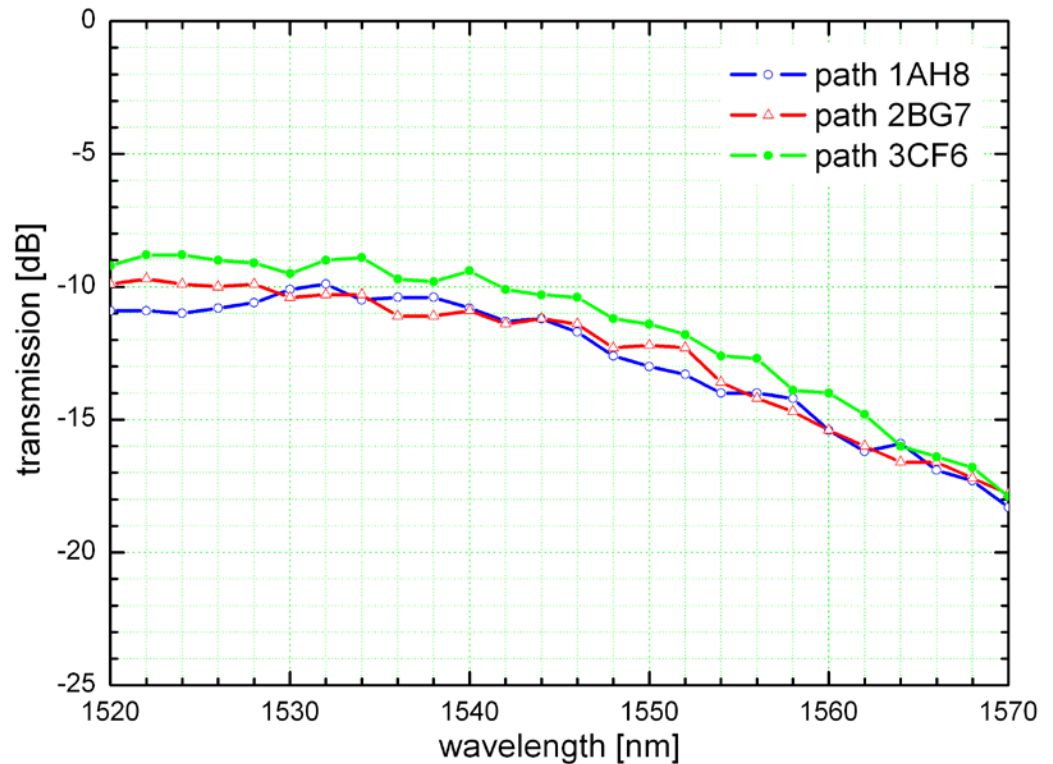
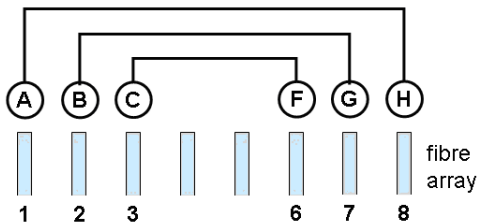
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Transmission test

SOI test chip

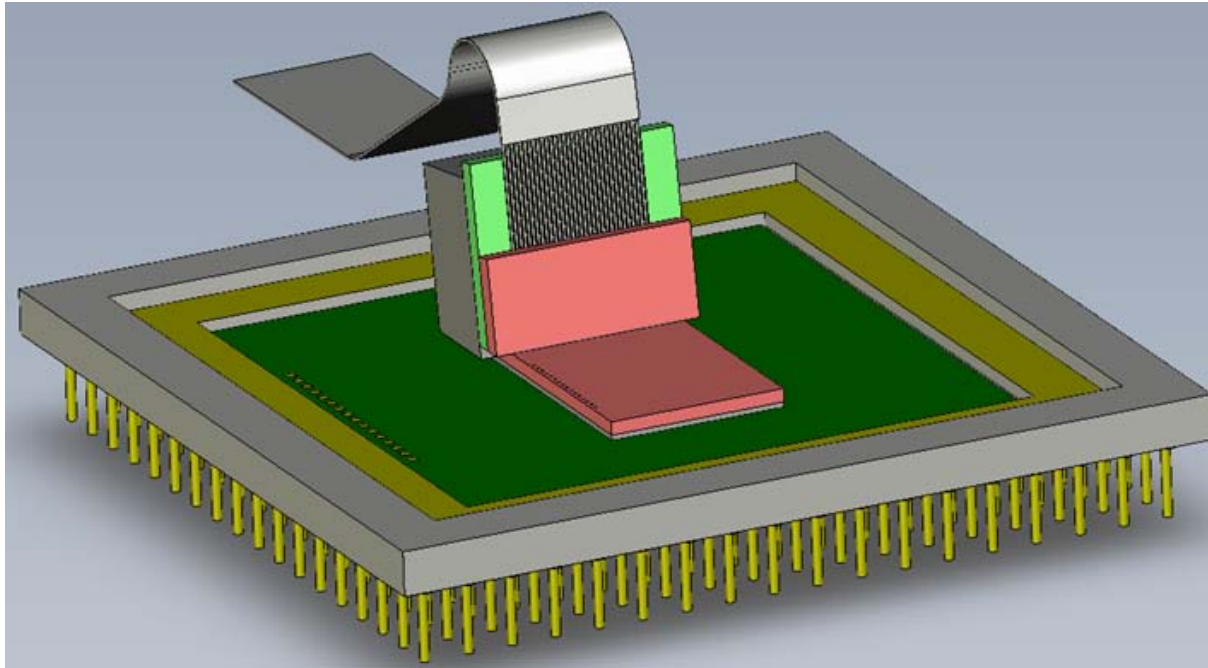


spare grating couplers shortened by simple waveguide



- using grating couplers
- about 1dB coupling penalty can be achieved accross 8 fiber array

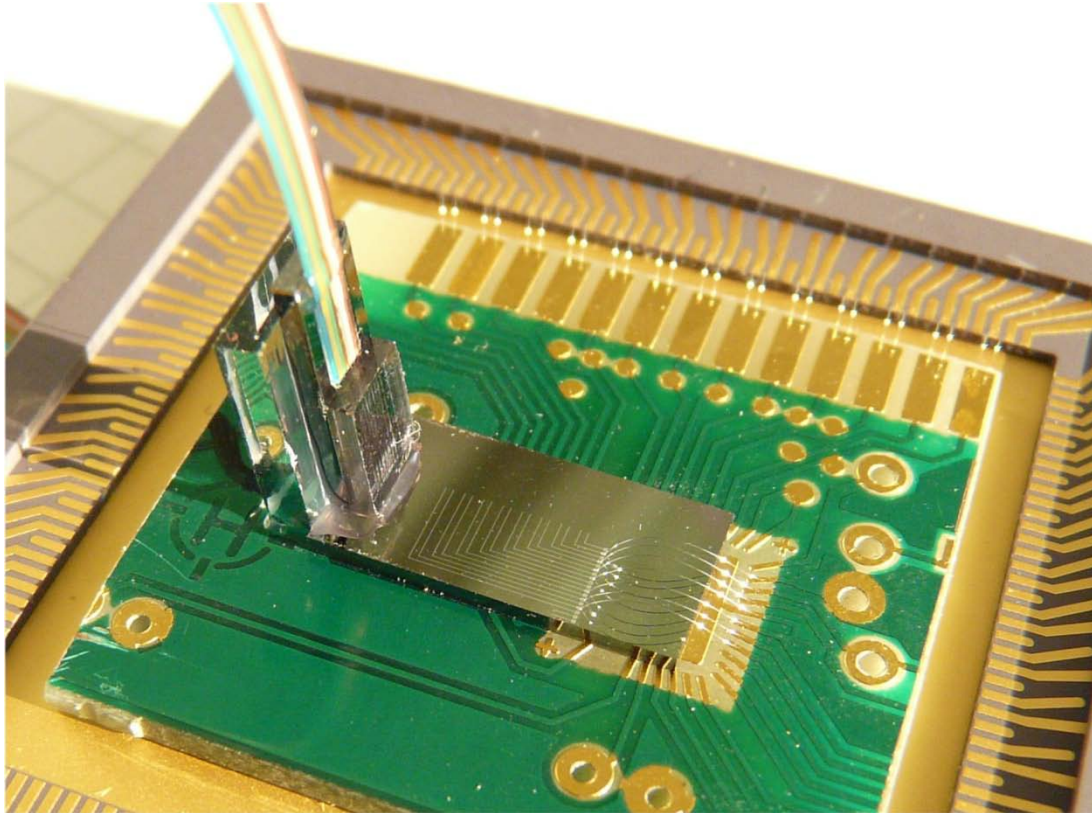
First approach to handling electrical & optical i/o



g-Pack

- enable multiple (~ 30) optical i/o
- multiple (~ 60) electrical LF i/o
- match ePIXfab standard chip size
- plug in a testbed

Example - g-Pack



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Future of silicon photonic packaging

- merging electronic & photonics technologies
- optical packaging needs to undergo a paradigm change
- costs will need to be reduced by 1-2 orders of magnitude
- up to now, low cost means single fiber or multi-mode fiber



Acknowledgements

- Tolga Tekin & Henning Schroeder from Fraunhofer IZM, Berlin
- Pieter Dumon & Wim Bogaerts from Uni Ghent
- Karsten Voigt from Technische Uni Berlin