Glass Waveguides for Board-level Optical Interconnects

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Outline

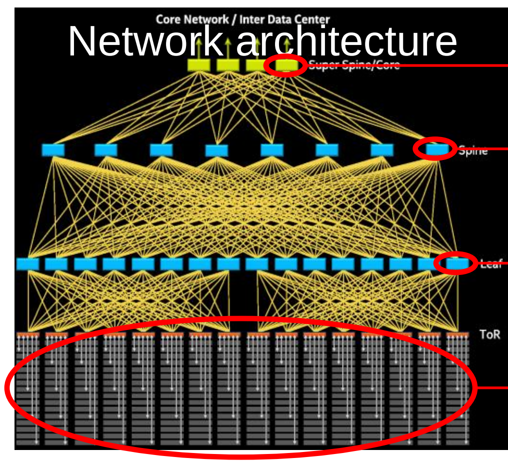
Motivation

SM waveguides & connectors for co-packaging of optics

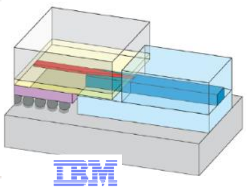
MM waveguides & connectors for printed circuit boards

Conclusion

Where is the need for novel photonic packaging concepts in a datacenter?



Fiber-chip-connectivity



Evanescent coupling

End-face coupling

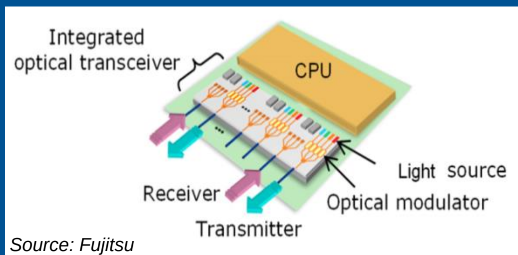
Grating coupling

Optical Printed Circuit Boards (OPCB)

PCB with optical layer

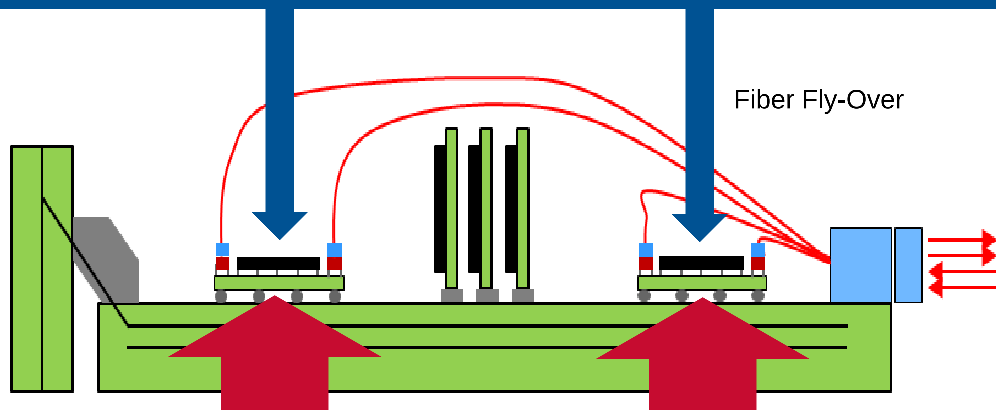
Silicon photonics co-packaging on CPU package

Silicon Photonics



Source: Fujitsu

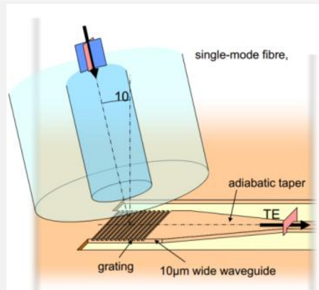
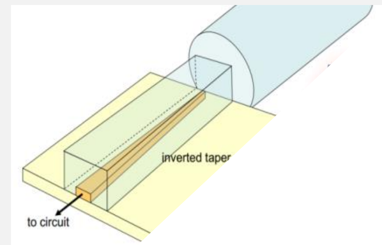
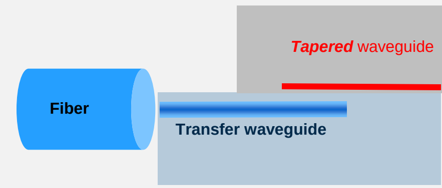
- Enables optical and electrical functions in same chip or package
- Provides bandwidth scalability (WDM & higher order modulation)
- Higher bandwidth density
- Reduces length of electrical lines and interfaces



Solutions for co-packaging of optics in multi-chip modules

- Novel fiber-to-chip optical interfaces
- Novel system-level packaging

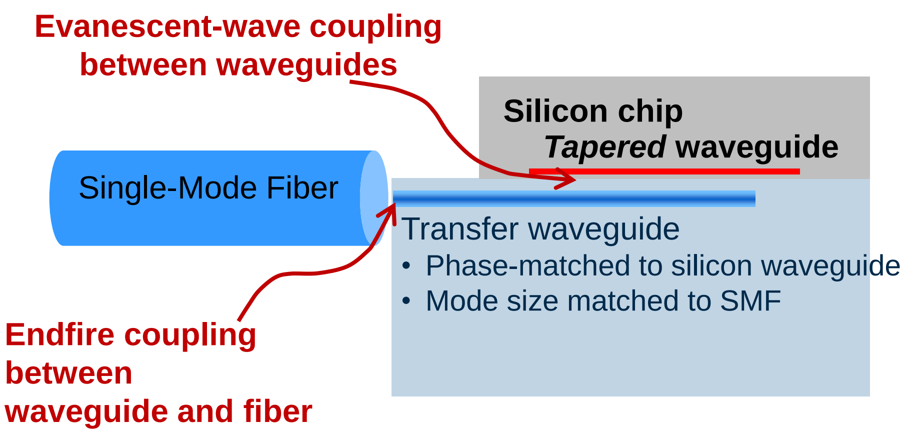
What are the three main classes of fiber-chip coupling?

	Grating	Endfire	Evanescent Wave
			
Chip I/O	Surface	Edge	Surface
Fiber direction	Out of plane	In plane	In plane
Bandwidth	Limited	Wide	Wide
Polarization dependence	Poor	Good	Good
SMF mode matching	Good	OK	Good
Number of “alignment steps”	1	1	2

Source: Grating and endfire coupling Images from: Wim Bogaerts, “Coupling light to silicon photonics circuits”. Lecture part of the EU “Helios” project. (2009) http://www.helios-project.eu/Download/Silicon-photonics-course

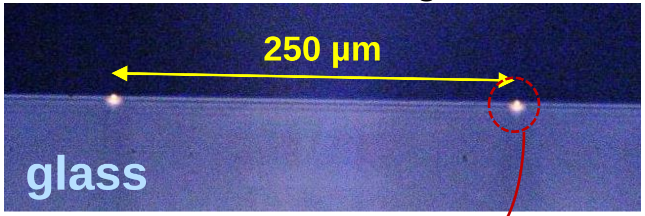
Single-mode waveguides for Si-photonics packaging
Evanescent-wave coupling with transfer waveguide

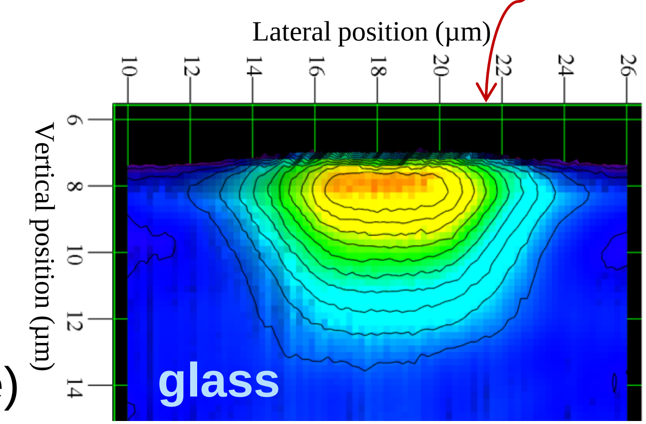
- A transfer waveguide provides mode-size conversion
- Tapering the width of the silicon waveguide relaxes tolerance on mode effective index and interaction length



- The transfer waveguide can be in glass or polymer
- Polymer benefits: mechanical isolation (highly flexible)
- Glass benefits:
  - Lower attenuation: ≤ 0.1 dB/cm vs. 0.3 - 0.4 dB/cm of polymer at λ=1310 nm
  - Endface durability

Front view of glass die showing two back-lit waveguides

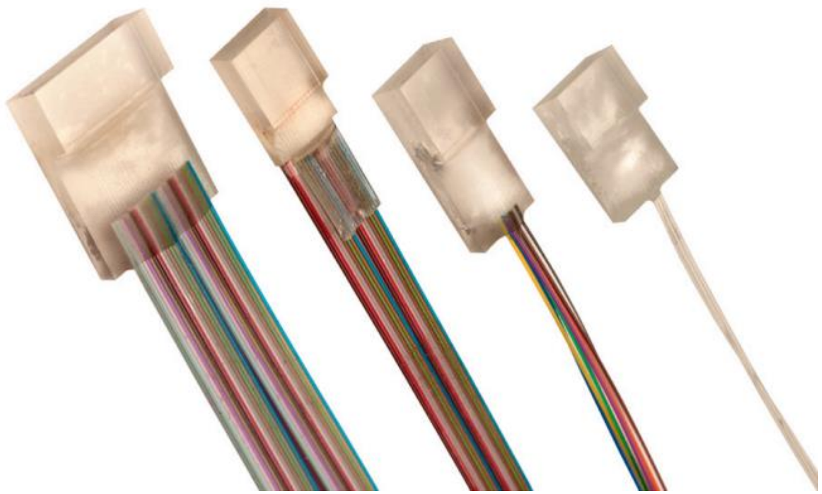




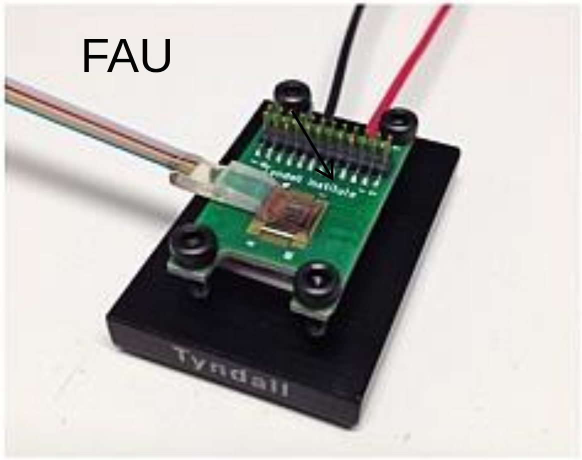
Measured refractive index
Color map scale: n_{core}-n_{clad}=0.008

State-of the art fiber-to-chip assembly

Fiber array unit (FAU)



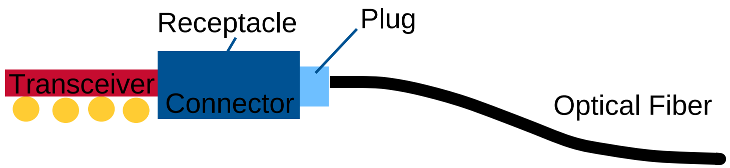
FAU to photonic integrated circuit (PIC) active alignment and UV adhesive bonding



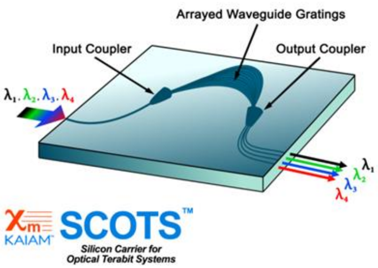
Limitations for packaging:

- Adhesive and fiber coating have to survive solder reflow with temperatures up to 260^{0}C
- Fiber pigtail interferes with post-assembly process

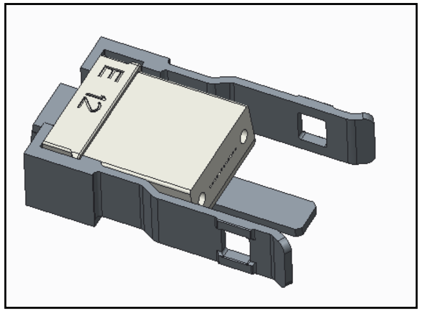
Novel connector approach



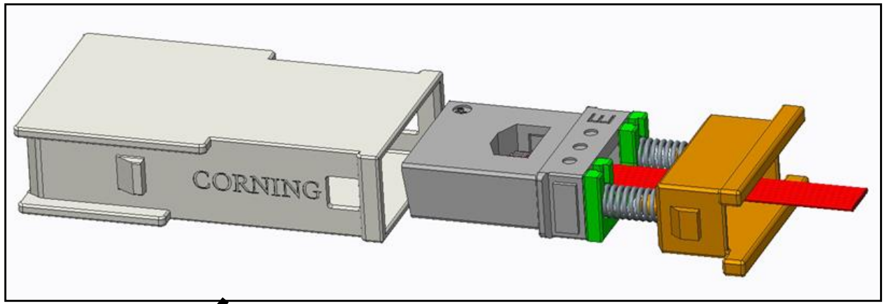
Transceiver

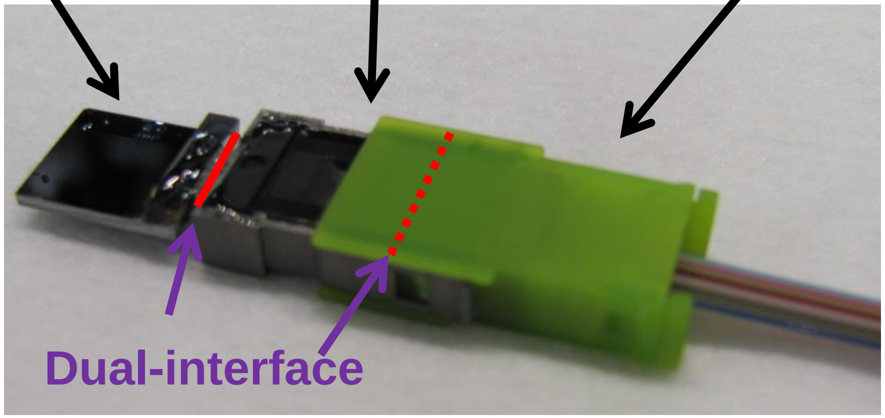


Receptacle

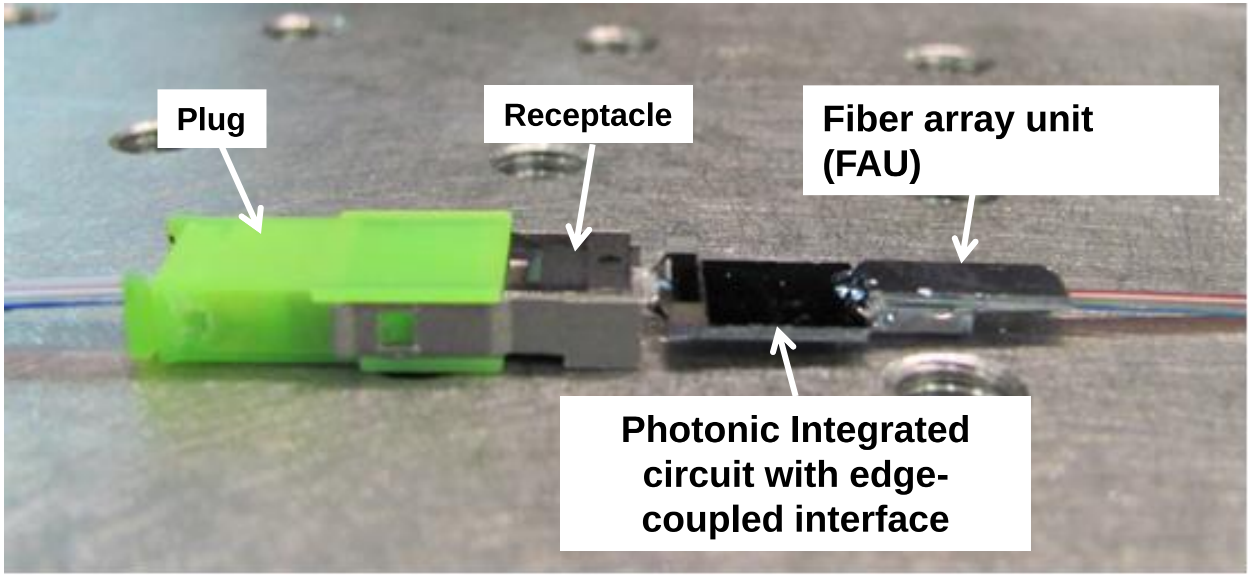


Plug



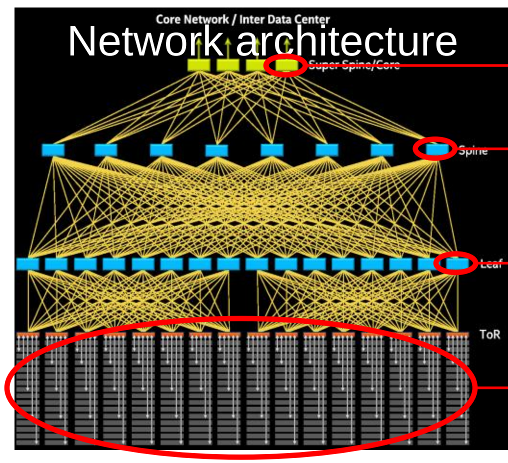


Assembly was built to characterize optical loss



- 1.77 dB average insertion loss including all interfaces and waveguide loss:
  - Loss between connector and receptacle
  - Loss between receptacle and PIC
  - Loss between PIC and FAU
  - Propagation loss of PIC waveguides
- Average insertion loss of the novel connector is 0.92 dB (0.58 … 1.27 dB)
- Reflectance was measured to be -55 dB or lower.
- Insertion loss variation after four mating-cycles is 0.8 dB for one of the eight channels, all other channels showed lower variation and were repeatable

Where is the need for novel photonic packaging concepts in a datacenter?



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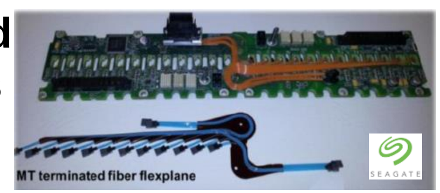
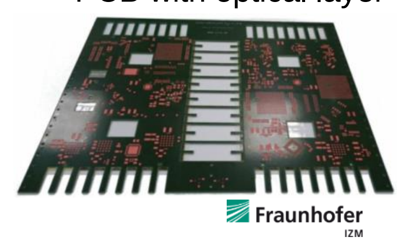
Optical Printed Circuit Boards (OPCB)



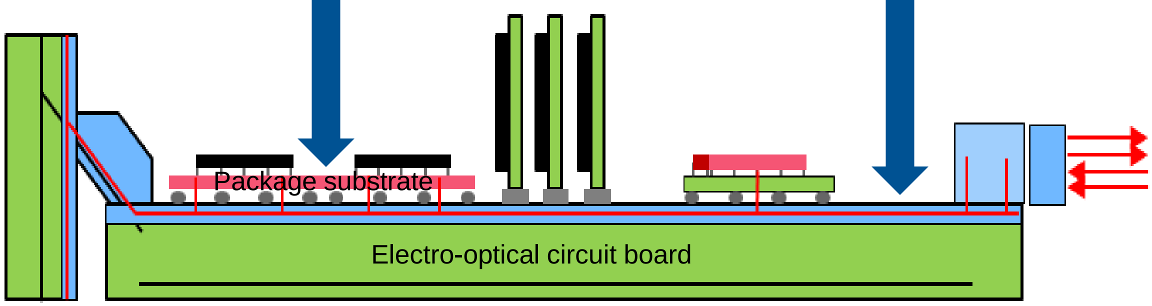
PCB with optical layer

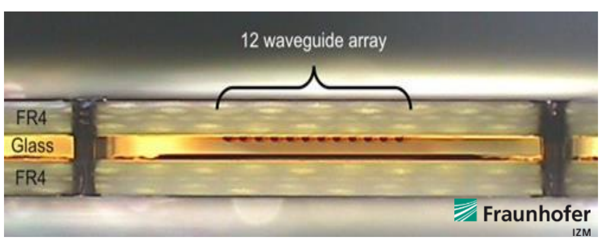


Glass waveguides for board-level optical interconnects

Integration of optical and electrical interconnects in the same substrate for chip packaging & e/o interconnection

Replacing fibers by integration of waveguides into the printed circuit board





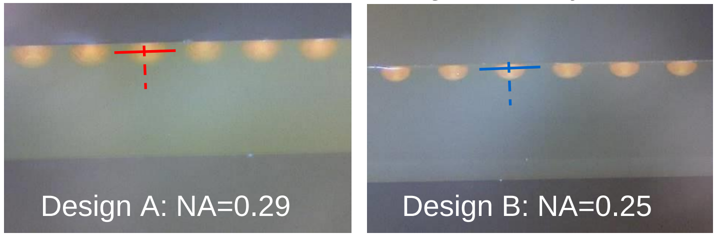
Glass Waveguides

- Low propagation loss at 1310/1550nm
- Benefits of glass for packaging

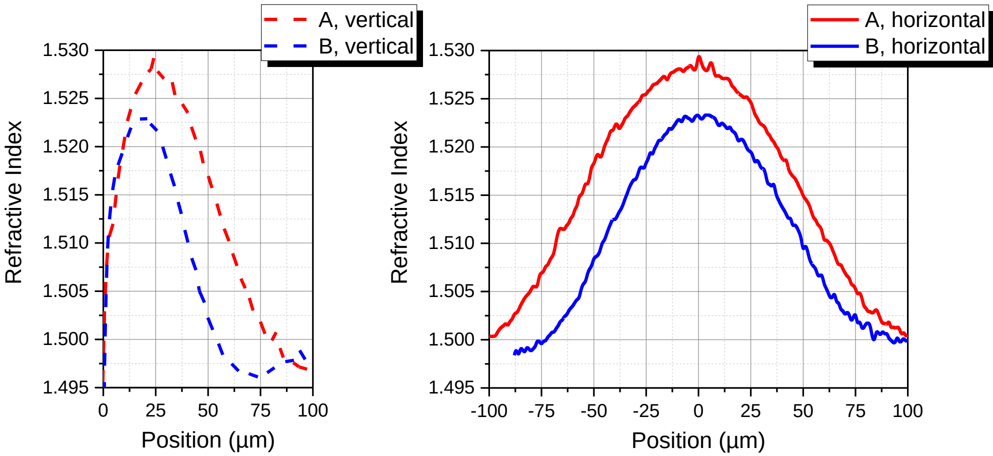
Multimode waveguides in CORNING® GLASS

- Collaboration with Fraunhofer IZM for fabrication of MM glass waveguides
- Two step thermal ion-exchange
  - Elliptical waveguide cross-section
  - Refractive index buried below glass surface
- Study of two different waveguide designs
  - Design A: NA=0.29
  - Design B: NA=0.25
- Low propagation loss for 1310nm

Cross section waveguide arrays



Measured refractive index profiles in glass

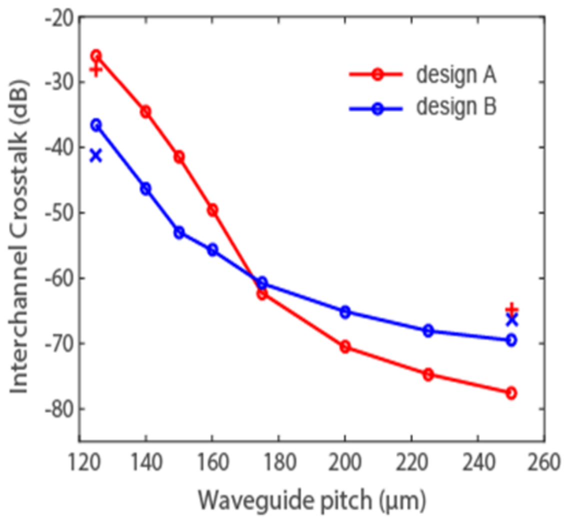


MM waveguide characteristics

Cross-talk

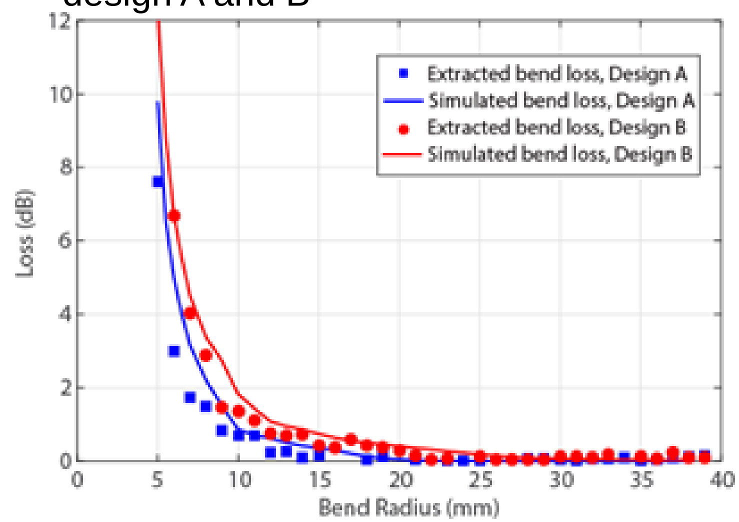
Design A and B:

- 250µm pitch: -65 dB and -66 dB
- 125µm pitch: -28 dB and -42 dB



Bend loss

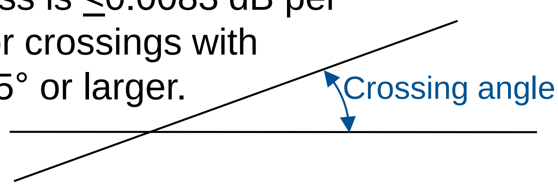
Minimum bend radius required to achieve bend loss below 1 dB is about 9 mm and 12 mm for design A and B



Crossing loss

dependent on angle

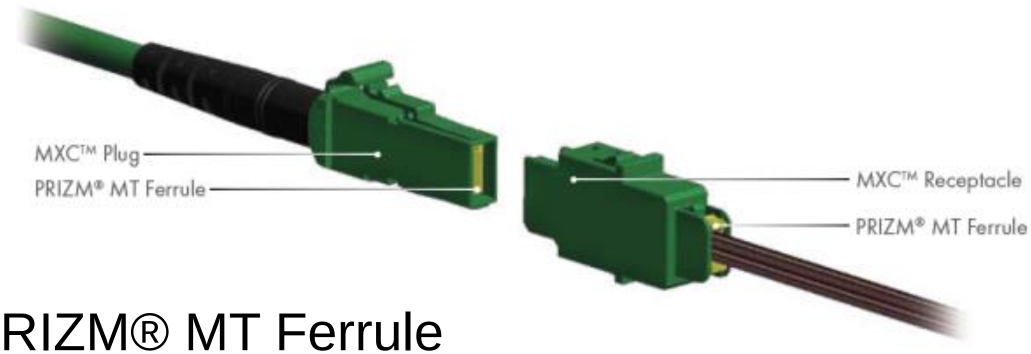
Crossing loss is ≤0.0083 dB per crossing, for crossings with angles of 45° or larger.



Design	λ [nm]	90° crossing	75° crossing	60° crossing	45° crossing	20° crossing
Design A	1310	0.0057	0.0075	0.0075	0.0083	0.0112
Design A	850	0.0046	0.0046	0.0050	0.0055	0.0083
Design B	1310	0.0104	0.0087	-	0.0076	0.0159
Design B	850	0.0023	0.0002	0.0016	0.0032	0.0108

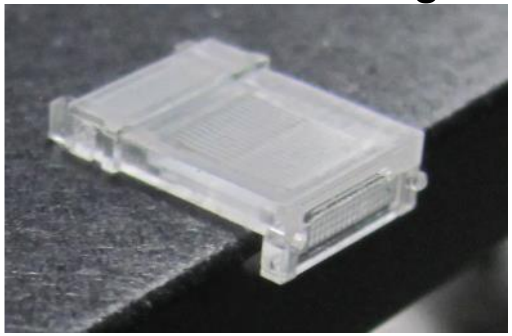
Multi-channel expended beam fiber to planar glass waveguide connector

US Conec expanded beam PRIZM® MT Ferrule and MXC® Plug

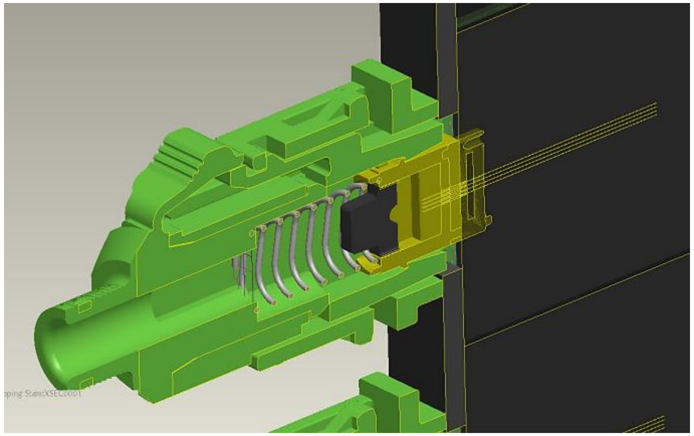


PRIZM® MT Ferrule

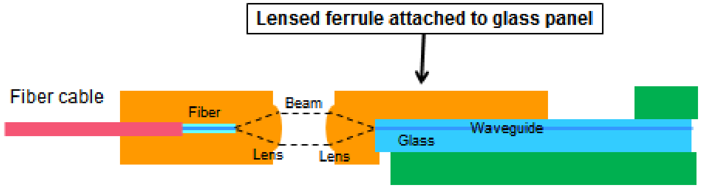
PRIZM® MT Ferrule after machining



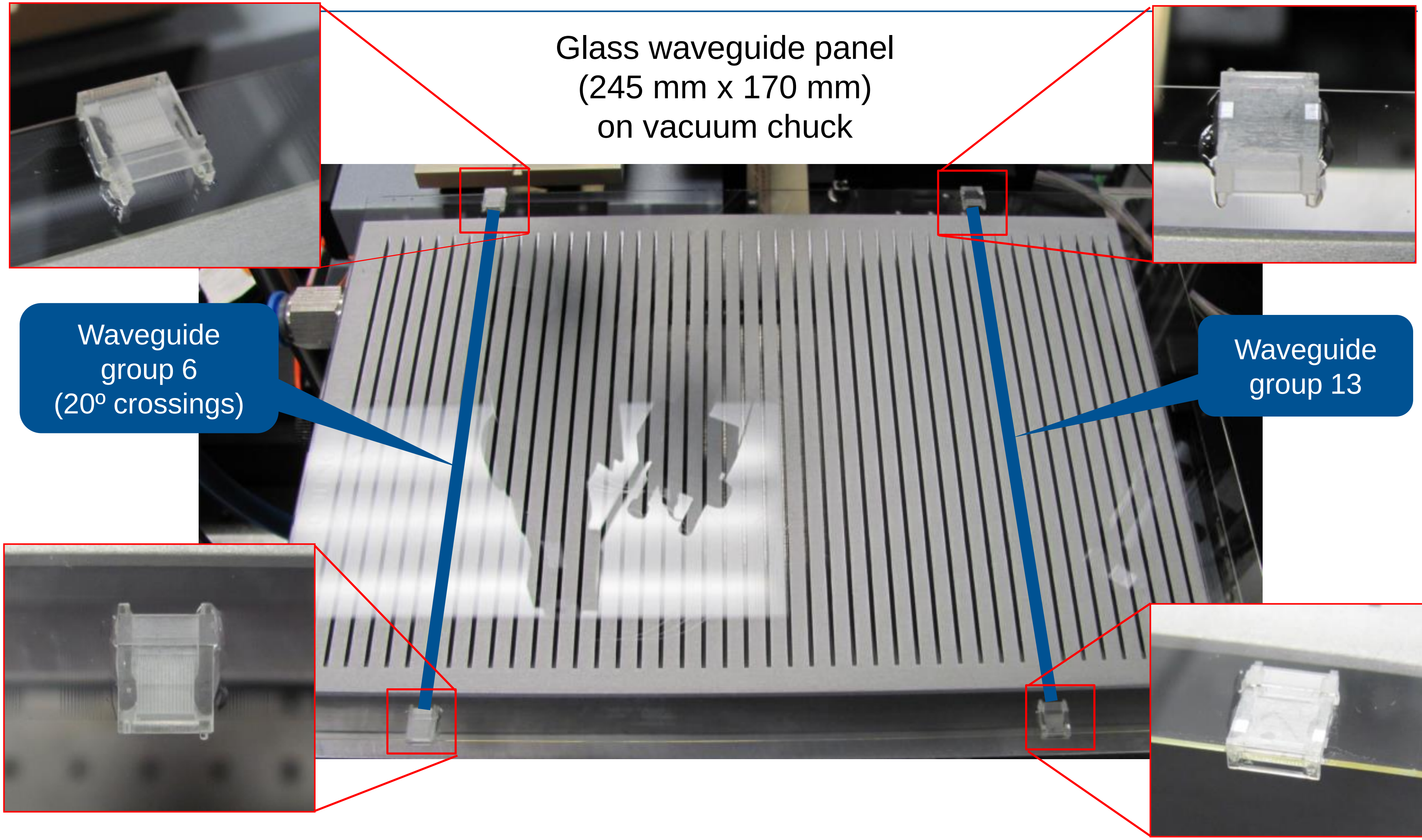
Concept for board connector



Cross-section view



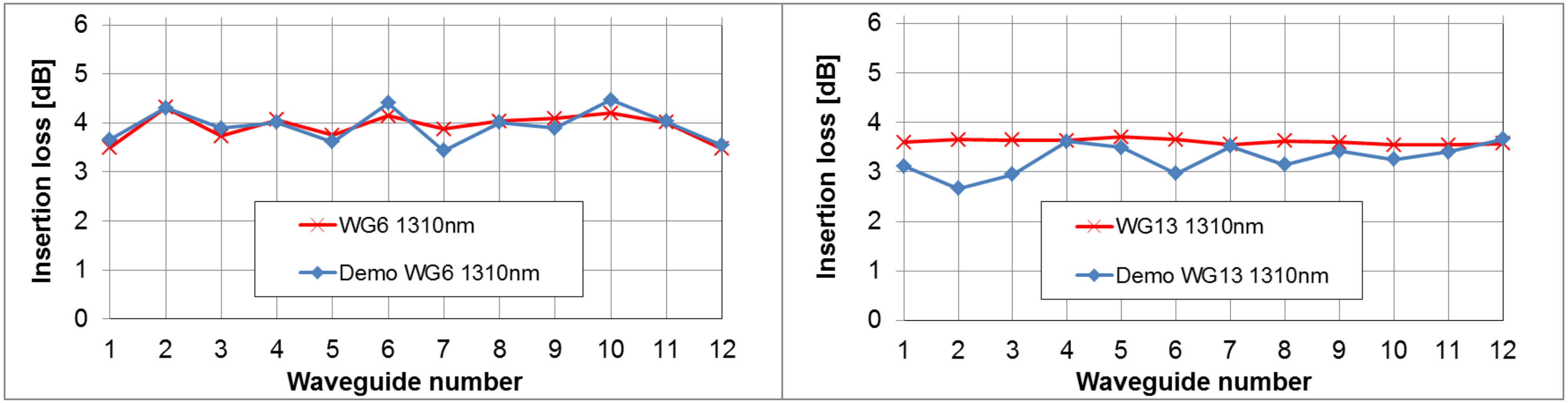
Assembled connectors on glass waveguide panel



Insertion loss characterization

Insertion loss measurement of waveguide group (WG6 and WG13) on the same glass panel

- measured without connectors, **λ=1310 nm**
- with connectors, **λ= 1310 nm**.



For WG13 (measured IL = 3.3 dB) we estimate that the loss introduced by each waveguide connector is

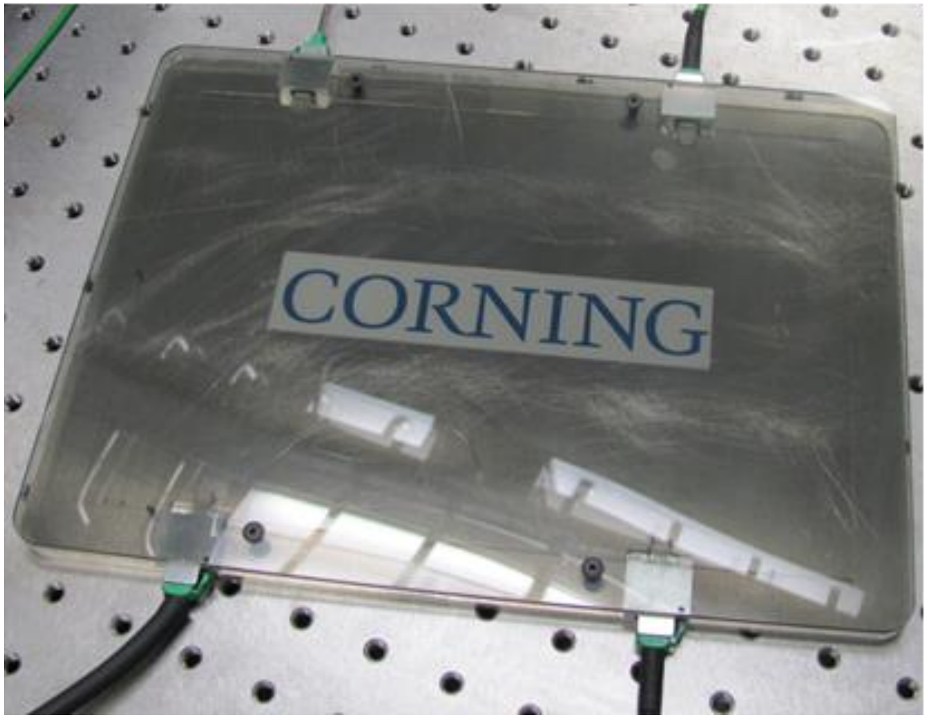
[3.3 - 0.5 - 0.85] / 2 = 1.0 dB

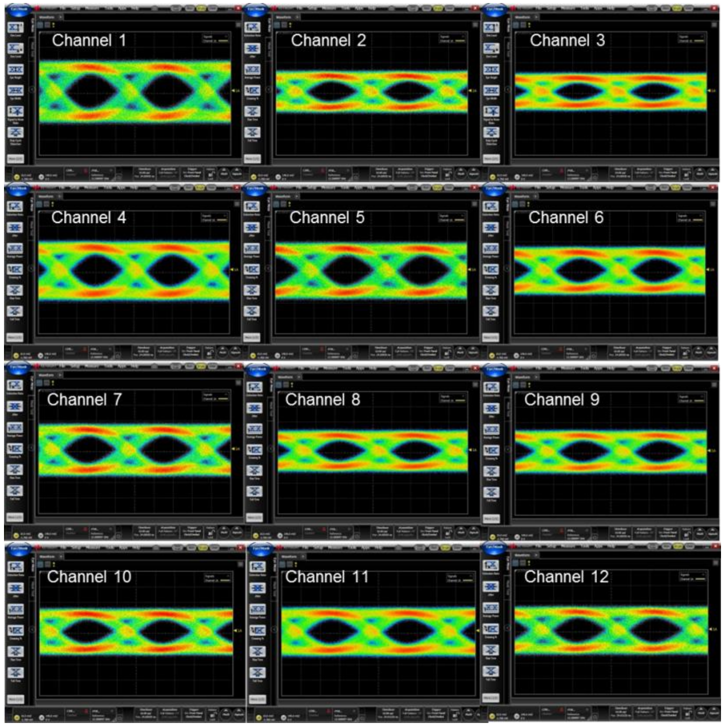
0.5: Fresnel reflections

0.85: Waveguide propagation loss (measured separately)

Full demonstrator testing

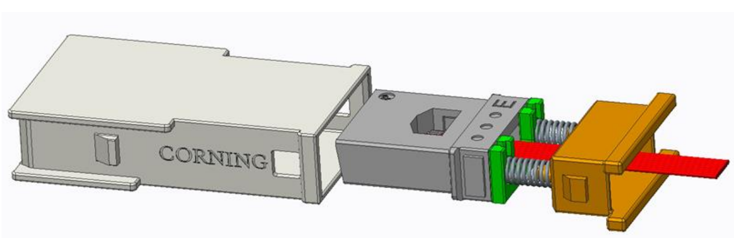
- Connectorized glass waveguide panel with the 25Gb/s NRZ signals tested
- Single-mode 28 Gb/s 1310 nm optical transmitter was operated at 25 Gb/s
- All channels produce an open eye

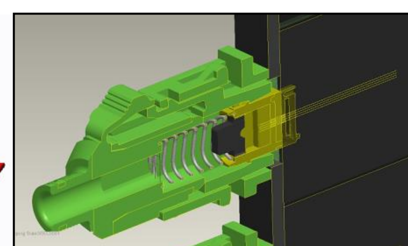


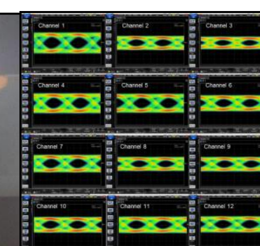


Summary

- SM transfer waveguide for fiber to chip coupling
- Novel connector concept for co-packaging of optics
- Low propagation loss of glass waveguides at 1310 nm
- Connector concept was developed and demonstrated
- Loss introduced by each waveguide connector is 1.0 dB
- Demonstrator (glass waveguide & connector) → 25 Gb/s per CH







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