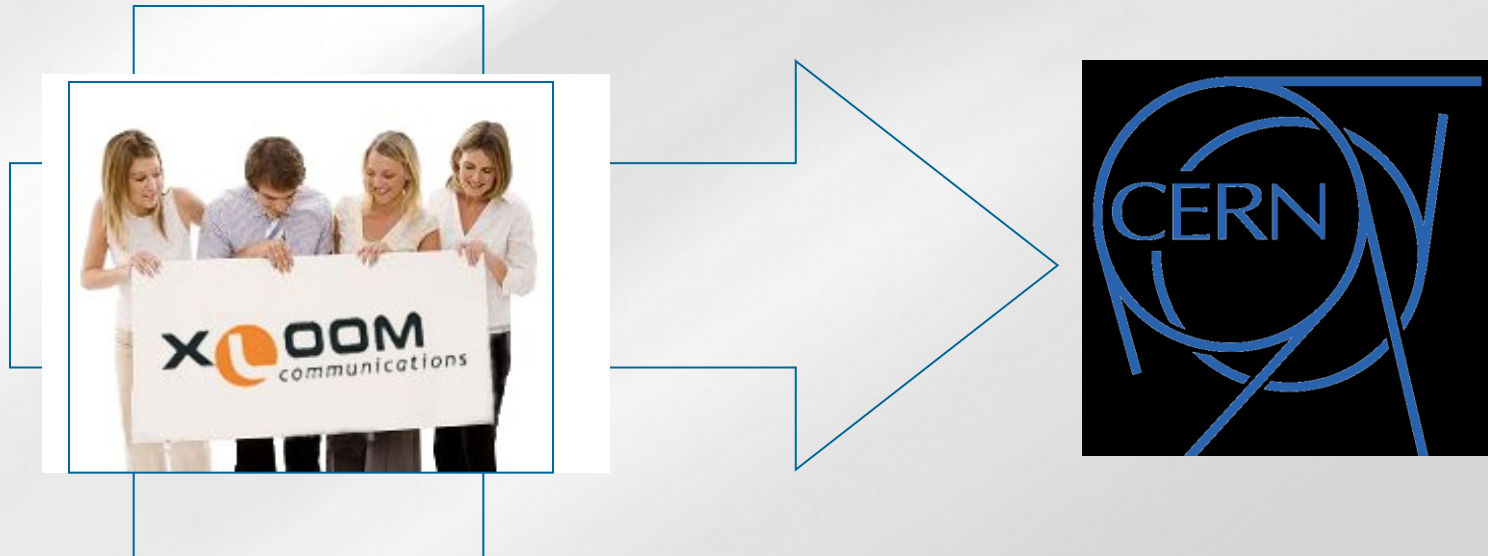
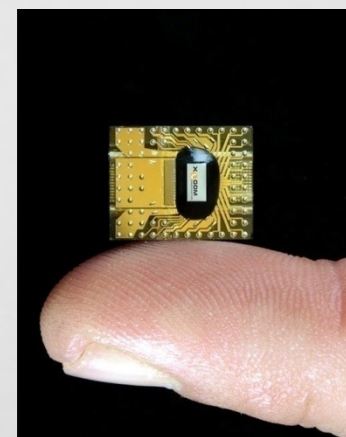


10GB-100GB Parallel Optical Interconnect Challenges

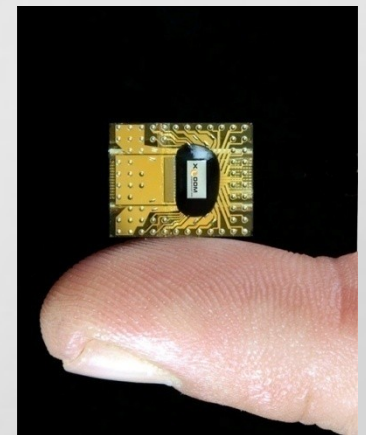


Dr. Hanan Yinnon
Consultant, Former CSO
XLoom Communications, Ltd., Tel Aviv, Israel
March 10th, 2011

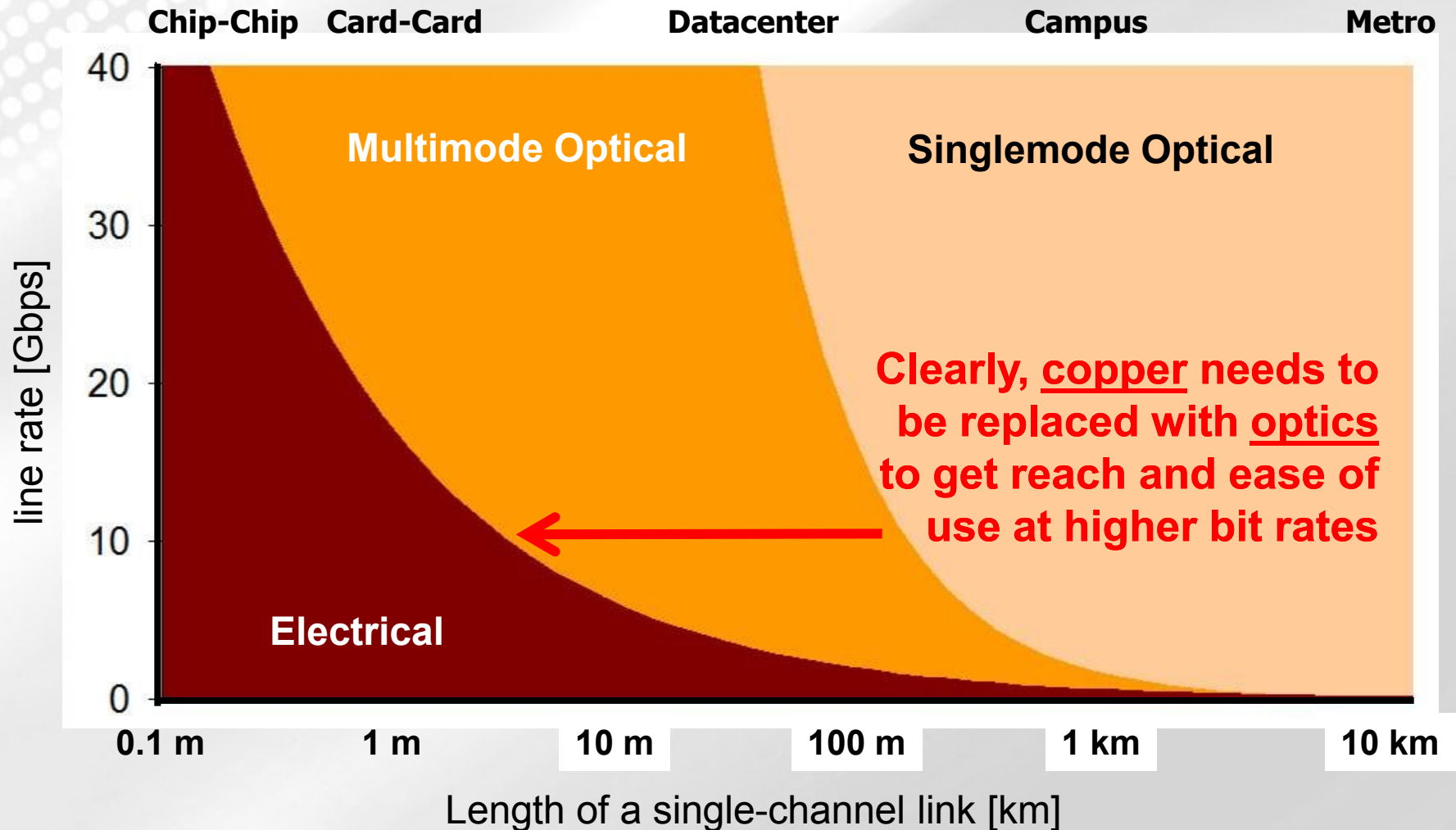
- ❑ The need for optical interconnect solutions
- ❑ Current solutions
- ❑ XLoom iFlame optical engine
- ❑ 4 parallel lane 5 Gbps transceiver based on XLoom iFlame - Avdat
- ❑ Future development



- ❑ The need for optical interconnect solutions
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Copper and fiber link data rates and ranges



Electronics

- Current electronic technology limits bit rate to around 40 Gbps per single transmitter

Optics

- Multimode fibers can be used at low wavelength (850 nm) where inexpensive lasers are available (VCSEL)
- However, Multimode fibers have limited bandwidth – max effective ~ 5GHz*km
- Lasers are also approaching the bandwidth limitation

Solutions

- Wavelength Division Multiplexing (WDM) – expensive, used for SM system only
- **Parallel multi-lane interconnects – viable solution for short lengths**

- ❑ The main problem is **cost**
- ❑ Optics and analog electronics cost **does not** scale like digital electronics
- ❑ Due to:
 - The need for manual or semi-automatic processes - mostly alignment issues
 - Sensitivity of diode lasers to operating conditions - need for optimization
 - Integration of optics and electronics requires combination of a variety of technologies besides semiconductor design and fabrication.
- ❑ Commonly used **Figure-of-Merit** for interconnects is given in **\$/Gbps**
- ❑ Today it is common to pay **\$ 2/Gbps/end** for optical interconnect, but Xloom's target is **<\$0.1/Gbps/end**

Design

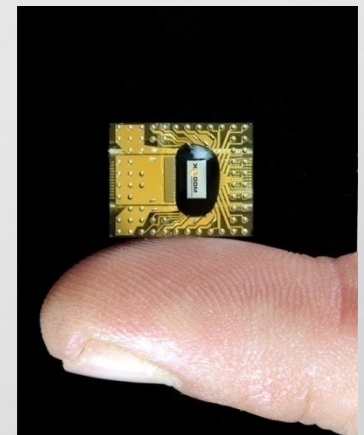
- **Multi-lane interconnects** – 4, 10, 12 or even more
- **Multimode fiber** – more tolerant to misalignment in light coupling
- **Vertical cavity laser diodes (VCSEL)** – lower component cost and lower power consumption for same speed, mounting ease

Manufacturing

- **Large-scale optical coupling alignment** – wafer scale and **passive** alignment should lend itself to full automation
- Controllable, repeatable process, not “rocket science”

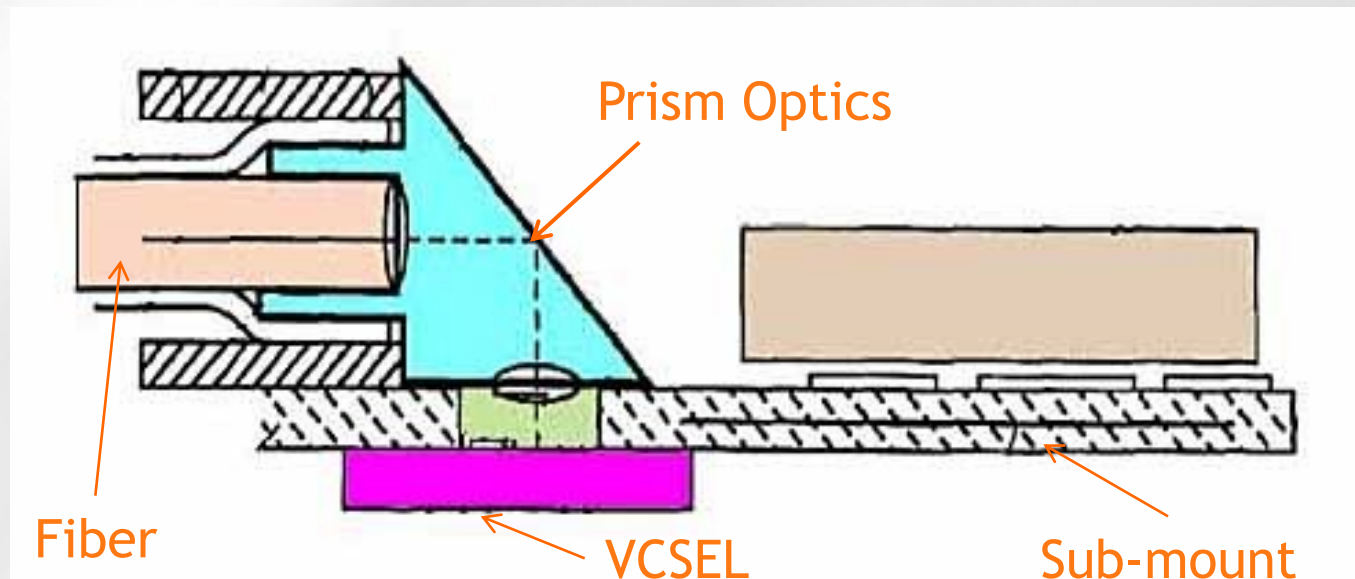
- ❖ IEEE 802.3ba - intended mostly for data centers
- ❖ Various link definitions: backplane, data cables, multi-mode fibers, single-mode fibers
- ❖ Largest market share expected to be multi-mode links
- ❖ Two MMF options:
 - ❖ 40GBASE-SR4 - 2 x 4 parallel lanes (duplex)
 - ❖ 100GBASE-SR10 - 2 x 10 parallel lanes (duplex)
- ❖ Two MM fiber types:
 - ❖ OM3 - max link length 100 m
 - ❖ OM4 - max link length 150 m

- The need for optical interconnect solutions
- Current solutions
- XLoom iFlame optical engine
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- Future development



Intel - Emcore Active Cable Manufacturing process

- ❑ Assembly of VCSELs on sub mount
- ❑ Attach sub mount to PCB under a hole in the PCB
- ❑ Active alignment of the coupling prism to the VCSEL
- ❑ Repeat the whole process for the Photodiode array



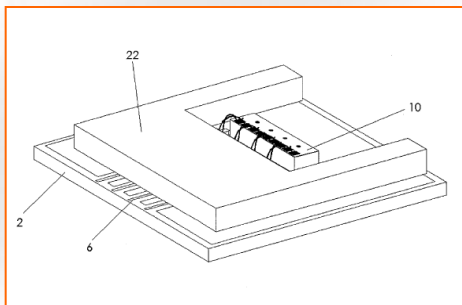
Intel - Emcore process

Main observations

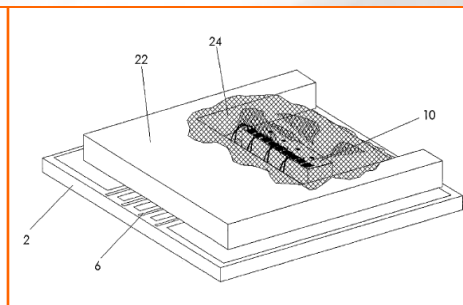
- Optical subassembly includes
 - Double active alignment of Fiber + lens prism to VCSEL array and PD array and adhesive curing cycles
 - Estimated process time 15 min per transmitter - Labor intensive manual process
 - No optical connector
 - Applicable only for active cables



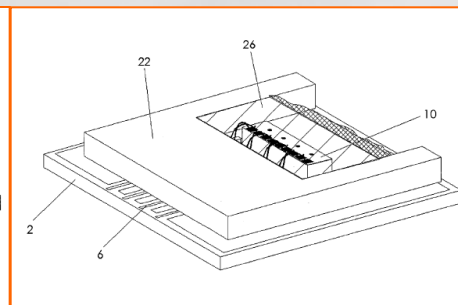
Reflex Photonics Manufacturing process



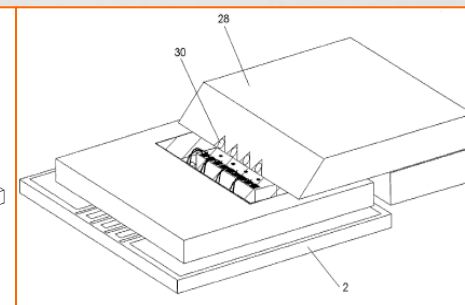
- Assembly of VCSEL / Photodiode array on substrate
- Placement of spacer plate on the substrate



- Cover VCSEL / Photodiode array with clear Epoxy

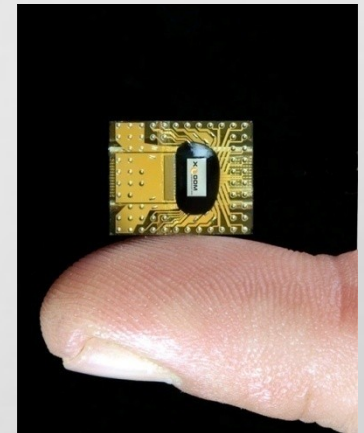


- Flat polish transparent epoxy



- Active align to fiber array module - Similar to the Infineon process

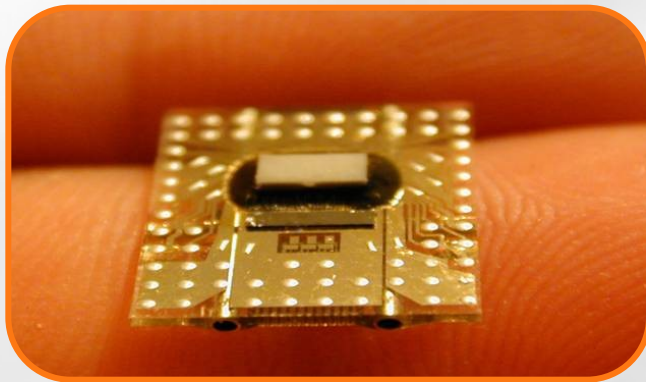
- ❑ The need for optical interconnect solutions
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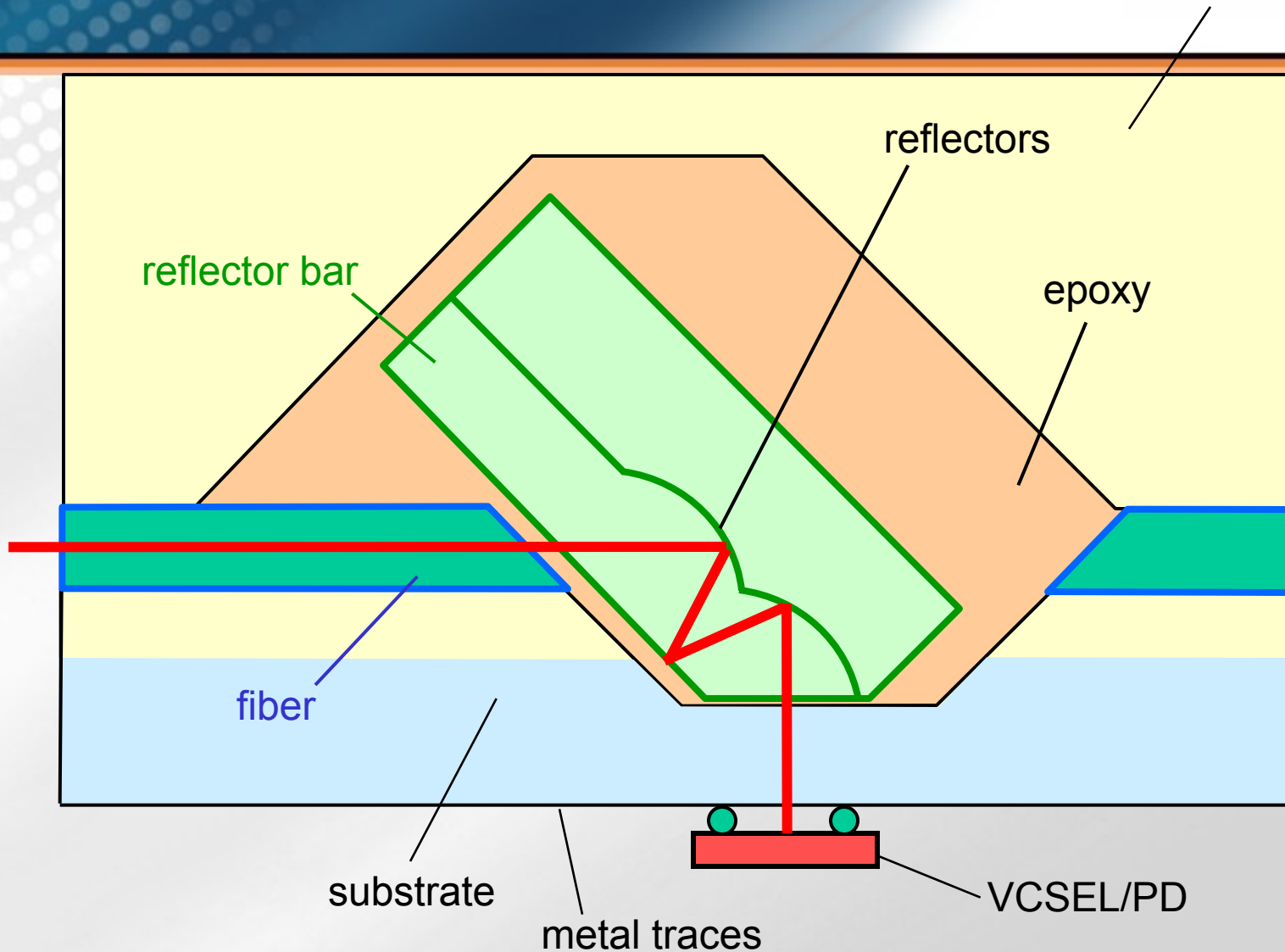
XLoom chip scale optical technology solves density, power, and reach

iFlame technology:

- ❑ Optical-to-electronic conversion on a miniature scale
- ❑ Commercially-available lasers/photodiodes and circuits
- ❑ Glass substrate allows for easy light coupling
- ❑ Aligned and assembled on the wafer level (6" in process)
- ❑ Standard semiconductor micromachining processes

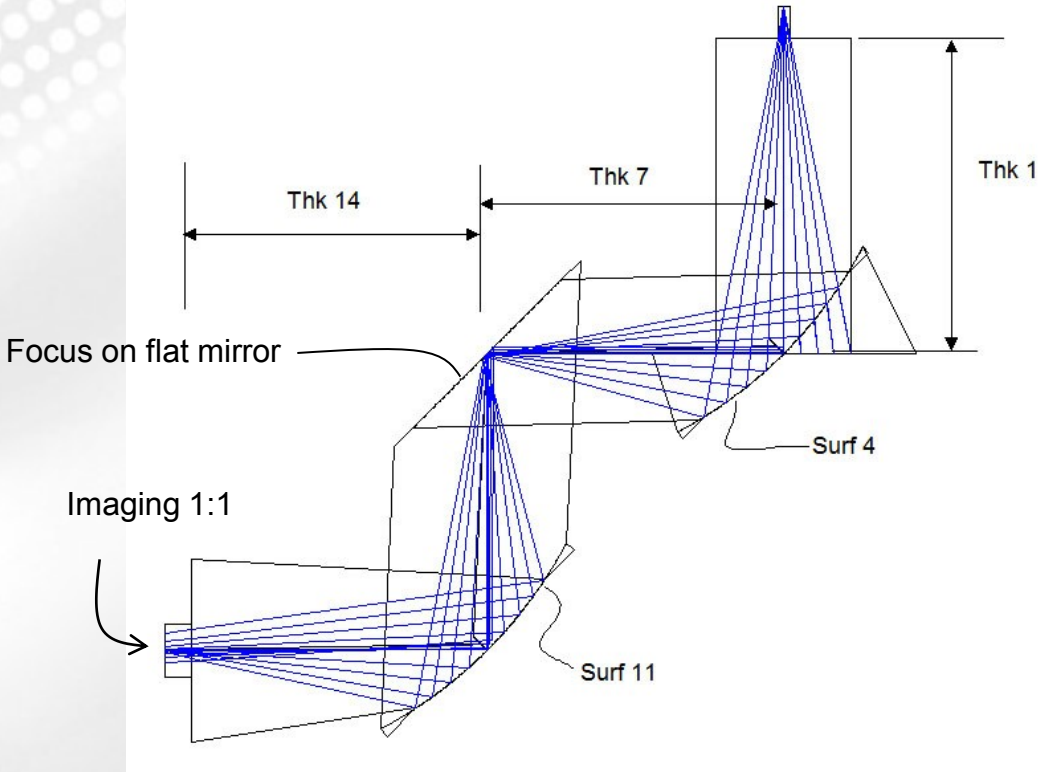


iFlame light-coupling scheme

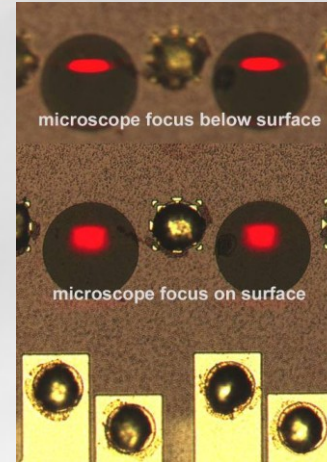


iFlame Lens Optical Design

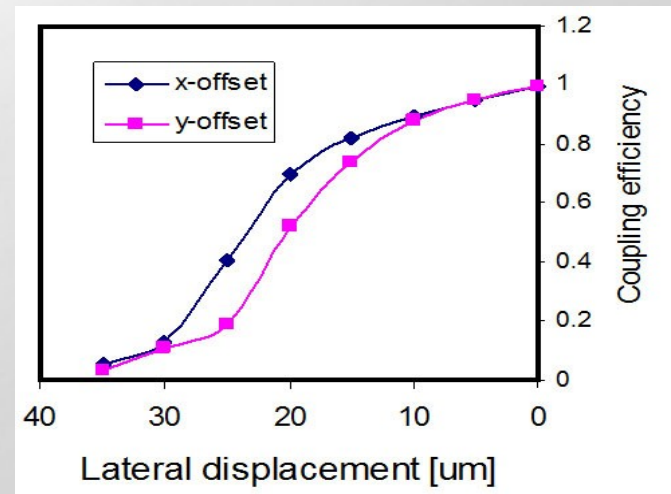
Ray-tracing optical design
(sequential analysis, using ZEMAX®)



Acceptance angle < NA of fiber/ VCSELs

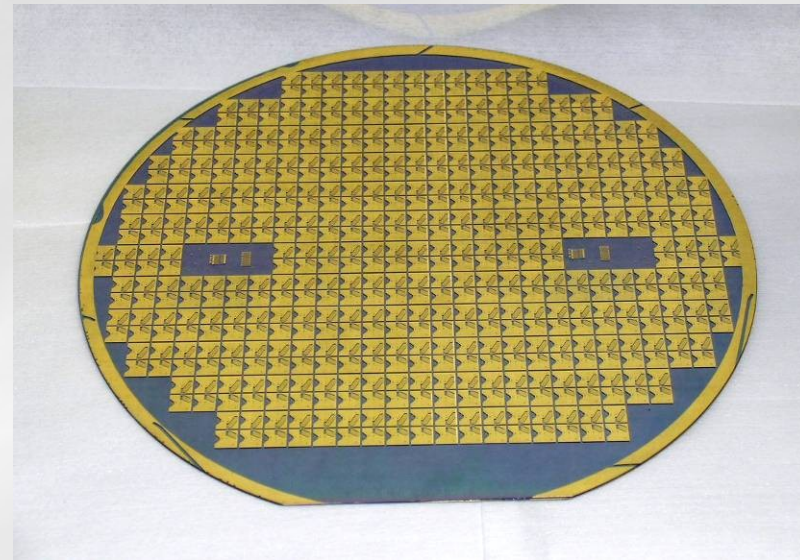
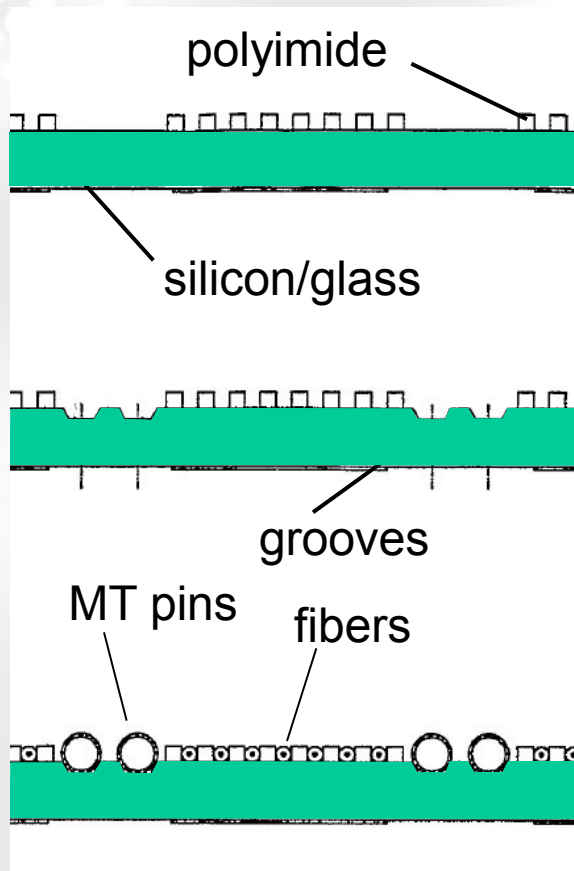


Near-field pattern at detector
Example of offset z-focus



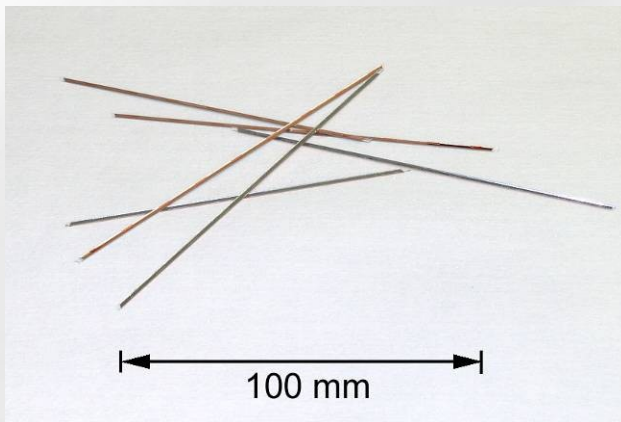
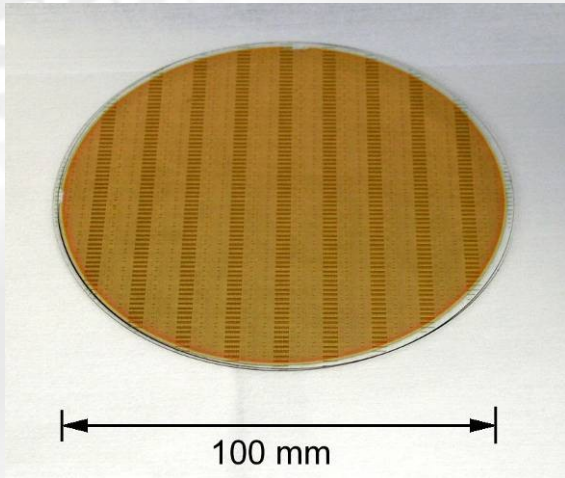
iFlame Manufacturing process

- structure is repeated in 2D on a 6" wafer
- grooves created at the same time on all devices
- simultaneous alignment of all devices
- Lead free (ROHS)

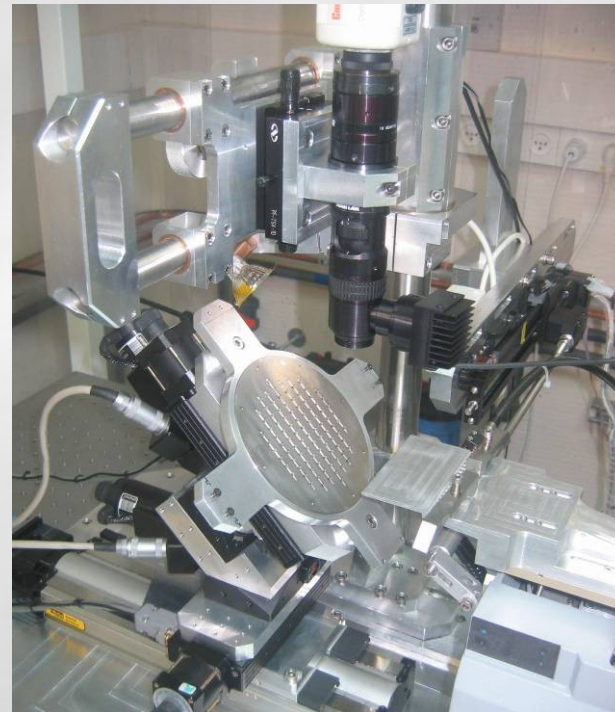


Patterned device wafer ready for saw

Reflector bars

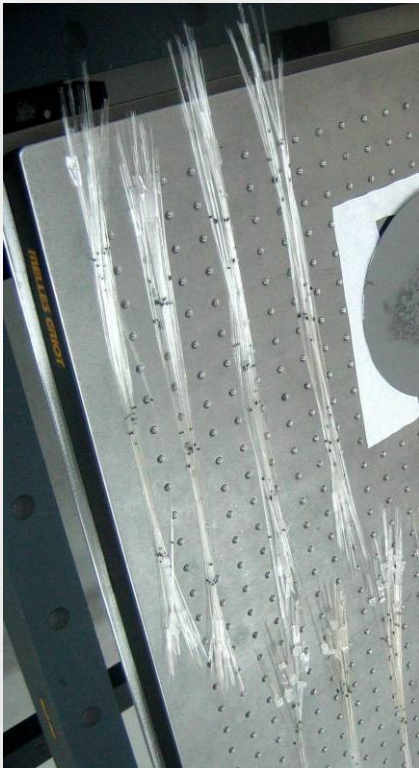


Reflectors bars are manufactured separately in a wafer form, cut, and attached to device wafer using an automated machine (passive alignment)



Standard Semiconductor Equipment Used in Assembly

Fibers inserted
into the alleys



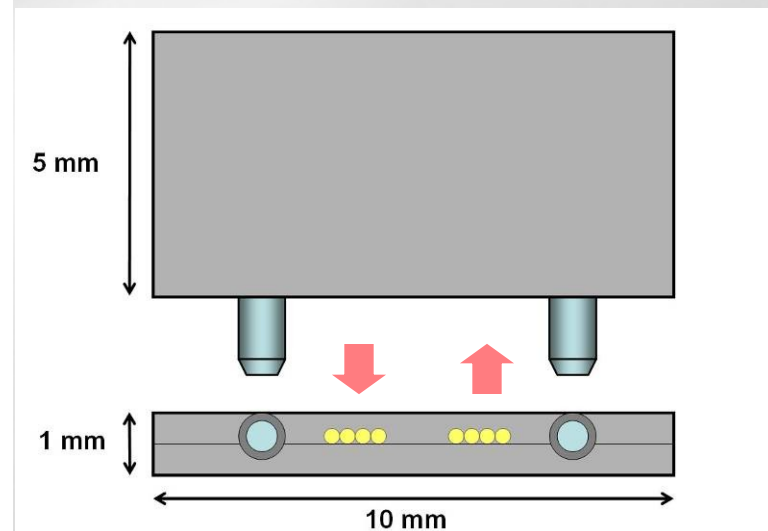
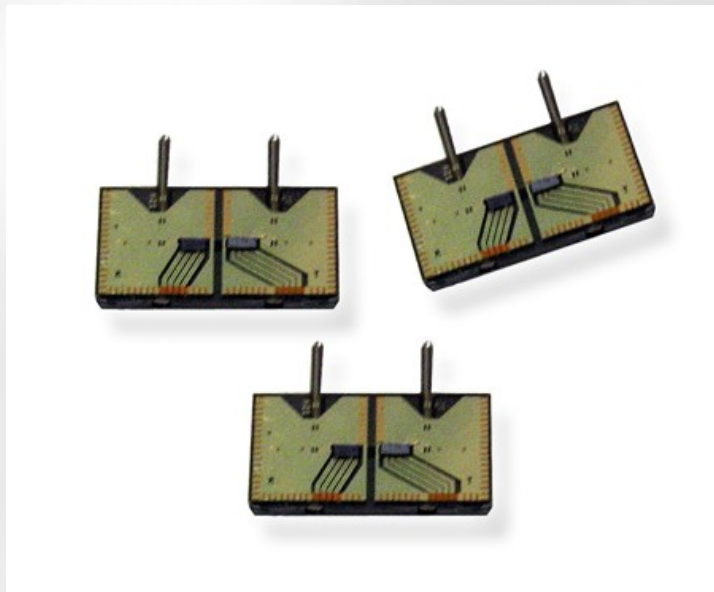
Saw cuts the grooves



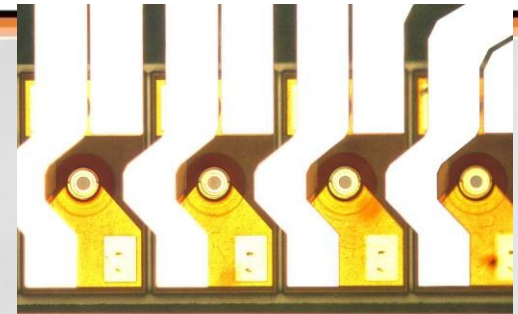
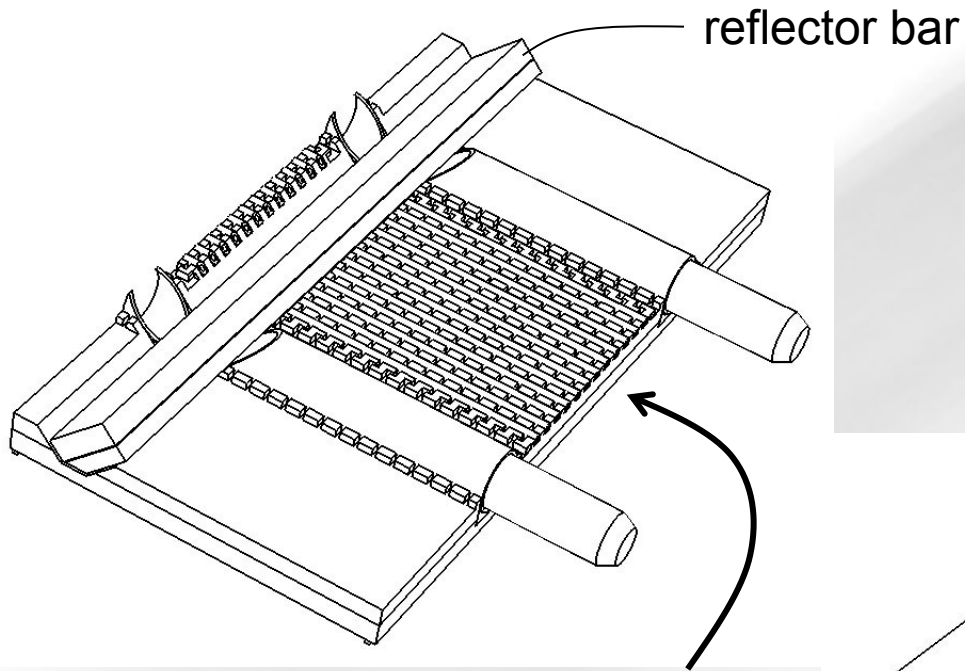
Flip-chip machine
mounts the lasers
and detectors



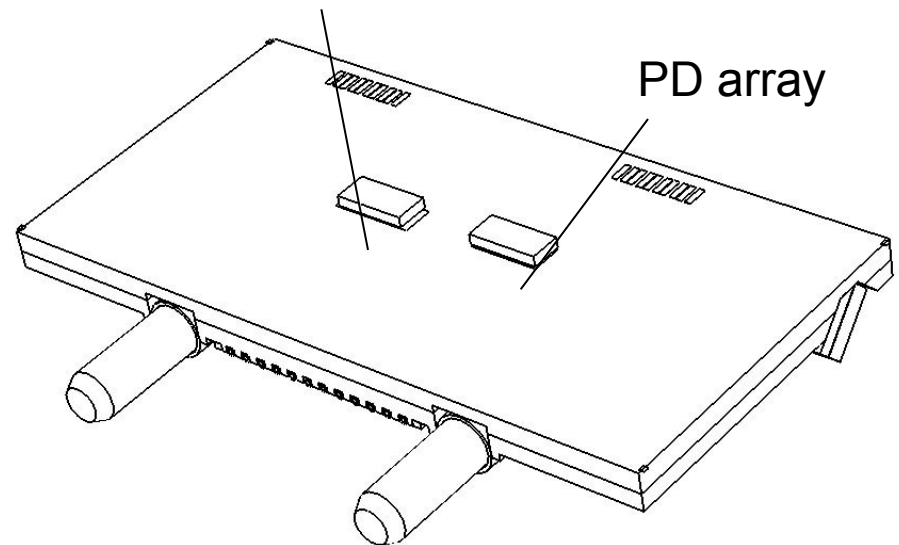
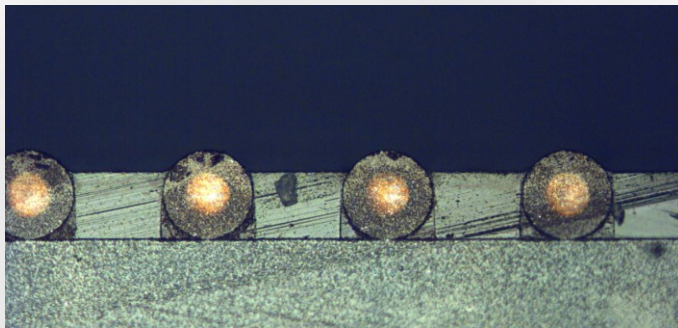
- ❑ **Wafer-level assembly** - simultaneous alignment of many module optics
- ❑ **Passive alignment** - visual, automation possible
- ❑ **Array optics** - multiple channels assembled simultaneously
- ❑ **Low profile** - multiple environments/applications



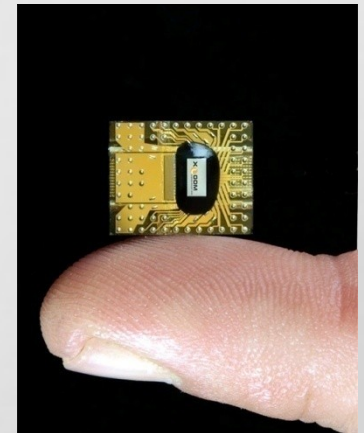
iFlame optical chip (without the cap)



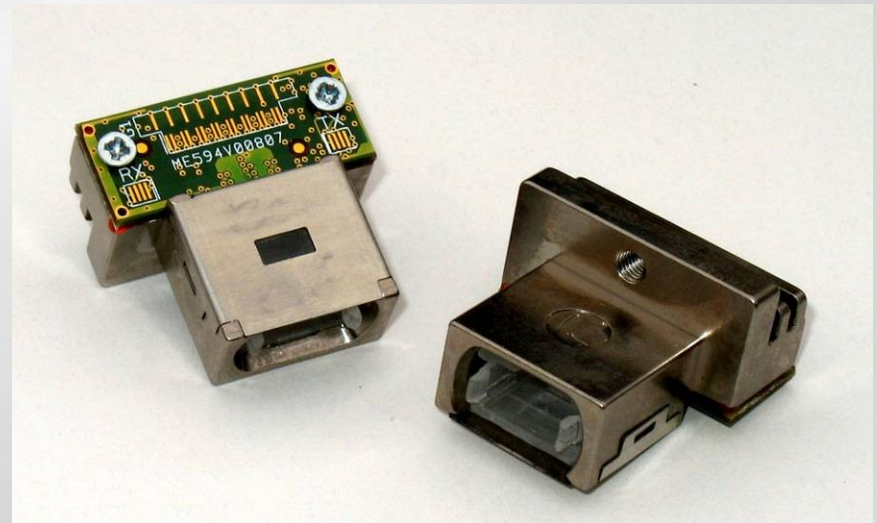
VCSEL array



- ❑ The need for optical interconnect solutions
- ❑ Current solutions
- ❑ XLoom iFlame optical engine
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- ❑ Future development



- Infiniband 4X DDR optical transceiver
- Plug-compatible with CX4 connector
- 20 Gbps bandwidth in each direction
- Room-temperature field replaceable
- Infiniband™, PCI-E, 10GFC, XAUI-ext.
- Switch and host-channel adapters (HCA)



InfiniBand™ Electrical VS. Optical cables and Avdat

CX4 Connector
Electrical cable connector
Avdat



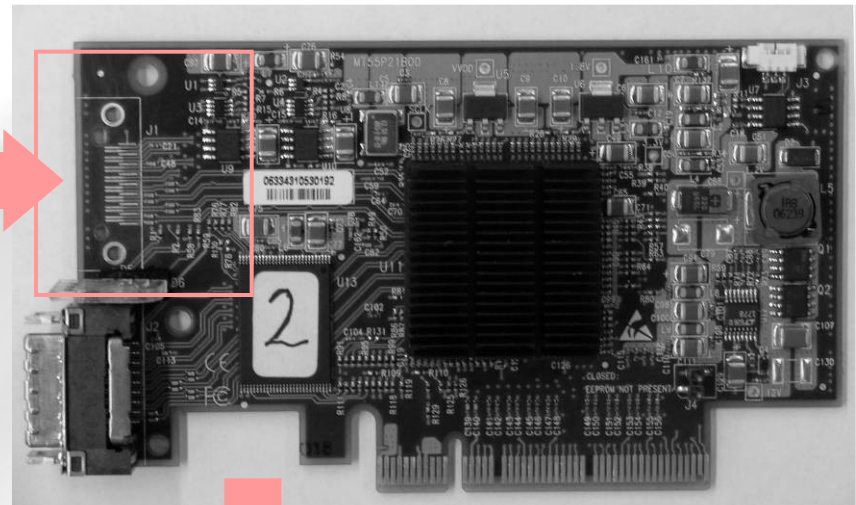
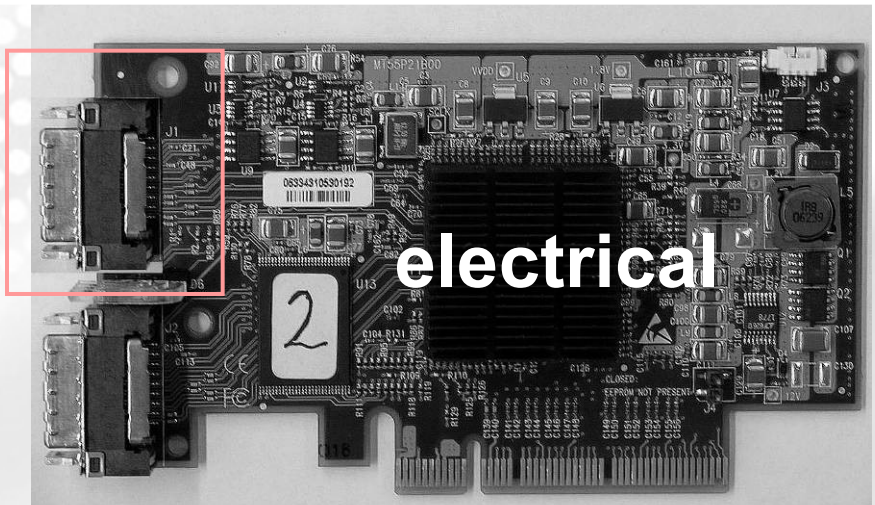
We're Connected at Supercomputing '07 with
Intel® Connects Cables

High-Speed 20 Gbps Optical Cables

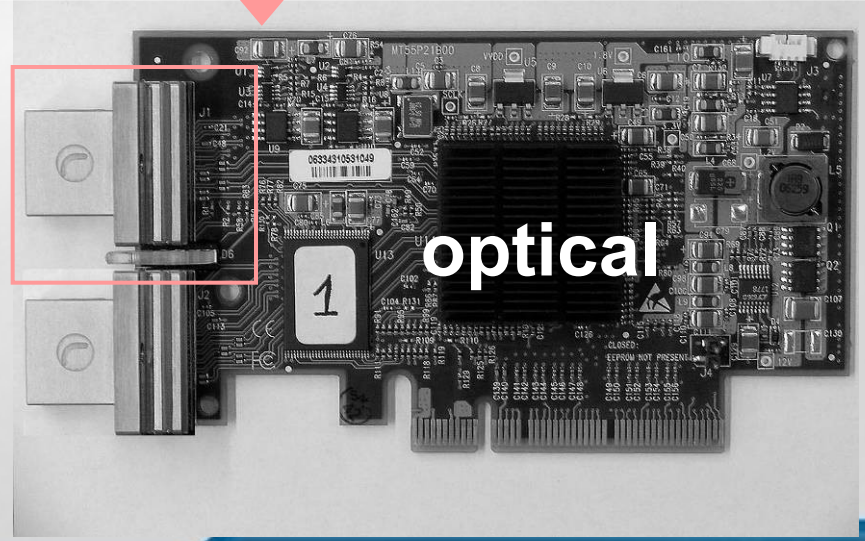
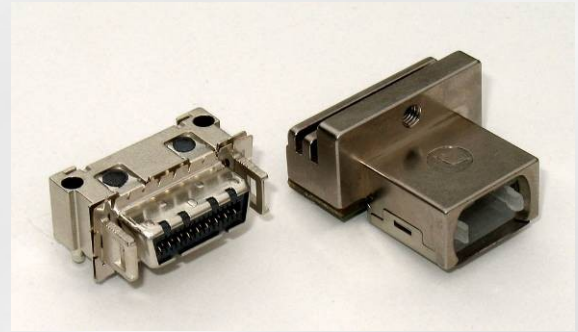
- Long distance: Up to 100 meters
- High data rate: 20 Gbps per cable
- Low bit error rate: 10⁻¹¹

Active Optical Cable

InfiniBand™ Optical Host-Channel Adapter (w/iFlame technology (Mellanox PCB))



Choose electrical or optical connector at a later stage in manufacturing



Parallel Optics Design and Manufacturing Challenges

- Signal integrity
 - **Microwave reflections** ⇒ output waveform, receiver waveform
 - **Crosstalk** ⇒ receiver sensitivity

- VCSEL performance adjustment
 - **Drive currents** ⇒ output waveform
 - **Over-temperature performance** ⇒ output waveform
 - **Thermal management** ⇒ output waveform, reliability (lifetime)

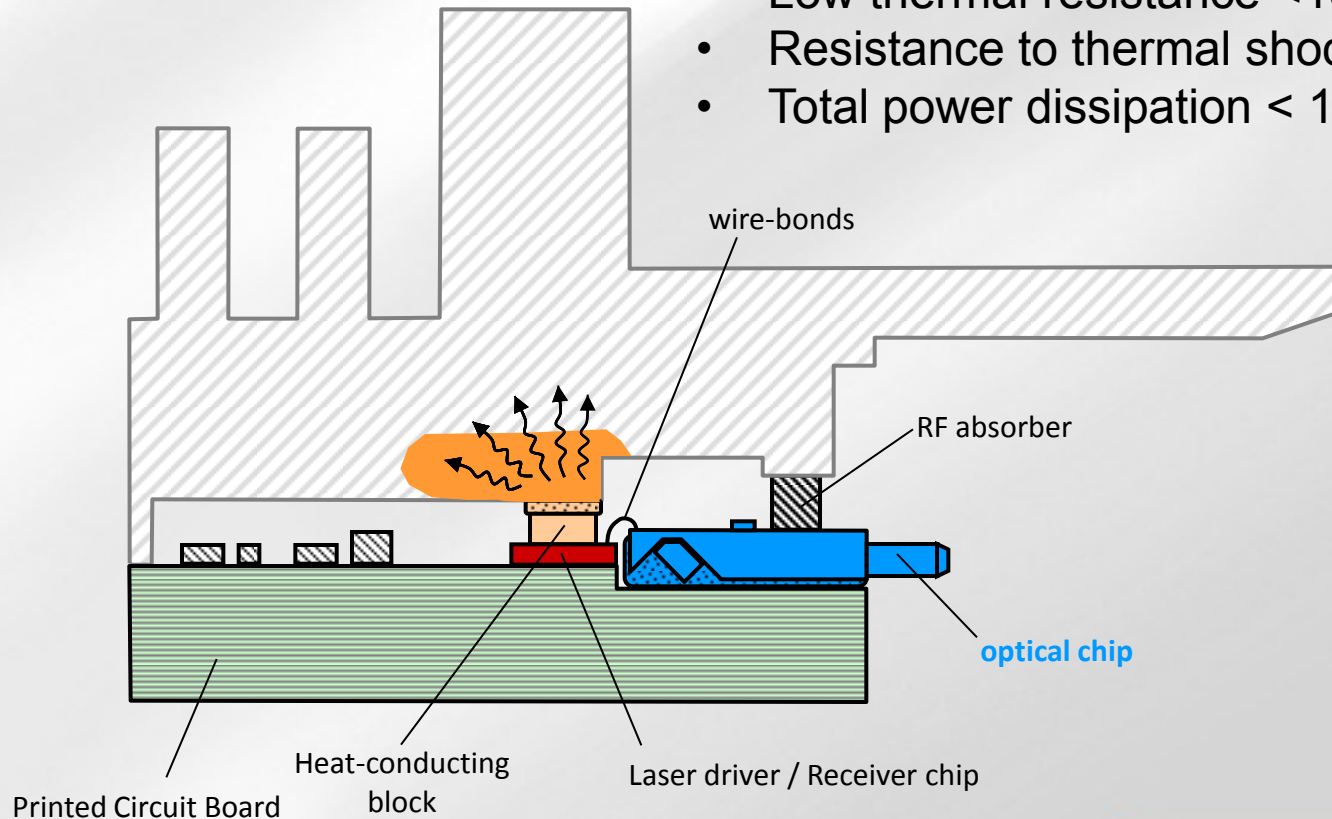
- Optical coupling
 - **Optical loss** ⇒ receiver sensitivity
 - **Coupled power ratio** ⇒ to suit fiber laser bandwidth

- Qualification
 - **Laser safety** ⇒ Must meet Class 1M
 - **EMI** ⇒ meet spec

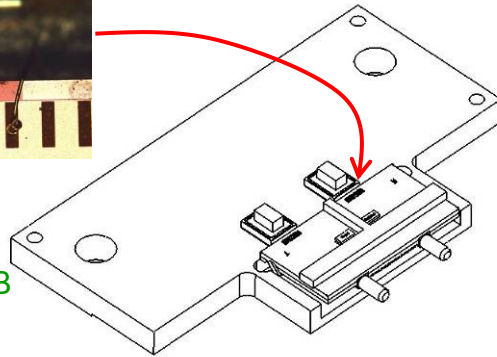
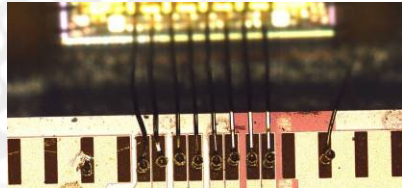
- Most heat generated in the receiver IC and the laser driver IC
- Lasers are very sensitive to heat (performance and reliability suffer)

Design features

- Low thermal resistance $< 15 \text{ }^\circ\text{C/W}$
- Resistance to thermal shock and thermal cycle
- Total power dissipation $< 1 \text{ W}$



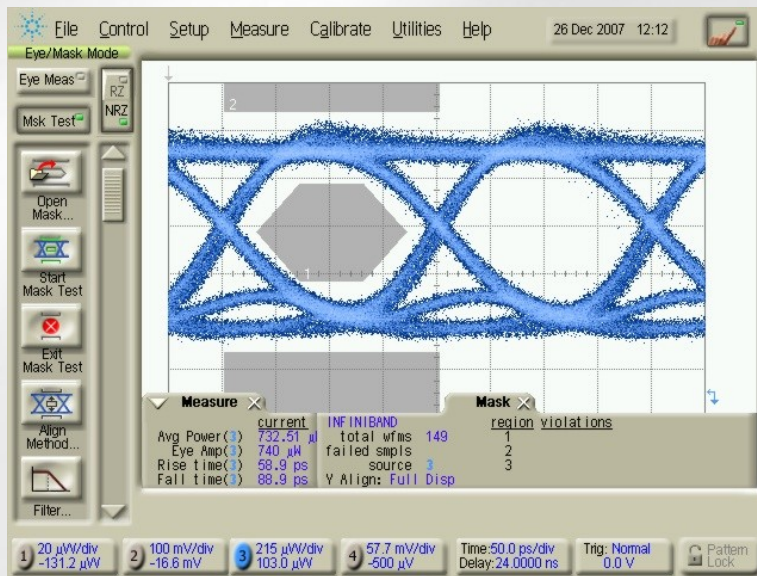
Laser performance challenges



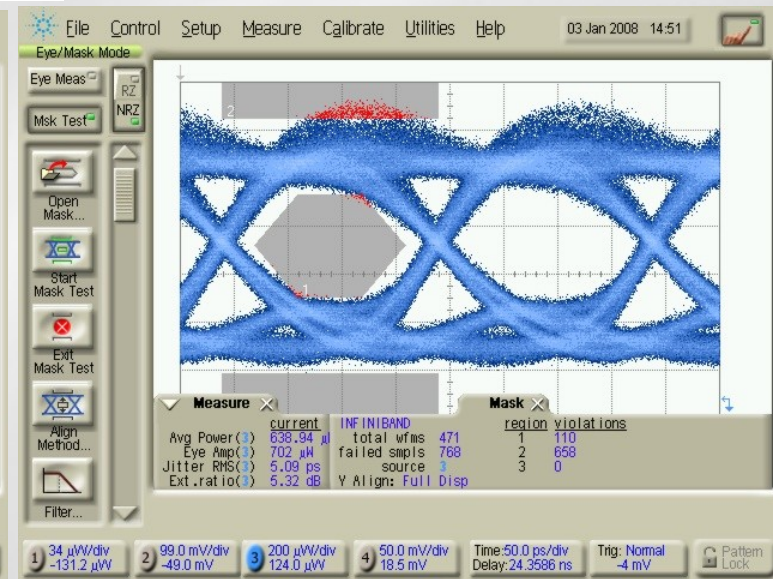
6-layer PCB

Laser dynamic nonlinearity **AND** long bond-wires (microwave mismatch) increase ringing in the light output.

The hump moves with current and bond-wire length



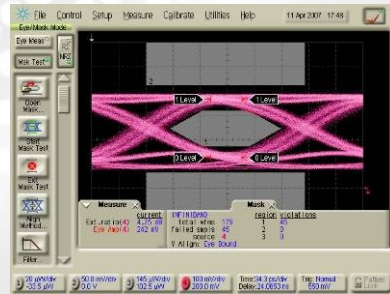
Short bond-wire (0.5 mm)



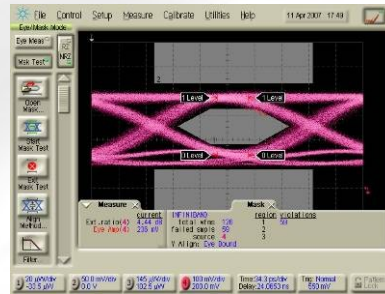
Long bond-wire (1.5 mm)

iFlame performance at 5Gbps per channel

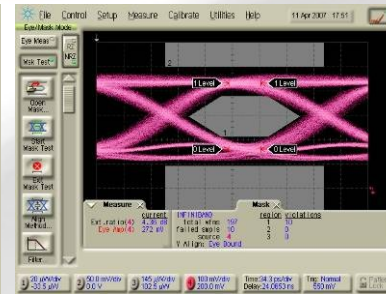
TX



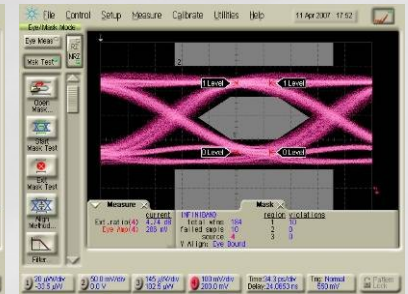
Ch 1



Ch 2

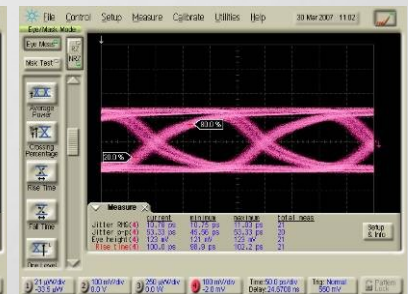
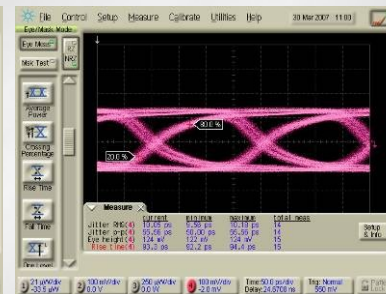
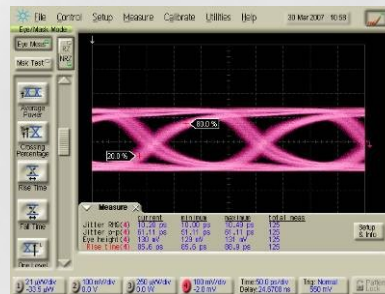
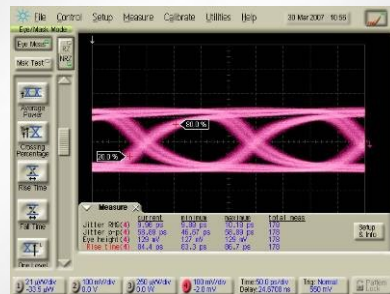


Ch 3

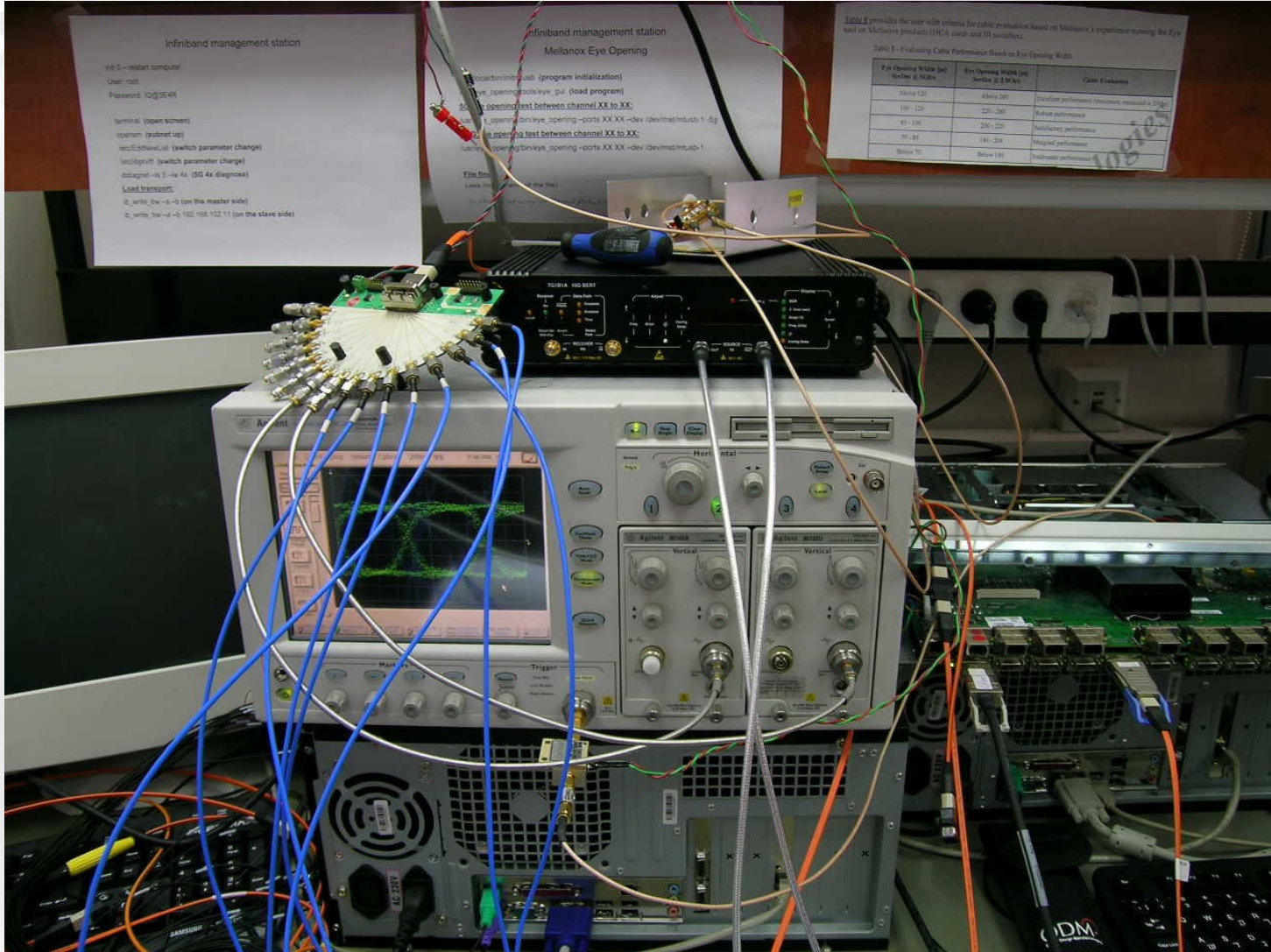


Ch 4

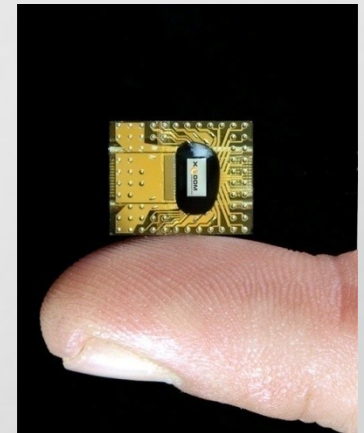
RX



Compliance with InfiniBand™ specifications at SDR and DDR Models applicable in PCI-E, and InfiniBand™ environments. Qualified: IEC/EN 60825-1/A2:2001 Class 1M, Laser safety FCC Part 15 Class B

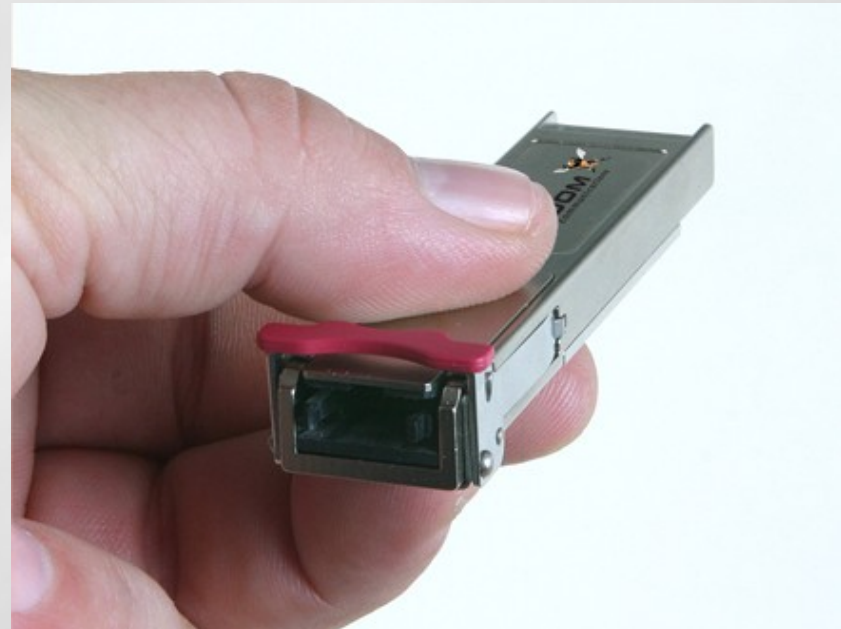


- The need for optical interconnect solutions
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- Future development

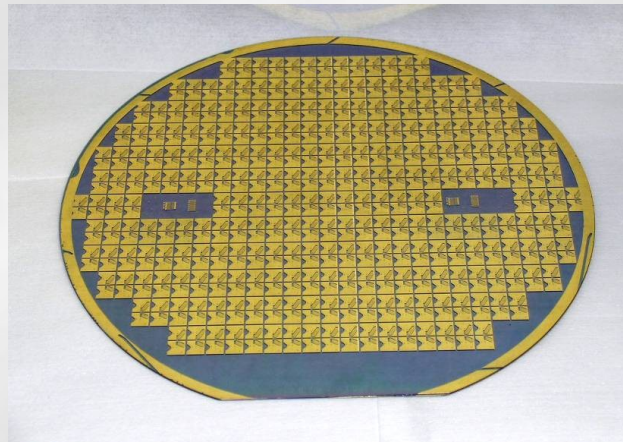


InfiniFlame 12X

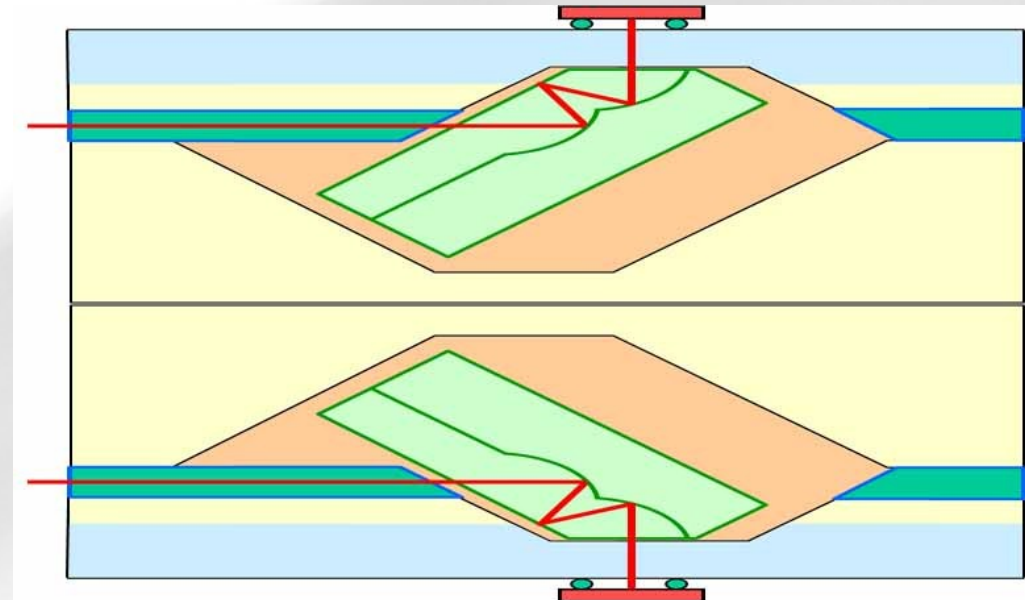
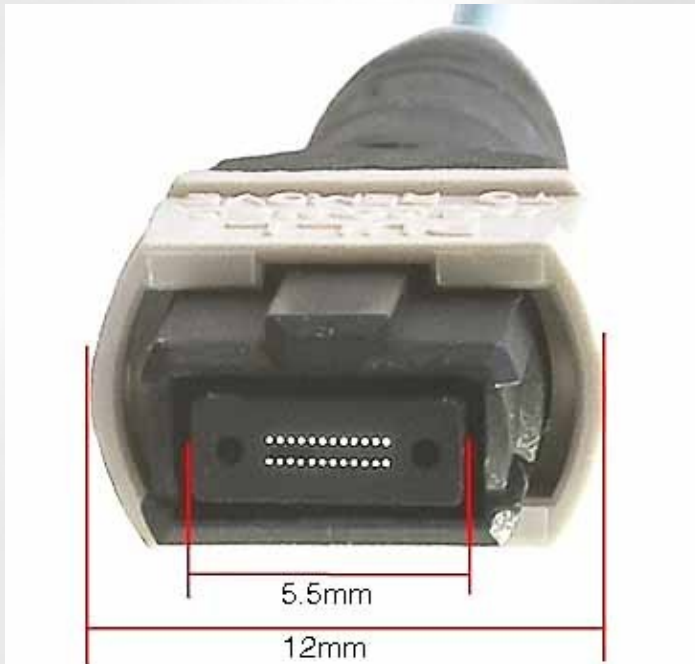
- Front panel pluggable transmitter/receiver set
- Low-profile; XFP form-factor; 30-pin connector
- MPO/MTP optical interface
- Enables 36-ports in a ½ height box
- InfiniBand, Fibre-Channel, Ethernet



- When producing optical engines for standard products (such as QSFP MSA) alignment pins must be included - production must be on a strip level
- Optics for active cables and other non-standard applications, not needing alignment pins, can be done on a wafer level - a major cost advantage



24 parallel channels on a single MPO



Initial designs have
already been
prepared

Thank You

