Silicon photonics and the data-centric datacenter

Marco Fiorentino, HP Labs
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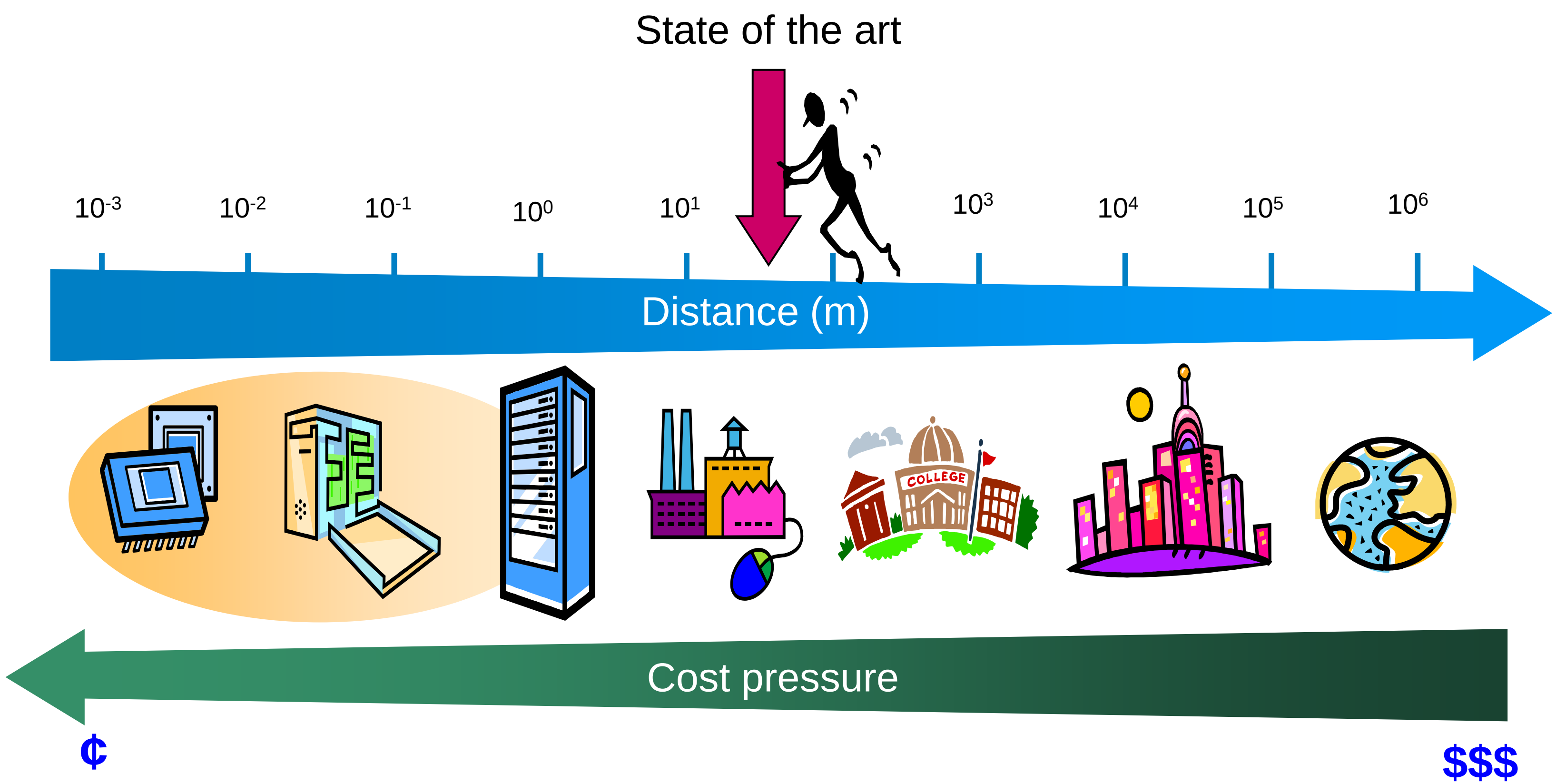
"In the last 7 years online data increased 56 times"

Google (2009)

Data-centric computing

- Data grows faster than computation
- Data-centric workloads
- From performance to efficiency
- Scalability

Optical interconnects



Advantages

More bits per "wire"	Less power per bit	Better signal integrity

Outline

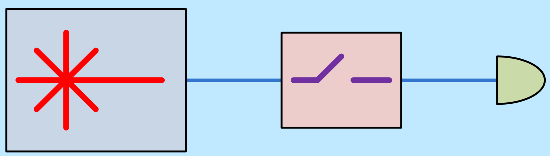
- Architectures
- Devices
    - Waveguides
    - Modulators
    - Detectors
    - Lasers

R. G. Beausoleil "Large-Scale Integrated Photonics for High-Performance Interconnects," to be published in ACM Transactions on Computational Logic

Architectures

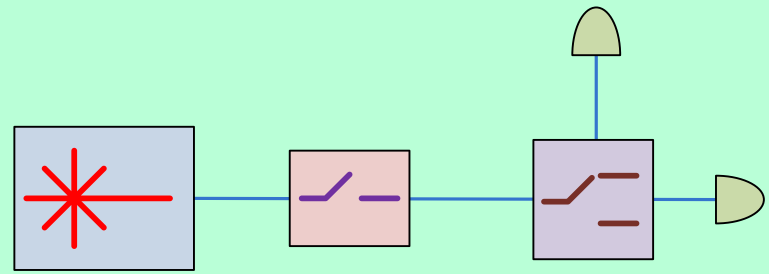
Network-on-Chip link topologies

Point-to-point



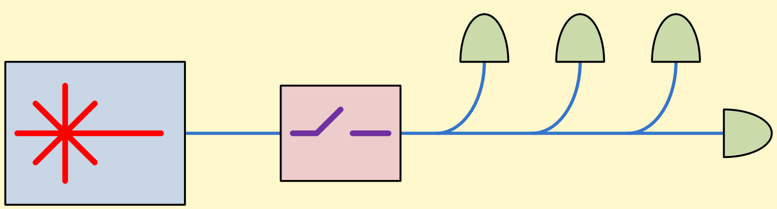
Sun/Oracle, MIT

Switched network



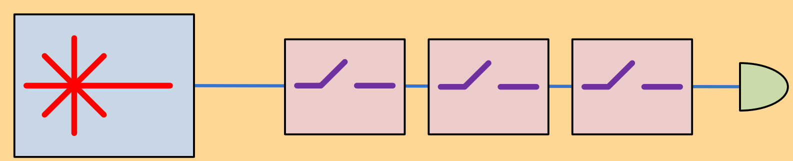
Cornell

Broadcast bus



Cornell, Northwestern

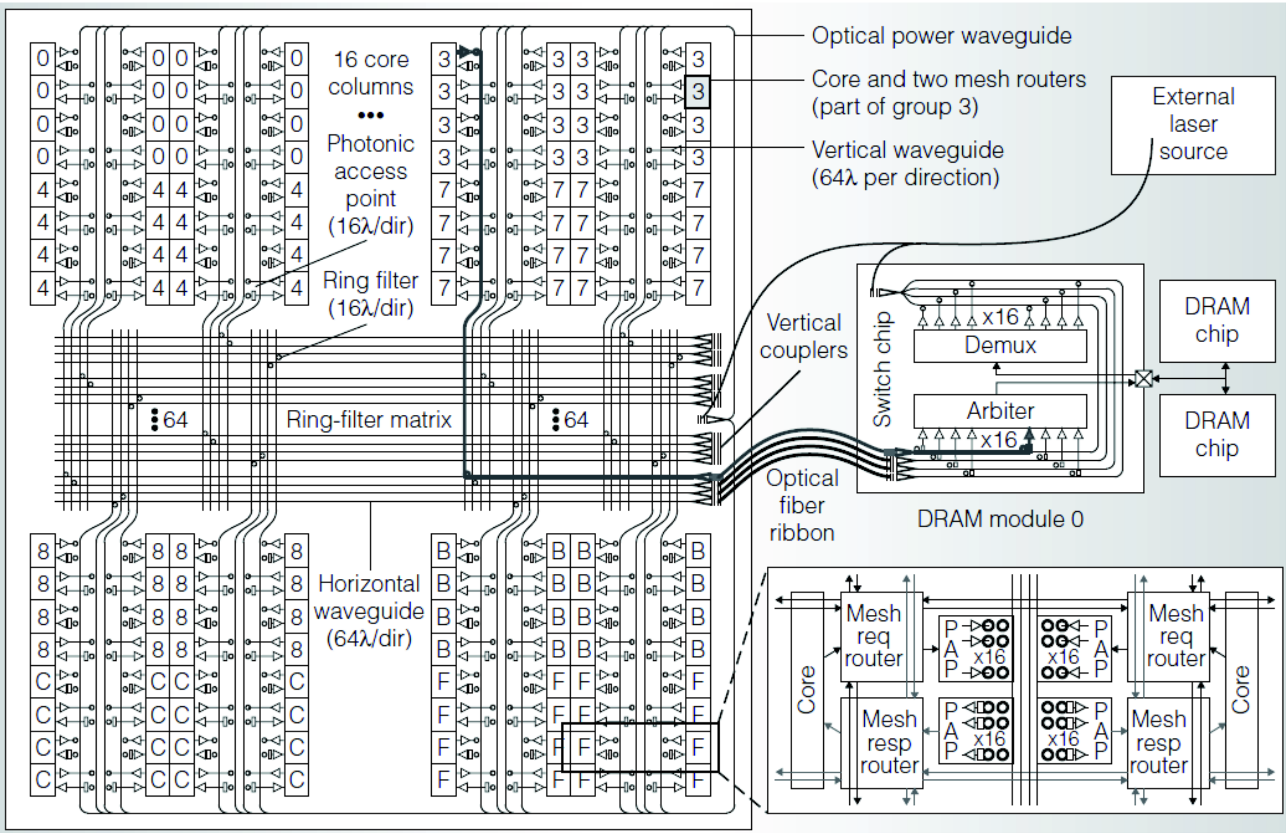
Multiple sender single receiver



HP

Architecture example 1

MIT Local mesh to global switch

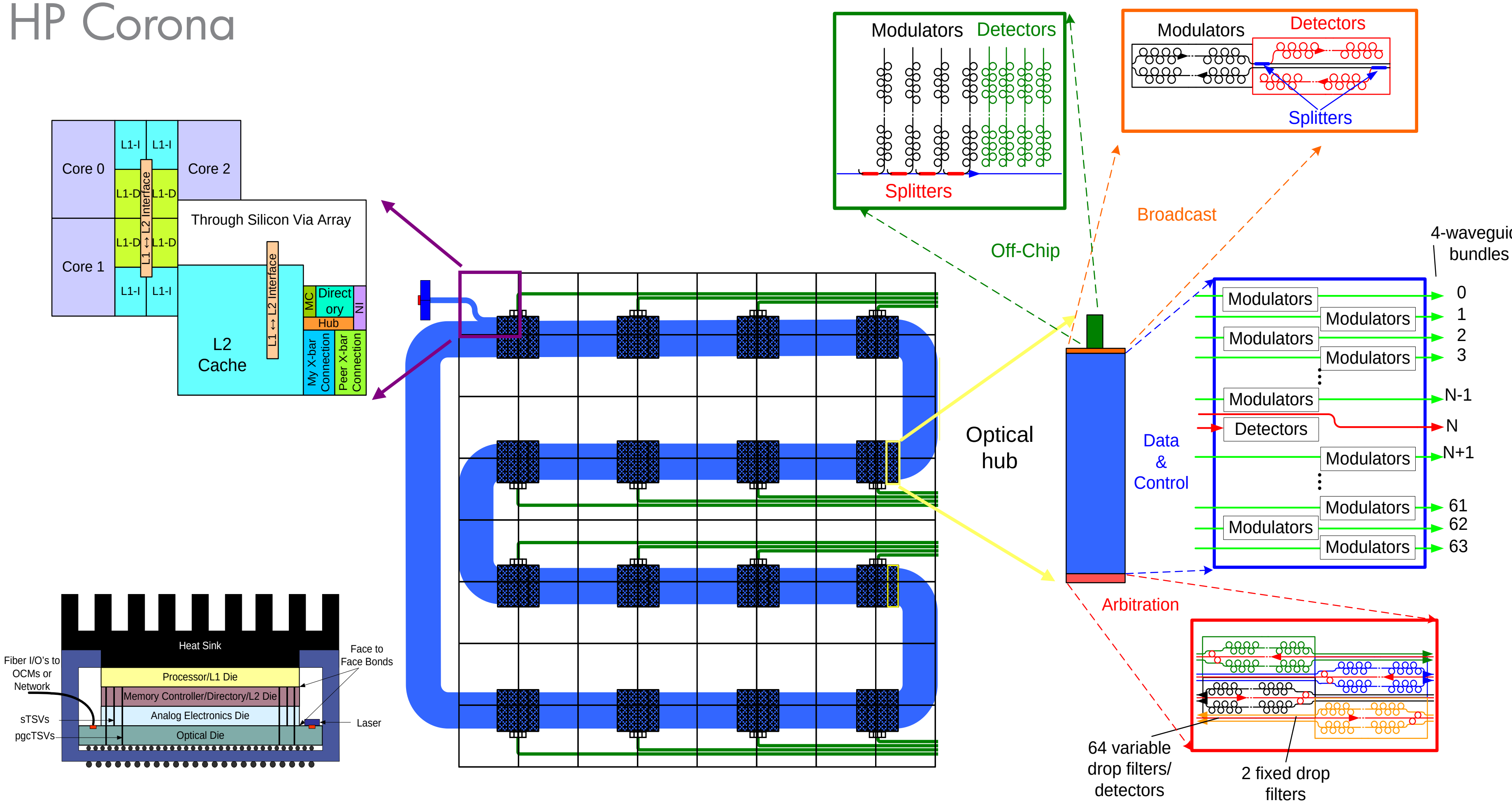


Batten 2009

- Point-to-point plus passive mesh
- DRAM-centric architecture
- 20W power envelope (network)
- 10x improvement over electrical

Architecture example 2

HP Corona



Vanatrease 2009

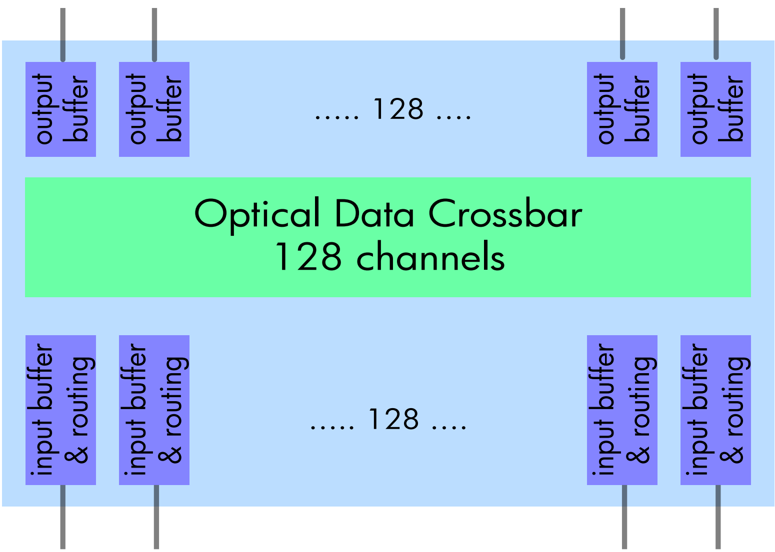
- Multiple-sender single-receiver links
- 1 byte/flop on chip and to memory
- 250W power envelope (compute + network)
- 20x improvement over electrical

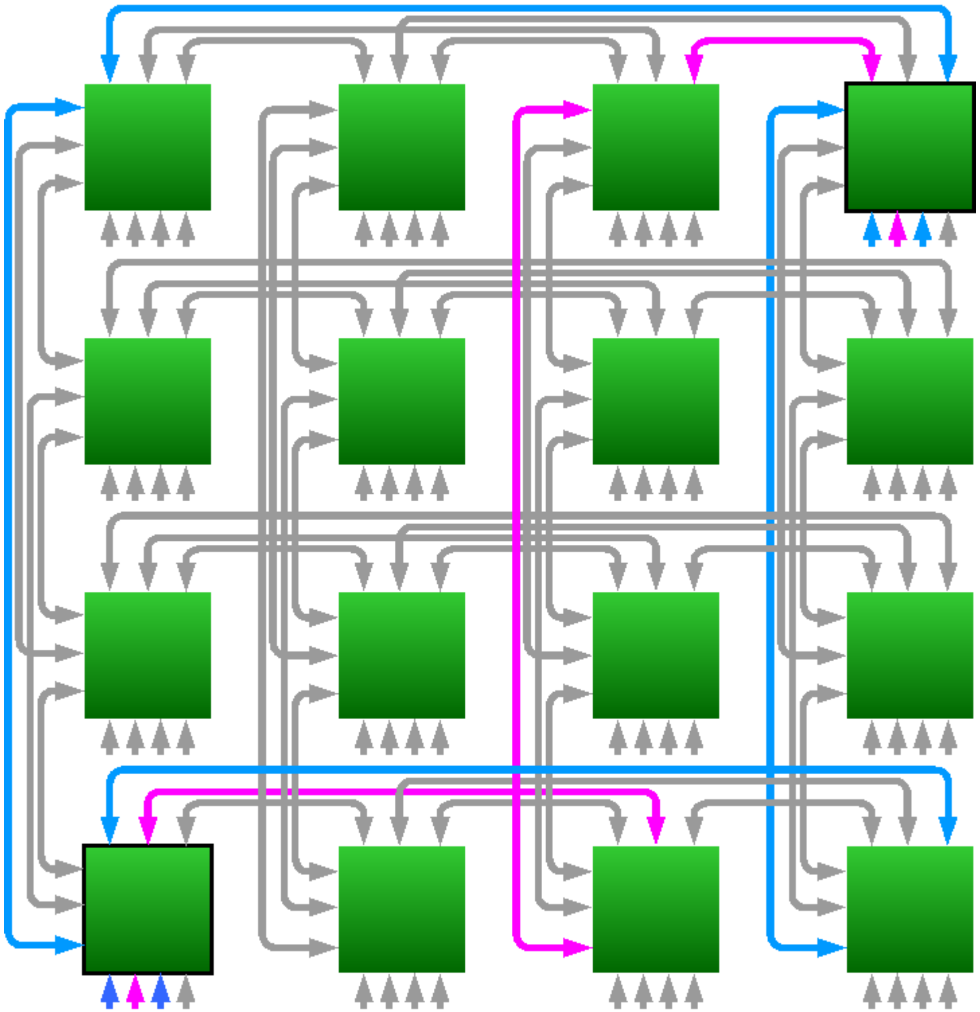
Architecture example 3

HP HyperX

•Crossbar used in high-radix switches

•Switch enables high connectivity topology

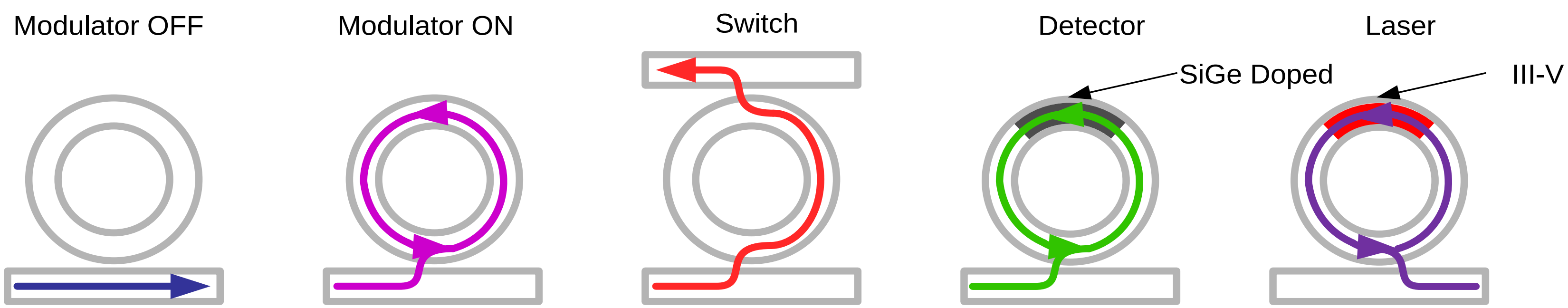




Ahn 2009

Technology requirements

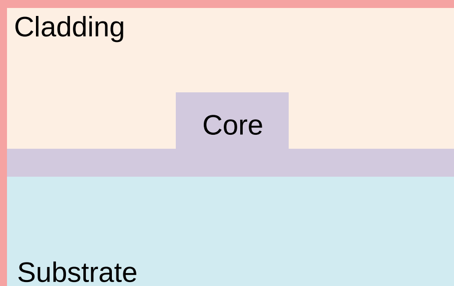
- DWDM: bandwidth density
- Silicon photonics: cost and scalability
- Ring resonators: technology of choice



Devices

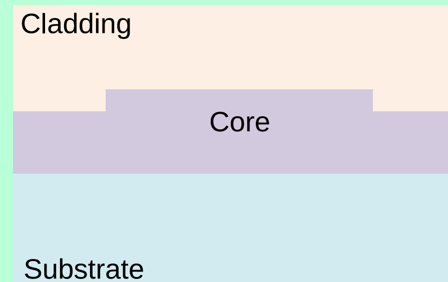
Low-loss waveguides

Silicon wire



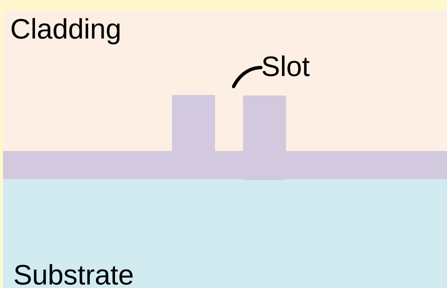
Loss 1 dB/cm

Rib waveguide



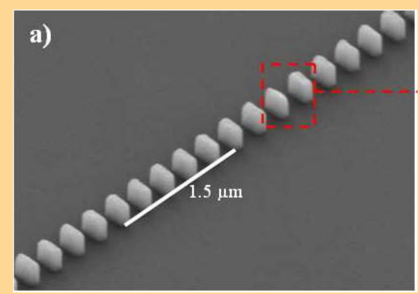
Loss 0.2 dB/cm

Slot waveguide



Loss 6.5 dB/cm

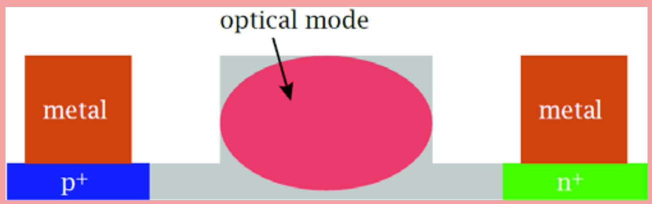
SWG waveguide



Loss 2.1 dB/cm (Bock 2010)

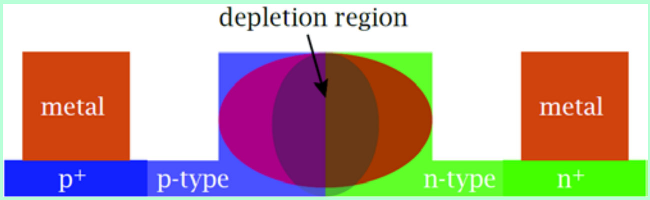
Modulation mechanisms

Carrier injection



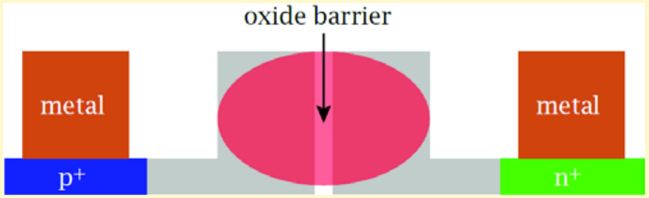
Cornell, HP

Carrier depletion



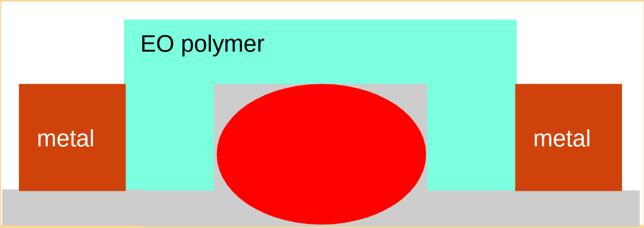
Sandia, Kotura

Carrier accumulation



Lightwire

Electro-optic polymer



Intel

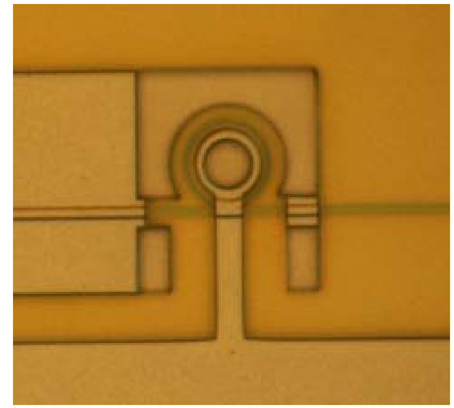
HP modulators results

10 µm silicon ring resonators

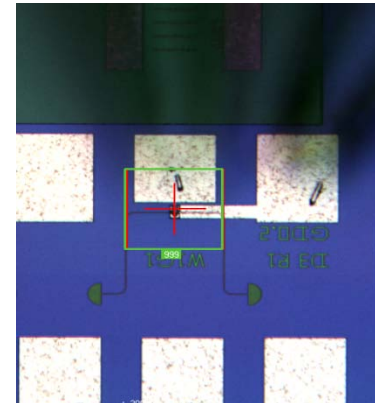
Results

- 45 fJ/bit
- 6 Gbps modulation (with pre-emphasis)

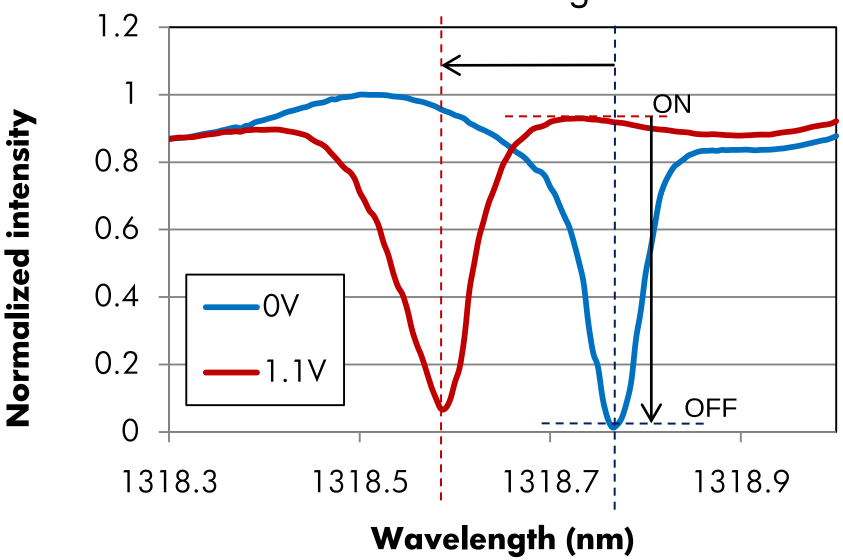
E-beam litho



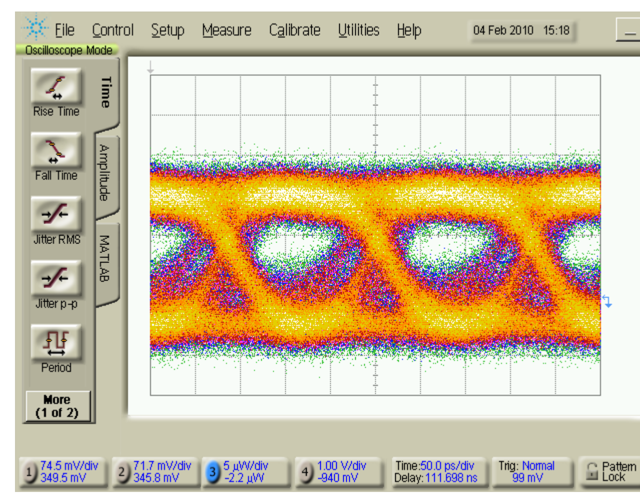
Photolitho



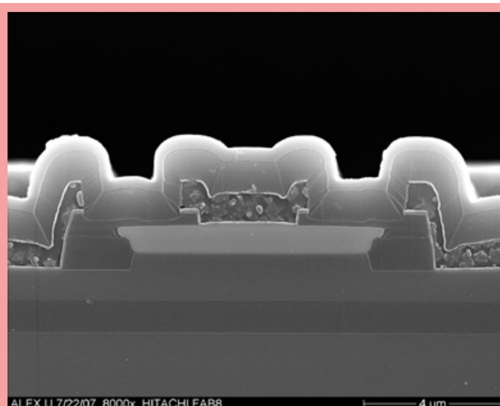
CW tuning



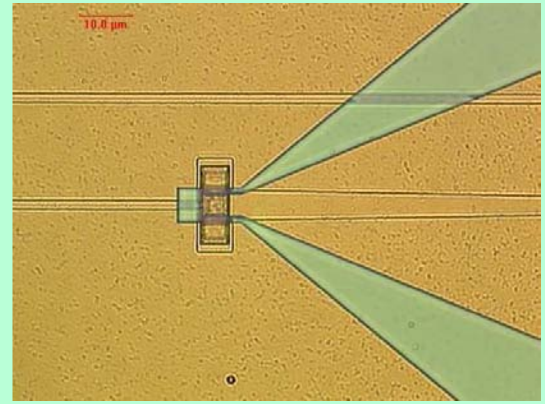
Eye diagram NRZ 6 Gbps



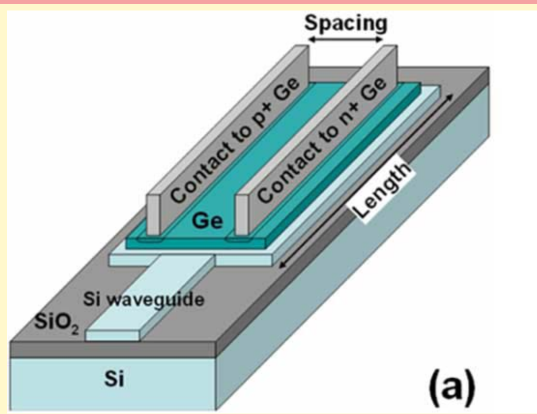
A detectors' menagerie



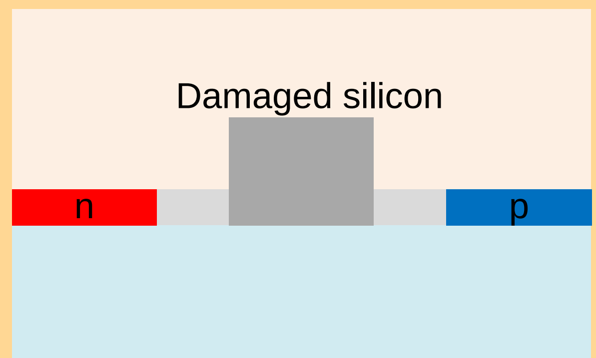
Intel Yin2007
Vertical Ge PIN on rib WG BW 31 GHz



CEA-LETI & Paris Vivien2007
Vertical Ge PIN coupled to wire BW 42 GHz



A*STAR Wang2008
Horizontal Ge PIN BW 18 GHz



Lincoln Lab Geis2009
Damaged silicon detector BW 35 GHz

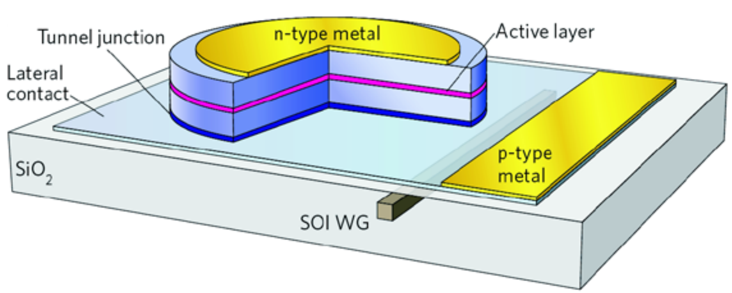
Laser: integrated vs. external

Integrated laser

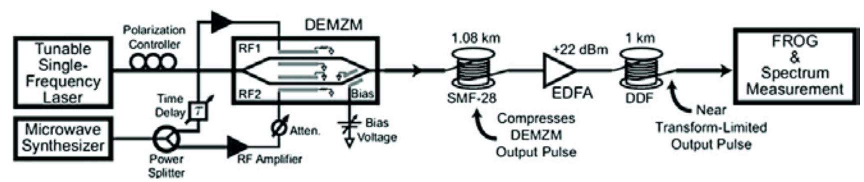
- The contenders
  - Bonded lasers (UCSB, Intel, Ghent)
  - Germanium laser (MIT)
  - III-V grown on Si (Michigan)
- Pro
  - Less packaging
  - Cheaper
- Cons
  - Thermal issues
  - Fabrication issues

External laser

- The contenders
  - Telecom grade commercial lasers
  - Quantum dot (Innolume)
  - Modulated (UC Davis)
- Pro
  - Power and thermal independent
  - Established technology
- Cons
  - Complexity
  - Cost



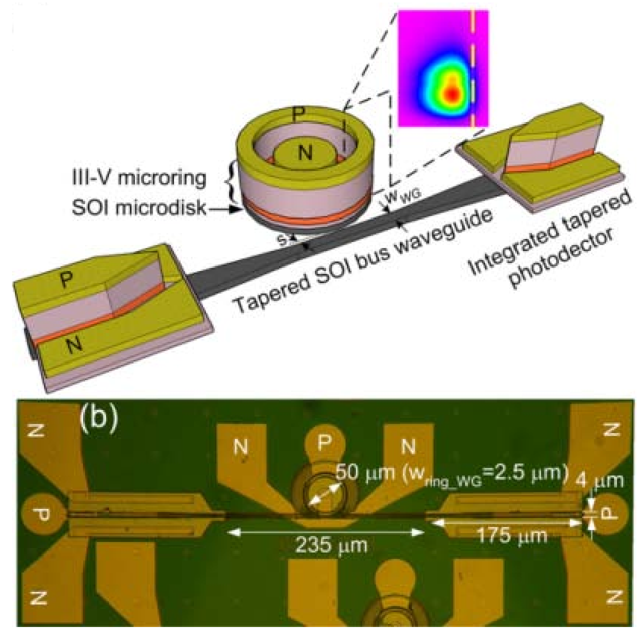
Van Campenhout 2008



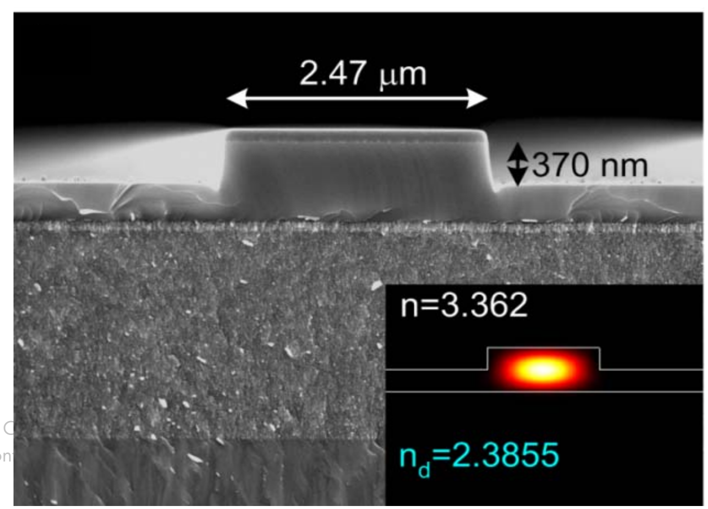
Zhou 2009

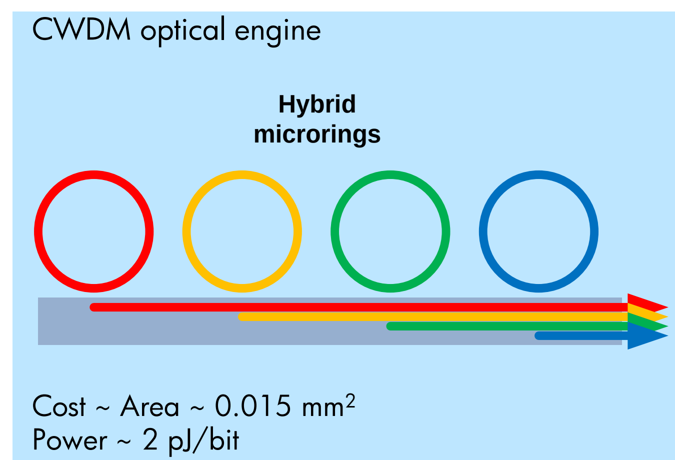
Integrated laser example: HP

- Idea: Hybrid Si/III-V laser with 12.5 Gb/s data rate
  - Wafer bonding + self-aligned process
- Results
  - 2.5 mW output,
  - < 4 mA min threshold
  - 5 GHz BW achieved, 10–12.5 GHz expected
- Future directions
  - Integration
  - Silicon on diamond



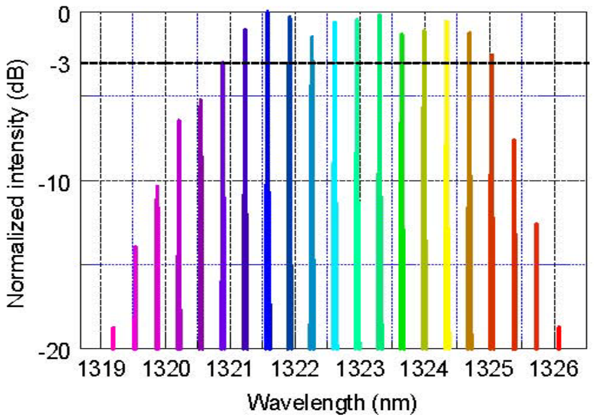
Liang 2010

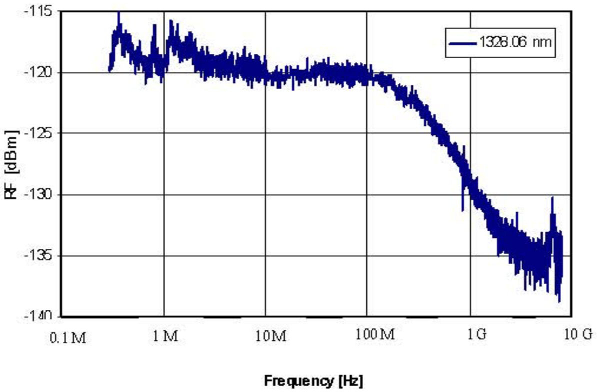




External laser example: Innolume

- Idea: quantum dot FP laser
  - MBE grown
- Results
  - 80 Ghz spacing
  - 8 lines
  - >-10dBm per line
  - Low RIN (-110 dB/Hz)
- Future directions
  - Add wavelengths





Wojcik 2009

Open problems and future directions

Work to be done

- Integration
  - How do we put it all together?
- Co-design
  - Drivers and receivers
- Fabrication
  - What happens if we try to build 1000s of devices on a chip?
- Power consumption and thermal

…and most importantly

- Business case
- Solution roadmap
- Supplier ecosystem

Thank you

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