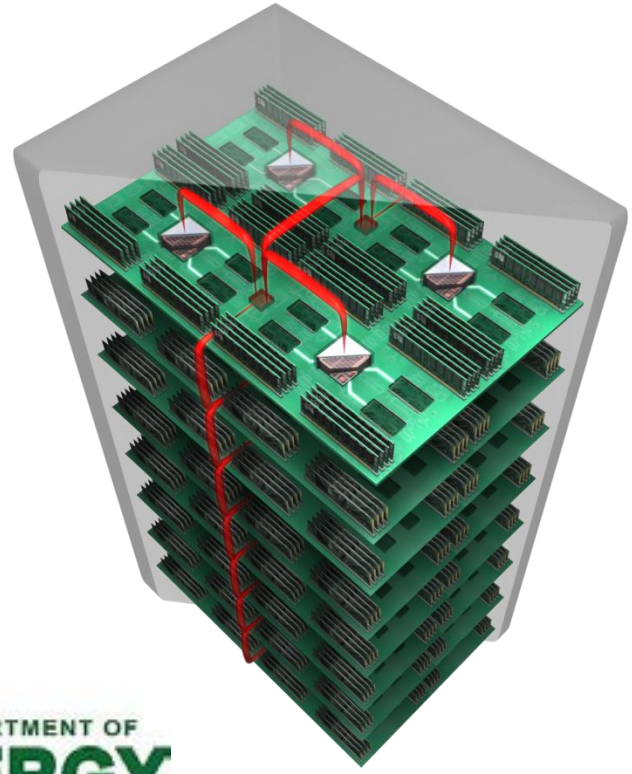

150
COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science
1864–2014



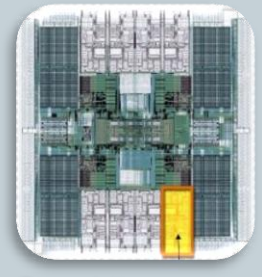

DARPA


NSF

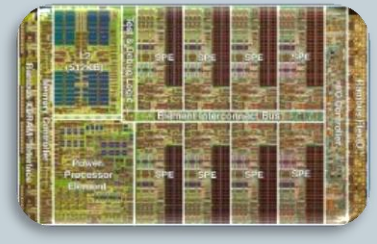

NATIONAL SECURITY AGENCY
UNITED STATES OF AMERICA


U.S. DEPARTMENT OF
ENERGY

Computation to Communications Bound

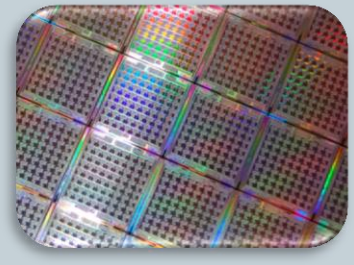


Sun Niagara
8 cores
2005

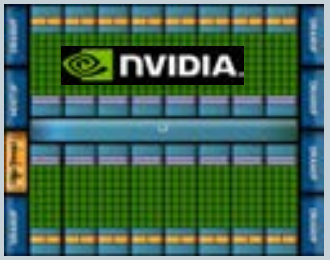


Sony/Toshiba/IBM Cell
9 cores
2006

Intel Polaris
80 cores
2007

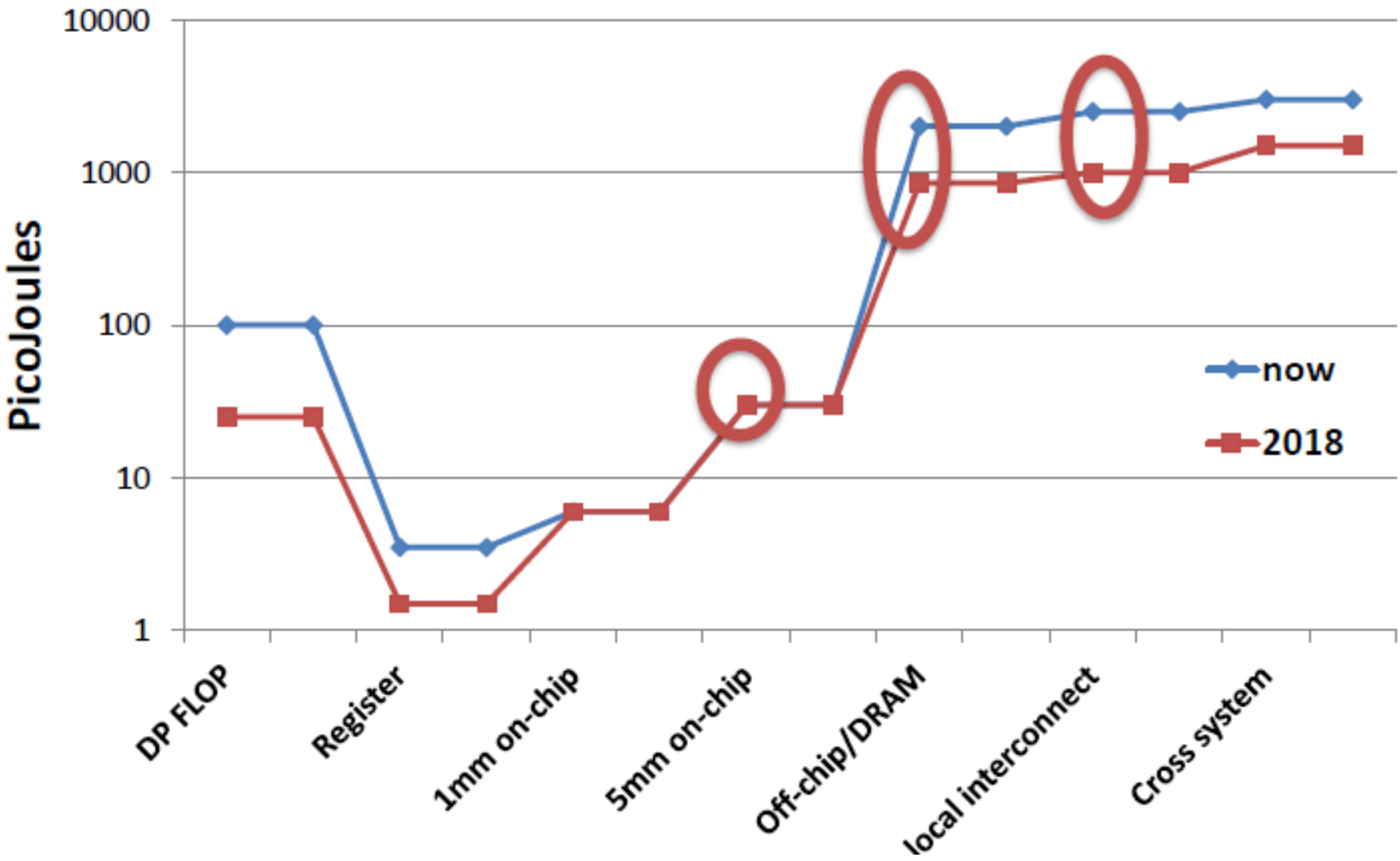


Tilera TILE-Gx100
100 cores
2009

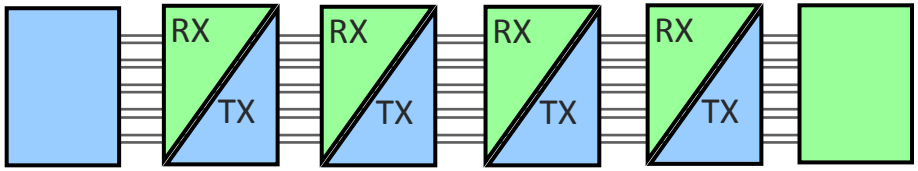


NVIDIA Fermi
512 cores
2012

Data Movement Dominates- Energy



Photonic Interconnects for Computing Platforms: Change the Rules for Bandwidth-per-Watt



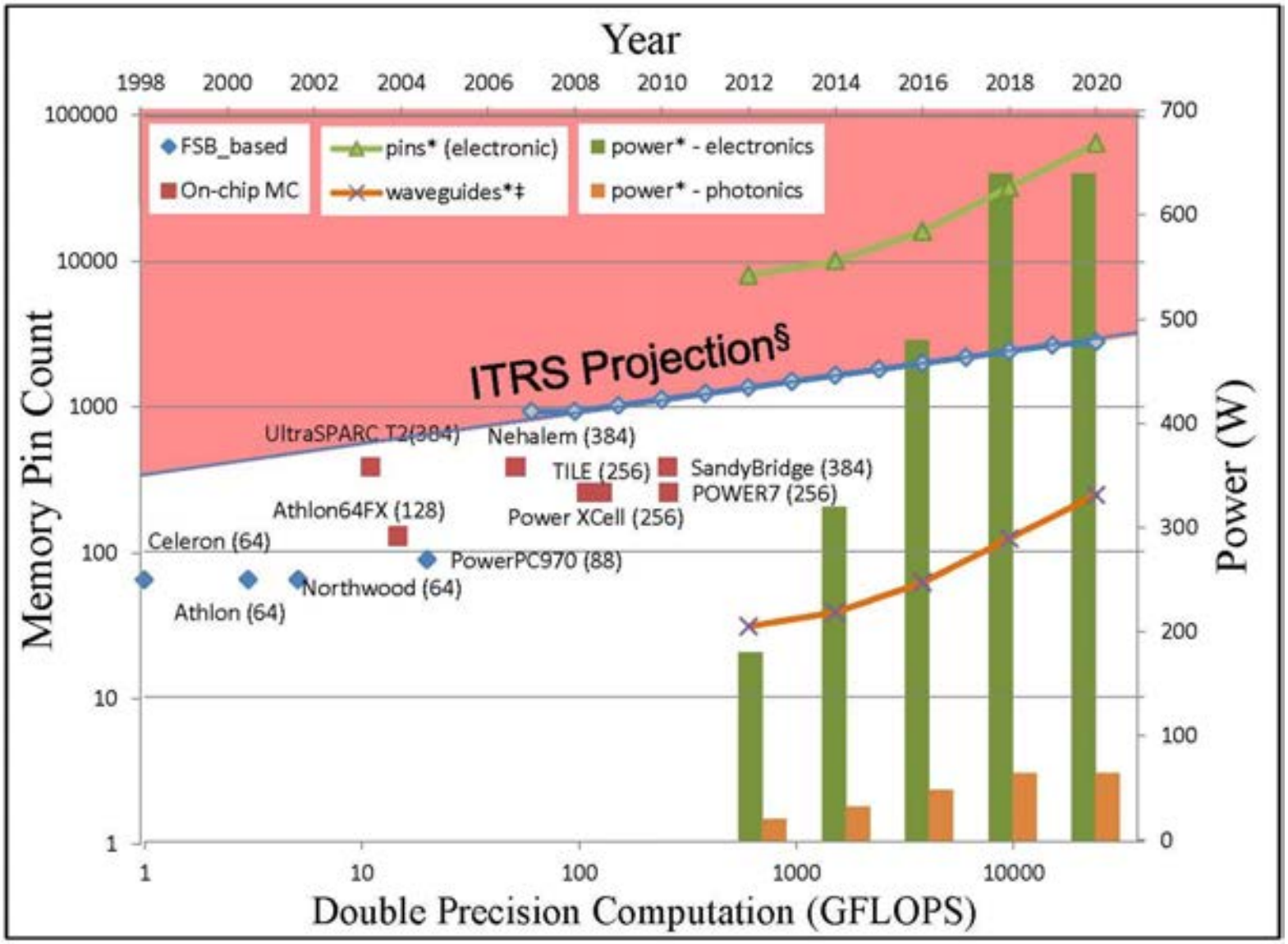
PHOTONICS

- Modulate/receive data stream once per communication event
- *Wavelength Parallelism :*
  - Broadband switch routes entire multi-wavelength stream
  - High I/O bandwidth density
- Distance Independence
  - Off-chip BW ≈ on-chip BW for nearly same power

ELECTRONICS

- Buffer, receive, and re-transmit at every repeater/router
- *Space Parallelism :*
  - Each bus lane routed independently (P N_{LANES})
  - Low I/O bandwidth density
- Off-chip BW requires much more power than on-chip BW

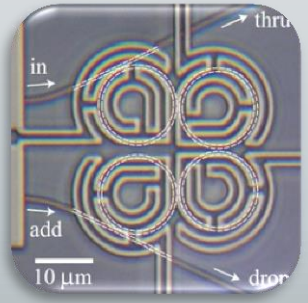
In the context of computing – Photonic communication can be fully exploited only by rethinking how to leverage its unique data-movement capabilities to realize new system architectures


Year
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
FSB_based
On-chip MC
pins* (electronic)
waveguides*‡
power* - electronics
power* - photonics
ITRS Projection§
UltraSPARC T2(384)
Nehalem (384)
TILE (256)
SandyBridge (384)
POWER7 (256)
Power XCell (256)
Athlon64FX (128)
Celeron (64)
PowerPC970 (88)
Northwood (64)
Athlon (64)
Memory Pin Count
100000
10000
1000
100
10
1
Power (W)
700
600
500
400
300
200
100
0
1
10
100
1000
10000
Double Precision Computation (GFLOPS)

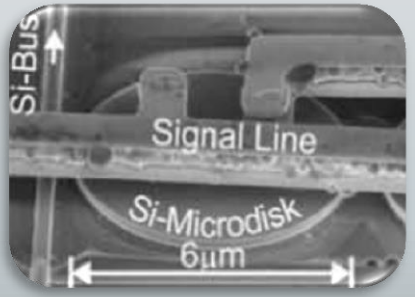
Silicon Photonics

Silicon-on-insulator (SOI) platform photonic building blocks:

High index contrast enables high confinement, low-loss propagation, virtually lossless bending

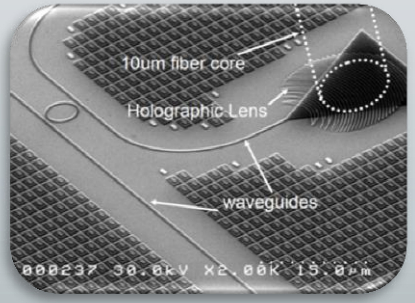


MIT



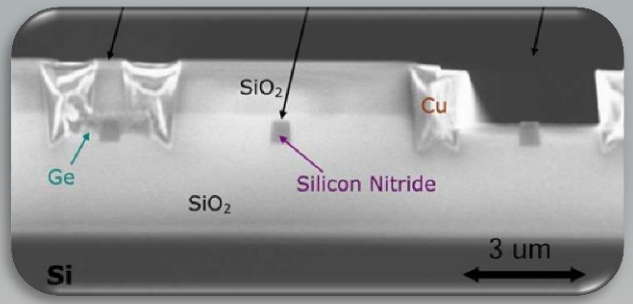
Sandia

Ghent

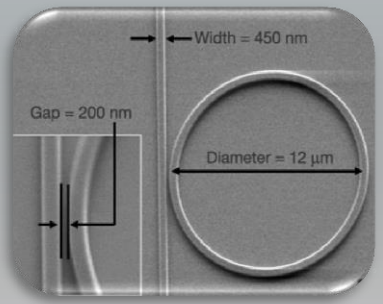


Luxtera

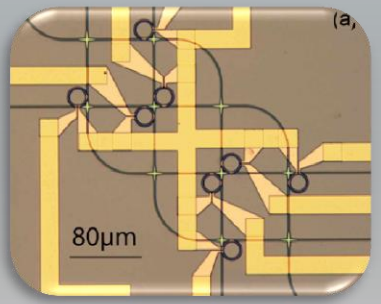
IBM



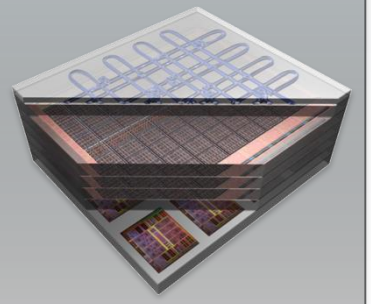
Intel



Cornell



Cornell/Columbia



Columbia

Silicon Photonic Interconnects in Computing

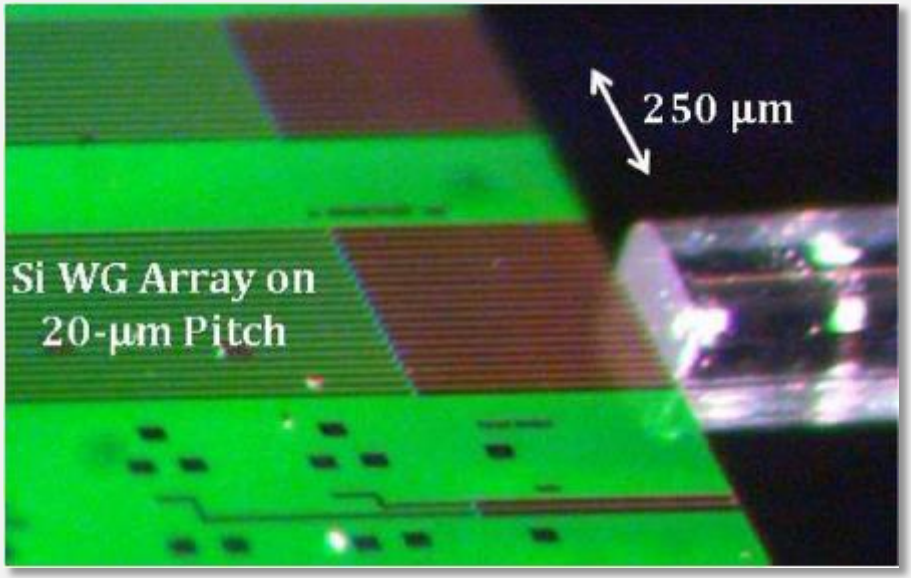
Silicon photonics:

Off-chip BW = On-chip BW for nearly same **power**.

Dense WDM = extreme **bandwidth density** - I/O bottlenecks

Broadband switch routes entire multi-wavelength stream.

Bandwidth density: ~ 2 Tbps/20 m pitch at chip's edge.



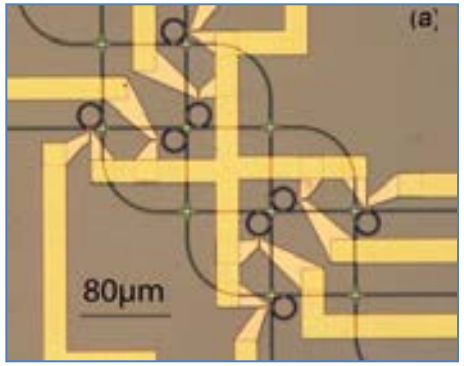
[F. Doany *et al.*, *JLT 29 (4) (2011)*]

Silicon Photonics – Optical Interconnection Networks

- **Silicon as core material**
  - High refractive index and high contrast – sub micron cross-section dimensions, smallest bend radius.
- **Small footprint devices**
  - 10 µm – 1 mm scale compared to cm-level scale for telecom components
- **Low power consumption**
  - Can reach <1 pJ/bit per full point to point link
- **Aggressive WDM platform**
  - Bandwidth densities 1-2Tb/s per pin
- **Silicon wafer-level CMOS processing**
  - Integration
  - Mass production, price
  - Compatibility with CMOS fabs, CMOS electronics

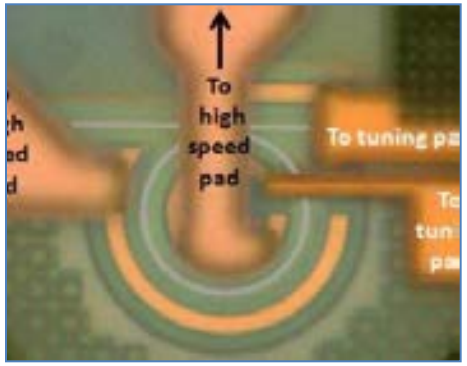
Silicon Microring/Microdisk Based Devices

Switching



(Cornell/Columbia)

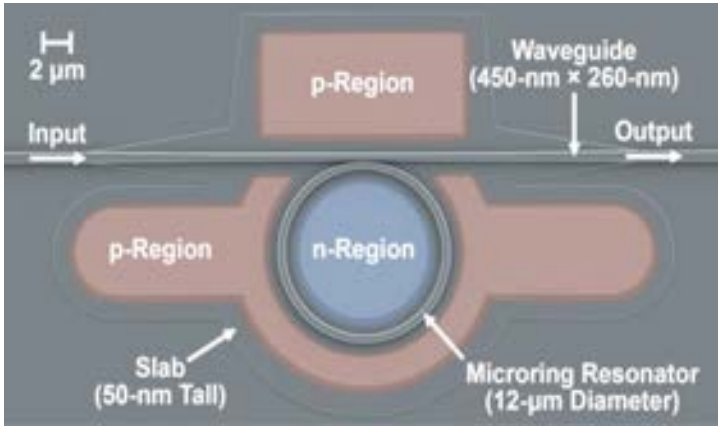
Modulation

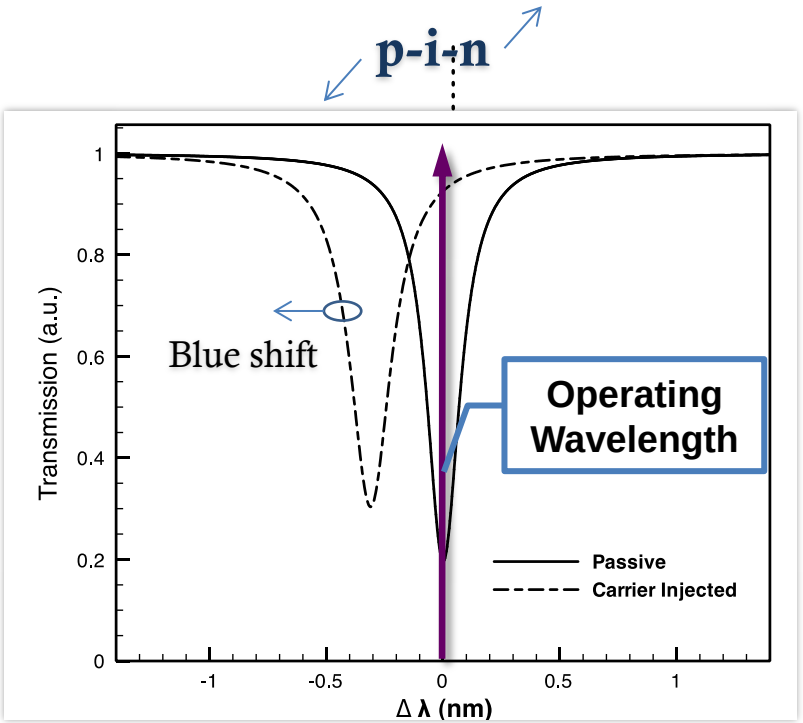


(Oracle)

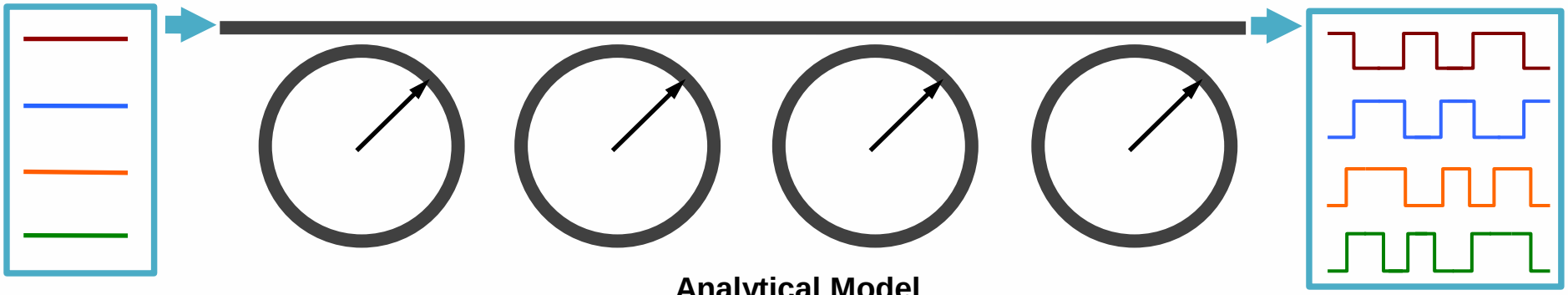
WDM Modulation & Demultiplexing

Active / Tunable Micoring Devices

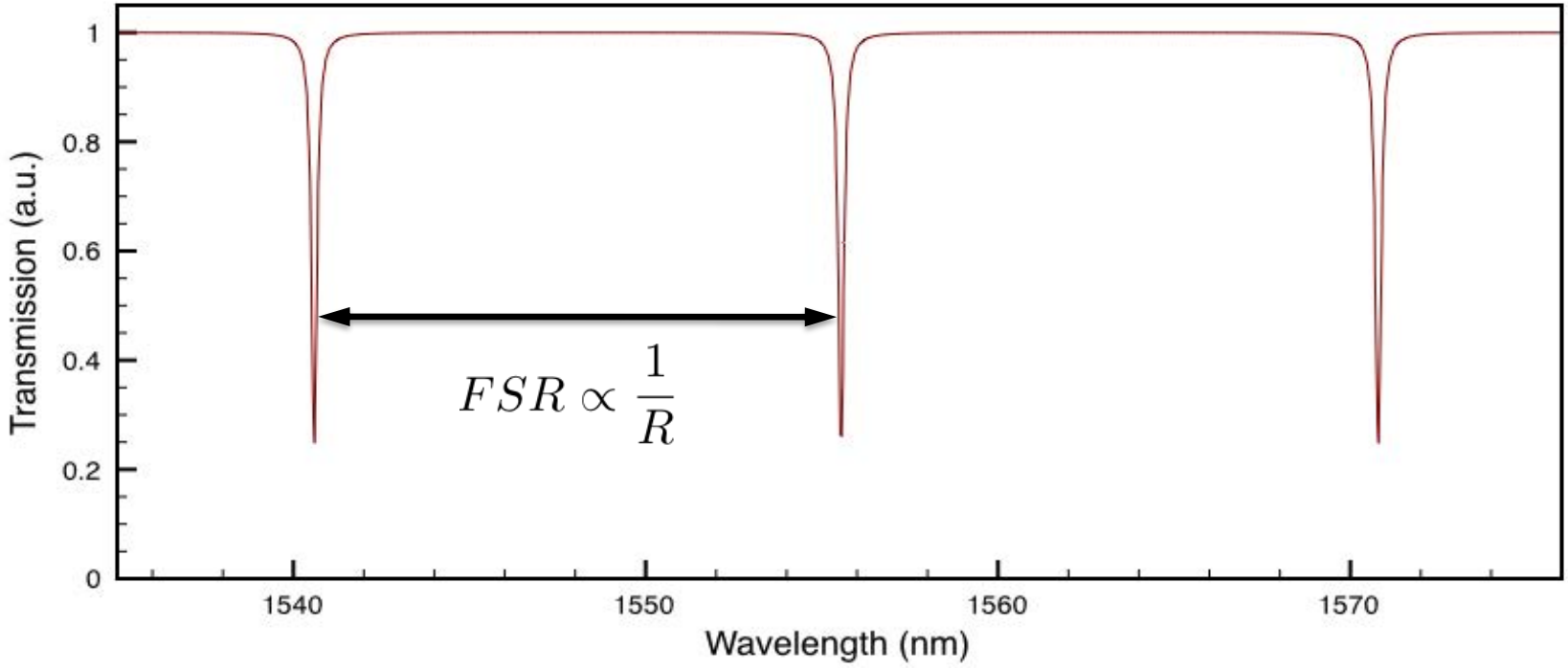




Microring-Based Comm. Links



Analytical Model



Dense WDM Microring Link Design