# Exploring Benefits and Designs of Optically Connected Disintegrated Processor Architecture

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# Motivation



- Transistor density grows exponentially
- But, processors are physically constrained
  - Low yield, bandwidth wall, power wall
  - *Dark silicon*: we can build dense devices we cannot afford to power
- Optically-Connected Disintegrated Processor **(OCDP)**
  - Divide (impractical) monolithic processor into chiplets
  - Improves yield
  - Breaks the bandwidth wall
  - **Breaks the power wall**
    - Spread out chiplets, cheaper cooling

# Motivation

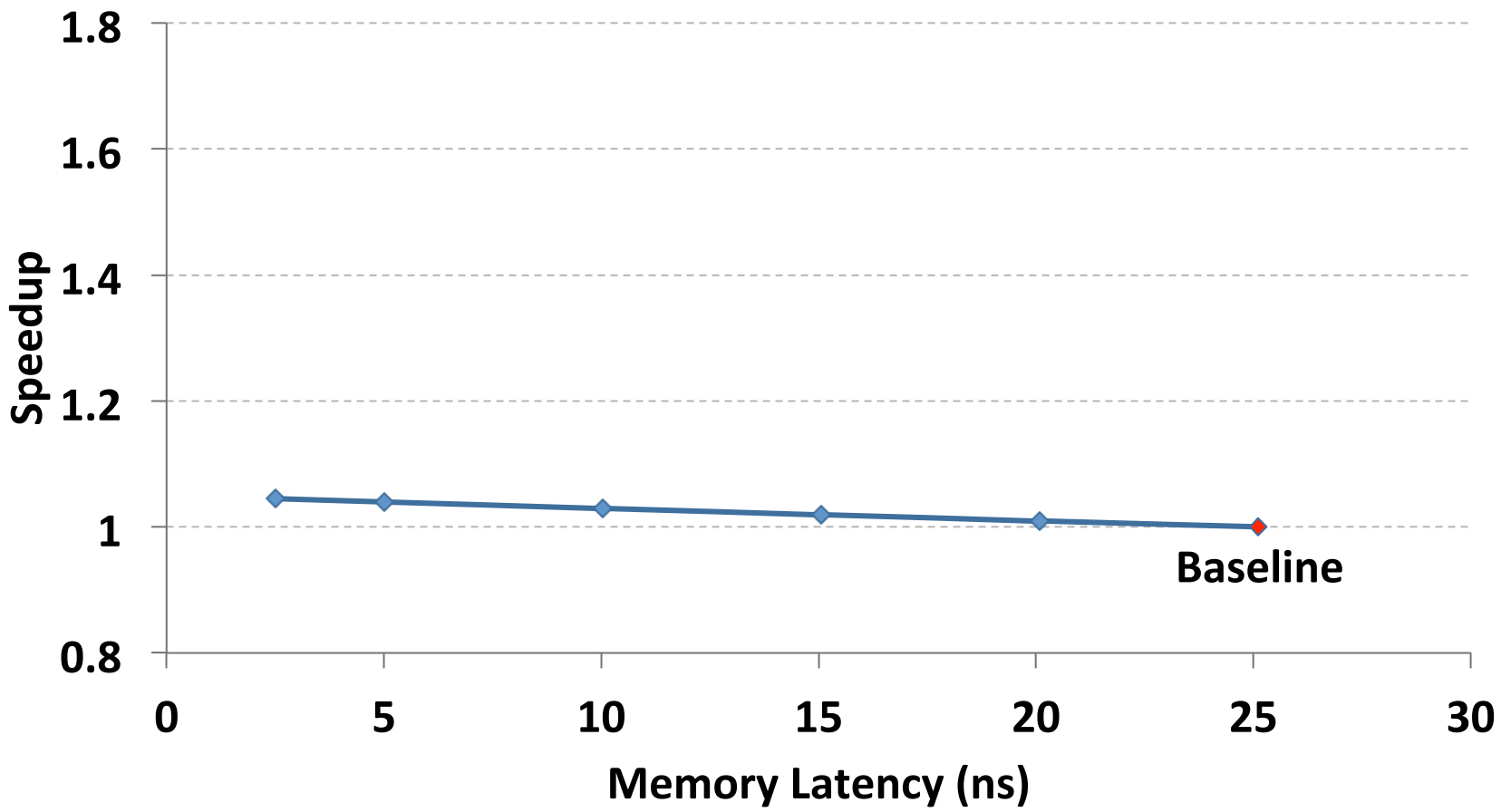


- Advantage of nanophotonics
  - Latency
  - Bandwidth density
- Using nanophotonics for inter-chip interconnect
  - Reduced memory latency
  - Increased off-chip bandwidth
  - Increased total chip area
  - Increased power budget
- Analytical model* for performance estimation

* N. Hardavellas et al., Tech Report NWU-EECS-10-05, Mar. 2010.

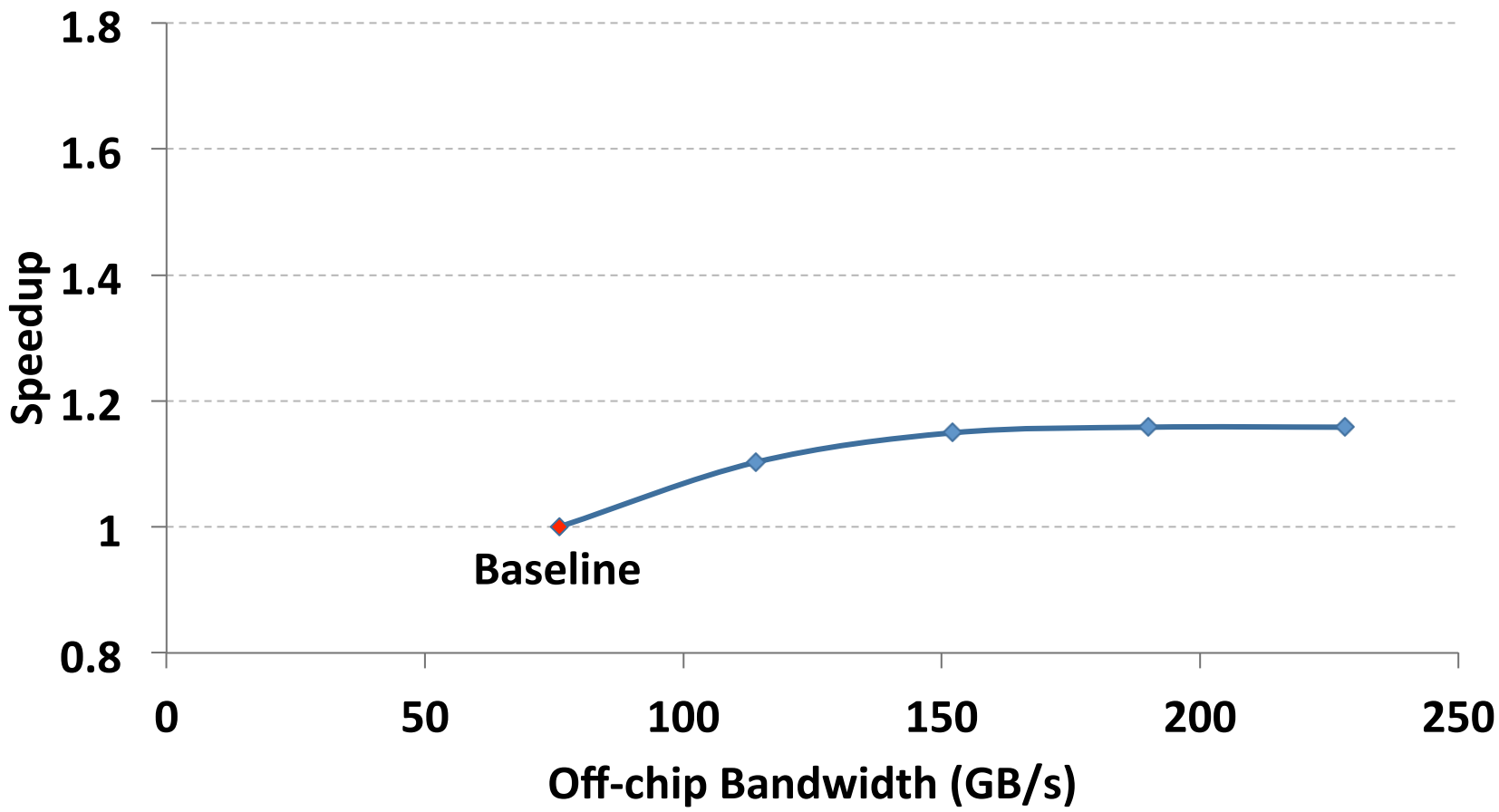
# Memory Latency





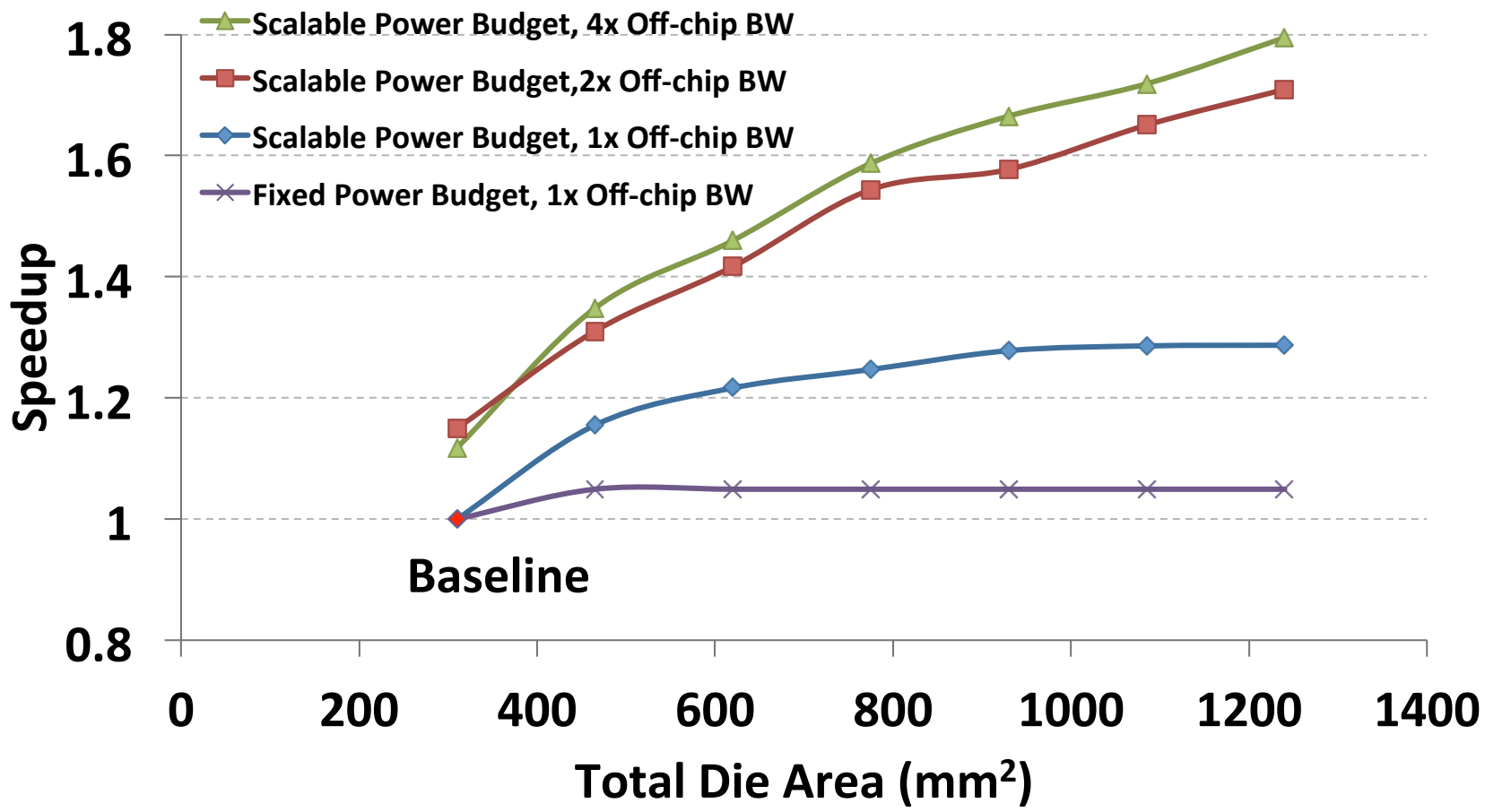
# Off-chip Bandwidth





# Scaling Power, Chip Area





# Motivation



- Performance impact
  - Reduced memory latency → minimal
  - Improved off-chip bandwidth → small
  - Total chip area → small
  - **Power budget → big**
- Power budget scalability is critical
  - Spread out chiplets
  - Cheaper cooling
- Optically-Connected Disintegrated Processor **(OCDP)**

# Off-chip Optical Channels



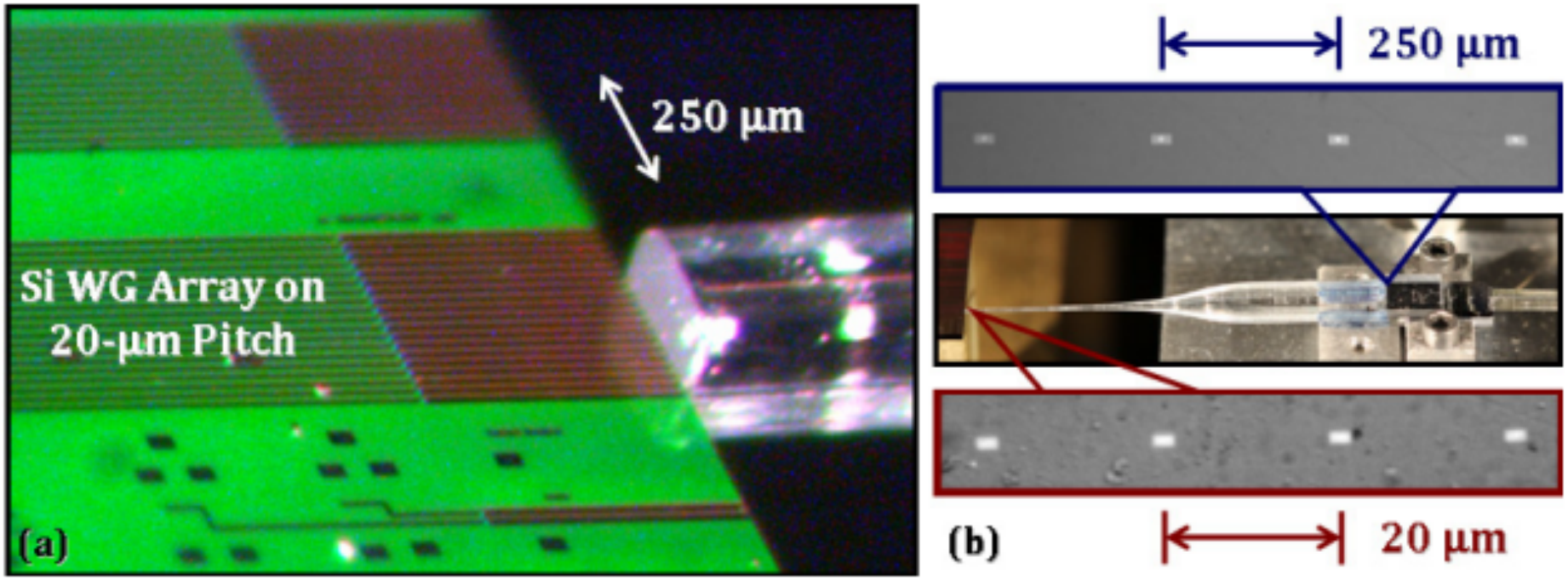
| Material | Optical Loss | Propagation Speed | Pitch (density) |
|---|---|---|---|
| Silicon Waveguide | 0.3 dB/cm* | 0.286c | 20um |
| Optic Fiber | 0.2 dB/km | 0.676c | 250um |

- Optical fiber is low-loss, high speed
  - Enables further spreading out chiplets
  - *BW density was a challenge*

* J. Cardenas et al., Optics Express 2009

# Dense Off-chip Coupling






- Dense optical fiber array [Lee et al., OSA/OFC/NFOEC 2010]
- <1dB loss, 8 Tbps/mm demonstrated

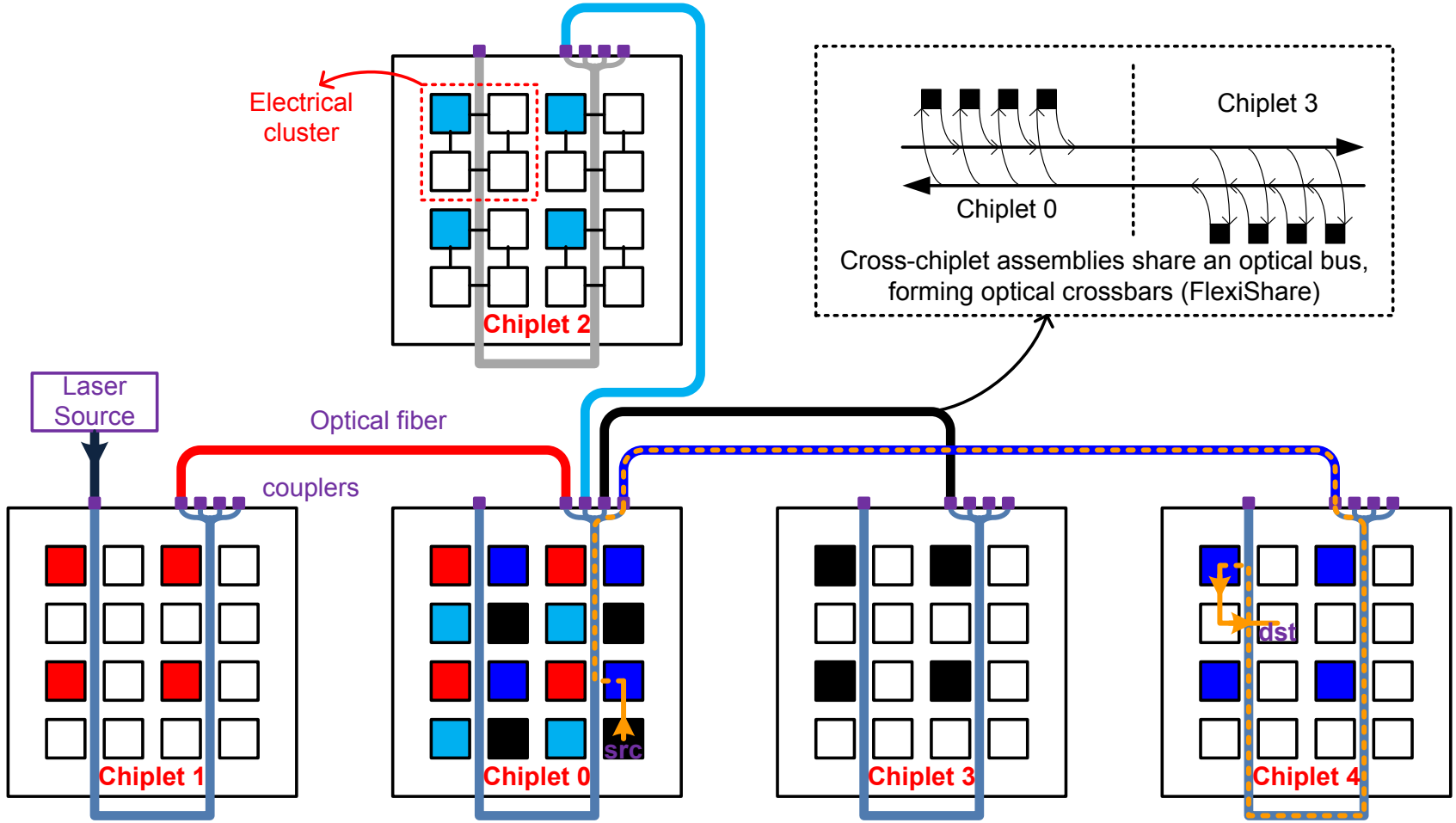
# OCDP Design Considerations



- Inter-chiplet optical channel technology
  - Optic fiber for low loss
- Inter-chiplet optical channel organization
  - Point-to-point [Koka et al., ISCA 2010]
  - Minimize waveguide and coupler loss
- On-chip topology
  - Scalable chiplet size
- ***On-chip / off-chip bandwidth interfacing***
  - Distributed BW, seamless integration

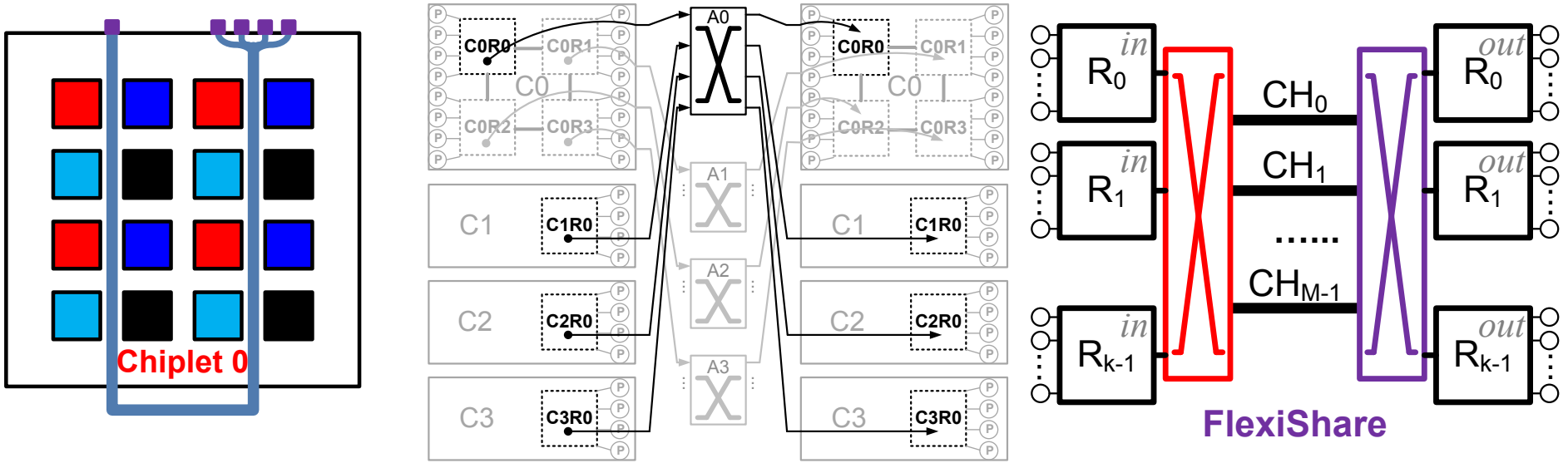
# OCDP Architecture

- Motivation
- **OCDP Arch.**
- Power Comparison
- Conclusion



# Firefly On-chip Topology

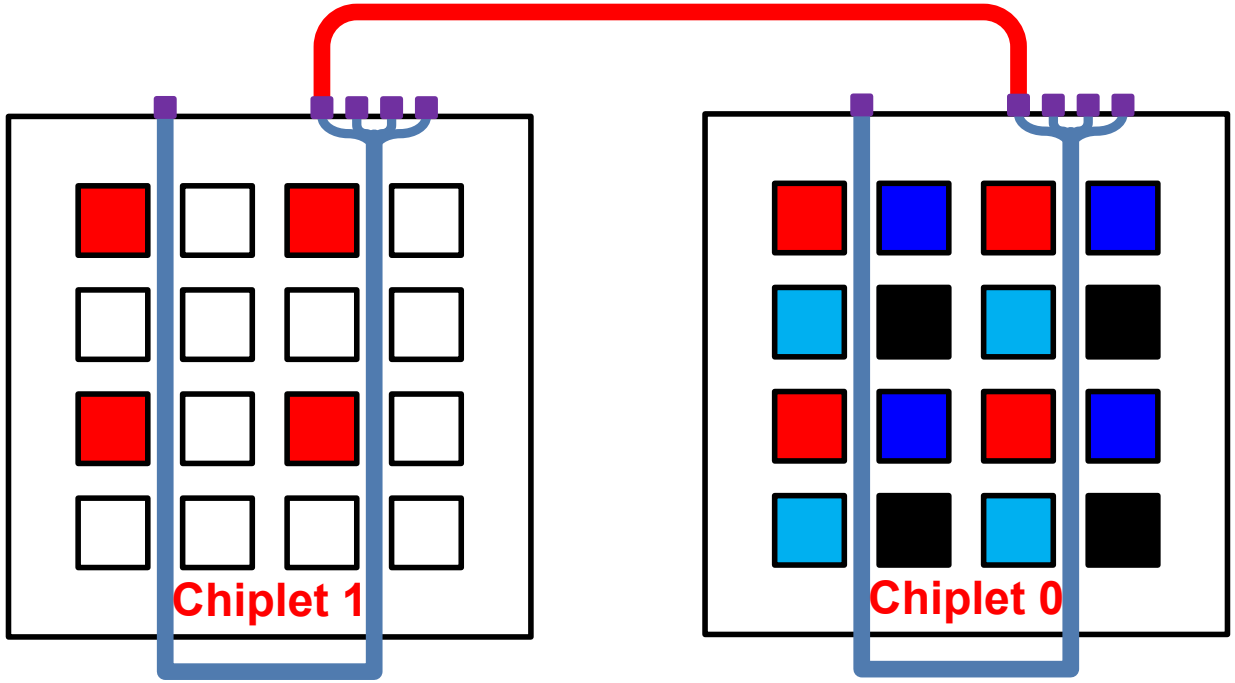





- ***Firefly*** on-chip topology [Pan et al., ISCA 2009]
  - Flexible chiplet sizing, optical on-chip communication
- ***FlexiShare*** optical crossbars [Pan et al., HPCA 2010]
  - Flexible bandwidth provisioning
  - Light-weight optical arbitration needed, proposed

# Extending across chiplets






- Distributed bandwidth across chiplets
- Flexible inter-chiplet bandwidth provisioning
- Minimal number of couplers
- Seamless on-chip/off-chip interfacing

# Technology Assumptions

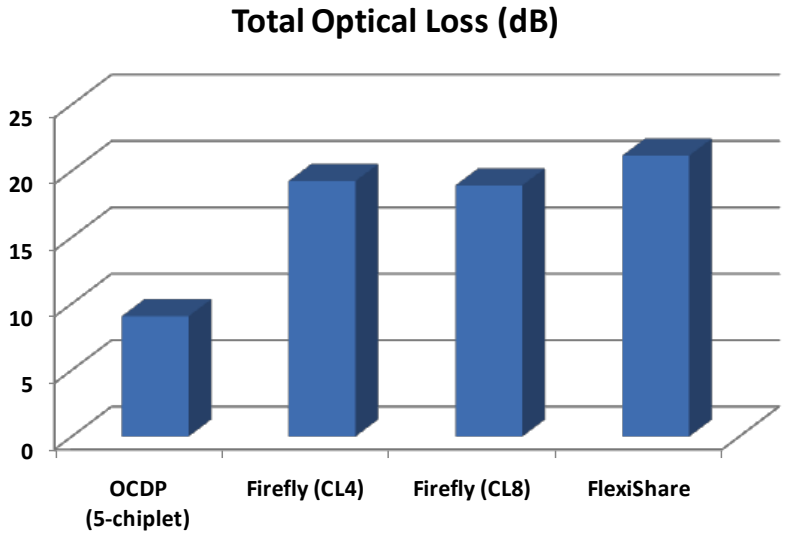


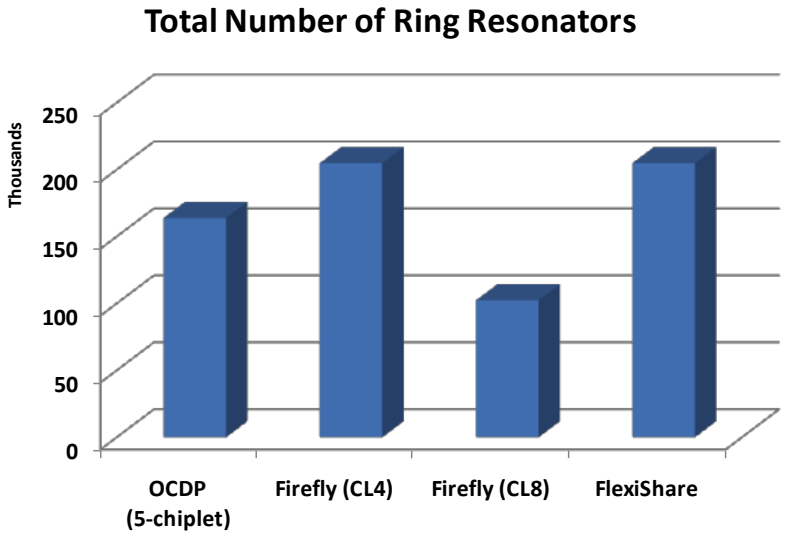
| Parameter | Loss | Parameter | Value |
|---|---|---|---|
| Coupler | 1 dB | Detector Sensitivity | 0.01 mW |
| Splitters | 1 dB | DWDM | 16 λ |
| Non-linear | 1 dB | fiber coupler loss | 0.1 |
| Modulator Insertion | 0.1 dB | fiber loss | 2.00E-06 dB/cm |
| Waveguide | 0.3 dB/cm | ring heating power | 40 uW/ring |
| Ring Through | 0.001 dB | Modulation Power | 80 fJ/bit |
| Filter Drop | 1.5 dB | Demodulation Power | 40 fJ/bit |
| PhotoDetector | 0.1 dB | | |

- Moderate DWDM (16-way)

# Optical Power (320-core)



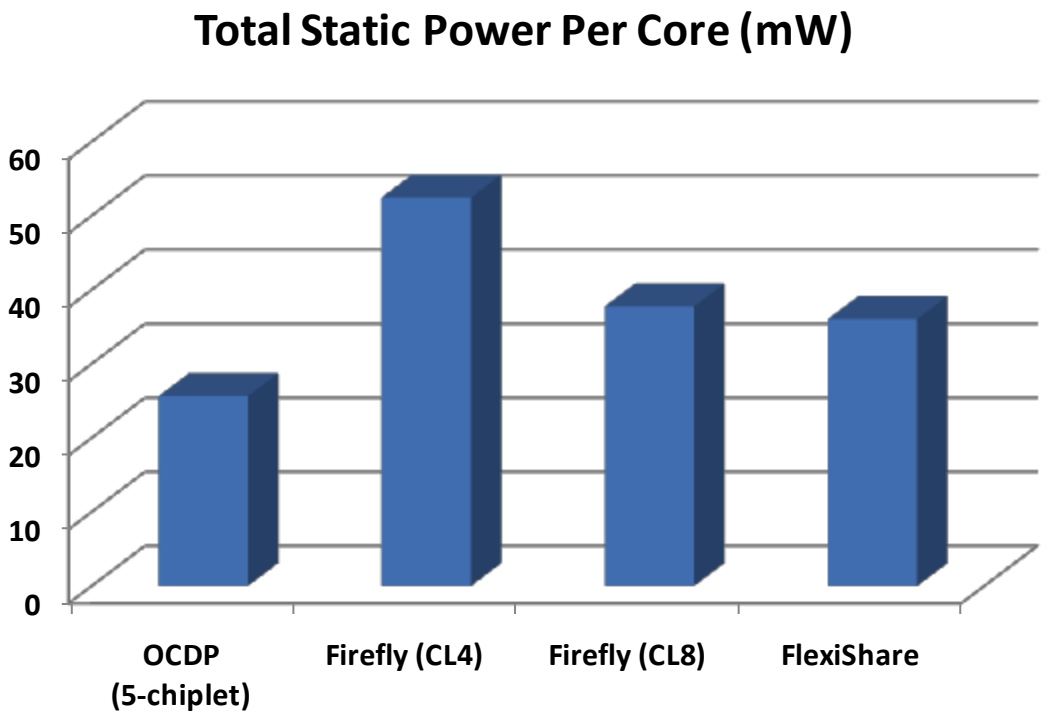



- 5-chiplet OCDP vs. single-chip topologies
- Total number of optical channels (wavelengths) held constant.

# Per-Core Network Static Power

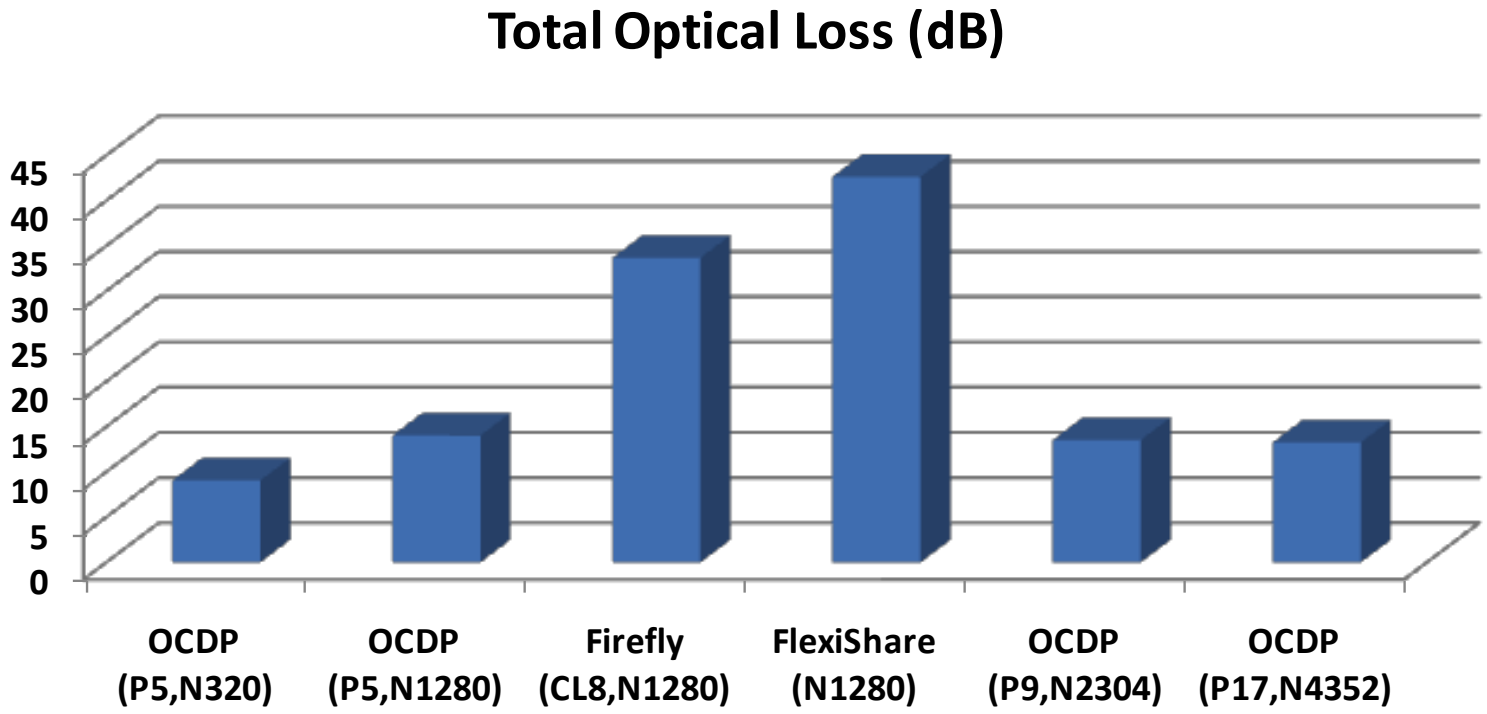
- Motivation
- OCDP Architecture
- **Power Eval.**
- Conclusion




- ~ 30% power reduction compared to the best alternative.

# Scaling Up

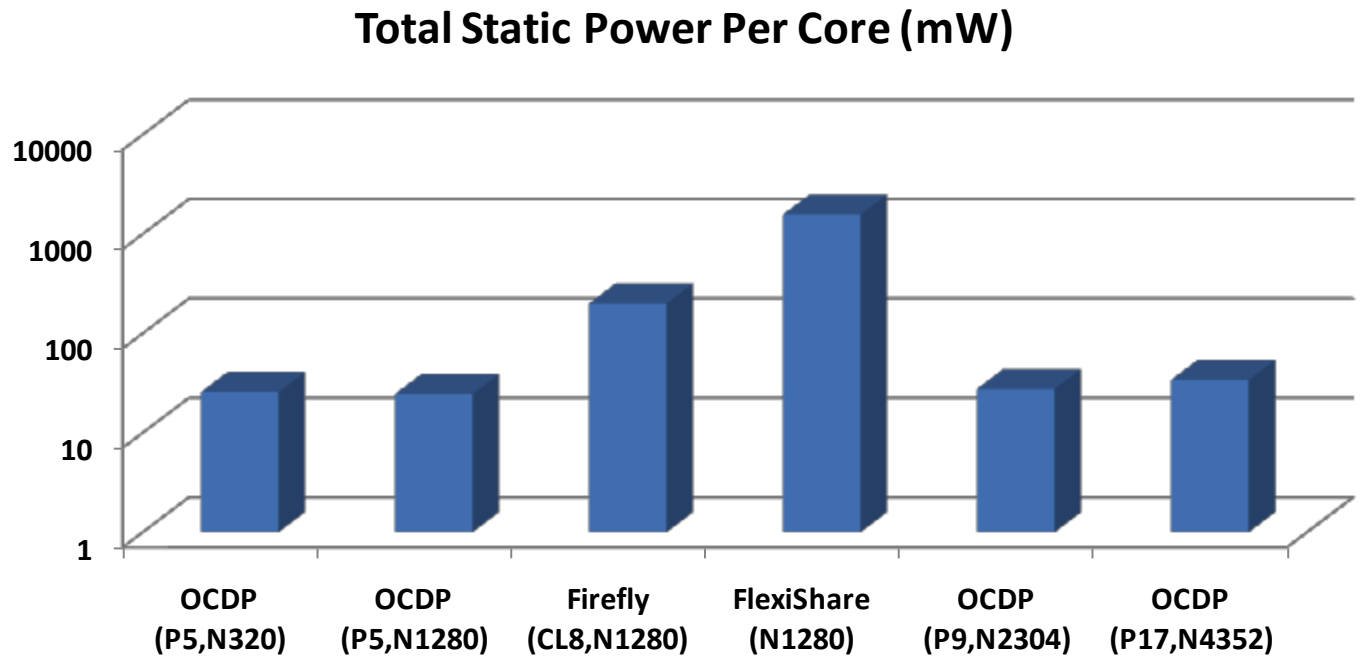





- OCDP limits the total on-chip waveguide length
- Better optical scalability

# Scaling Up






- OCDP shows very good power scalability.
- Single-chip is impractical for 1280-core processor

# Conclusion



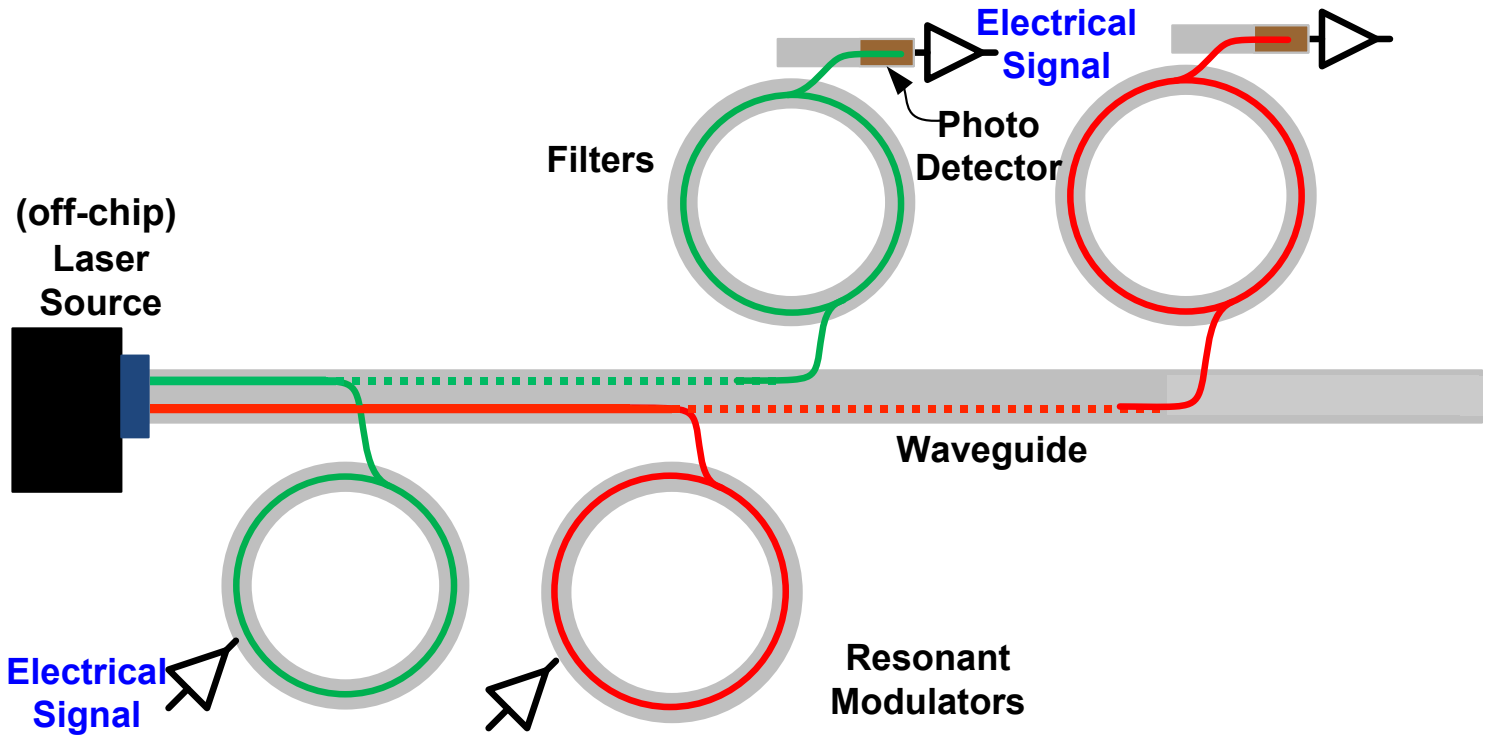
- OCDP leverages
  - Low latency / high bandwidth density
  - Low loss optic fibers
- Power scalability is critical
  - Minimize optical loss on the path
- Seamless on-chip / off-chip interfacing
  - Firefly intra-chiplet (distributed off-chiplet BW)
  - Point-to-point (Dragonfly) inter-chiplet
- Performance evaluation needed
- Chiplet composition to be explored

Questions?

# THANK YOU!

# On-chip Optical Channel






- Silicon photonics with DWDM