# Large Scale Photonic Integration:
## *A Technology Review*

Geoff Bennett, Infinera

# Why should you care…

…about Photonic Integration?

Data
Processing

Data
Communications

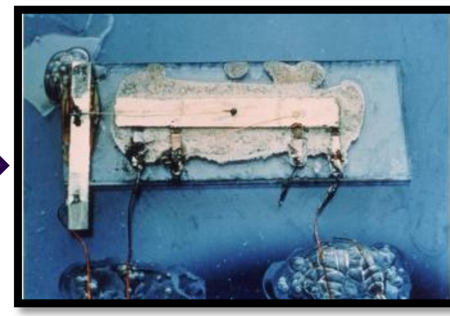
# What is “Integration”?

## *A History Lesson: Electronic Integration*

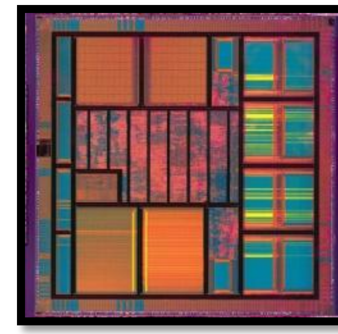
Valve

Transistor


Integrated Circuit



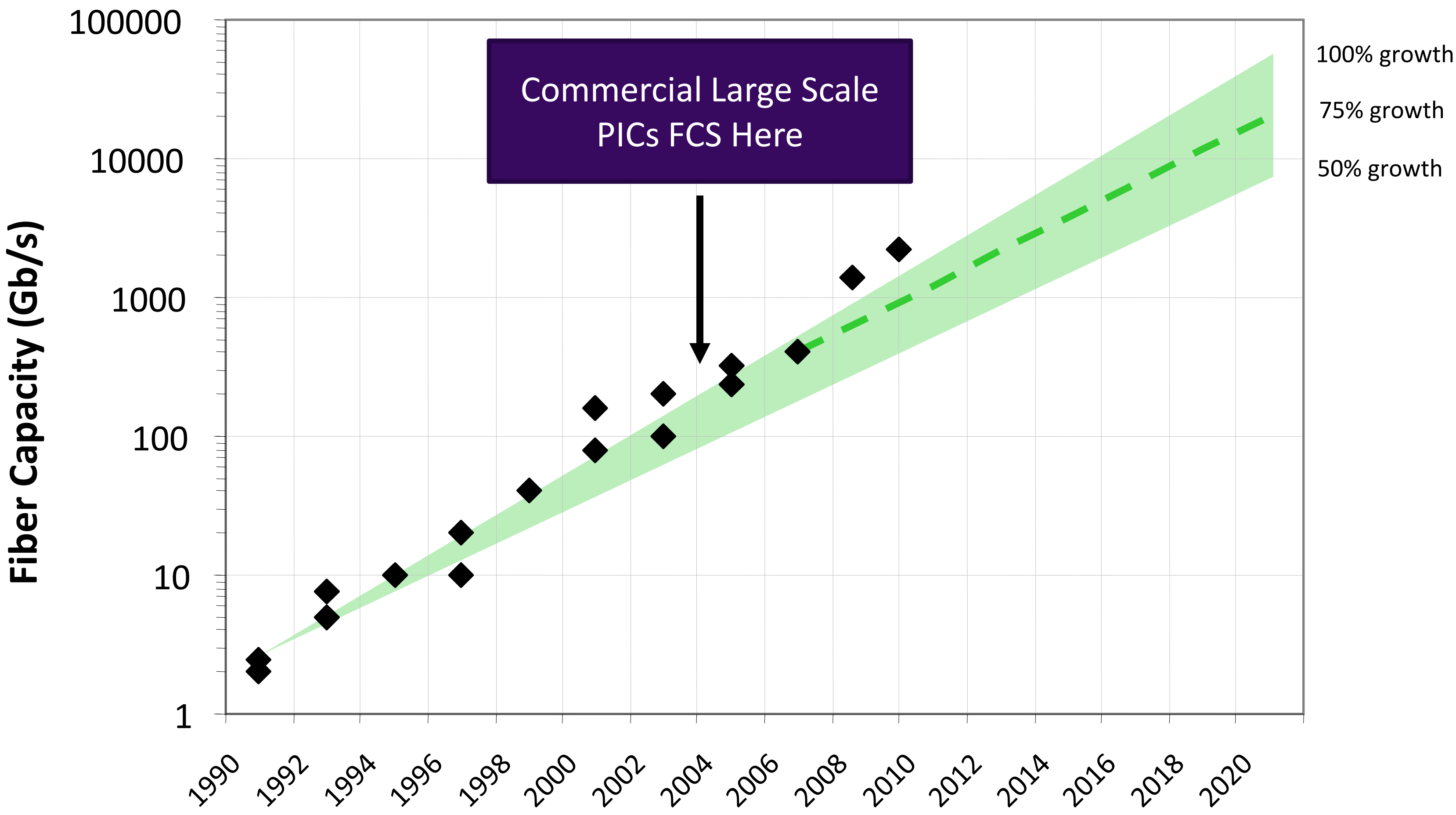
VLSI



- Smaller size
- Lower power use
- Automated manufacturing
- Higher reliability
- Lower cost
- Long service life

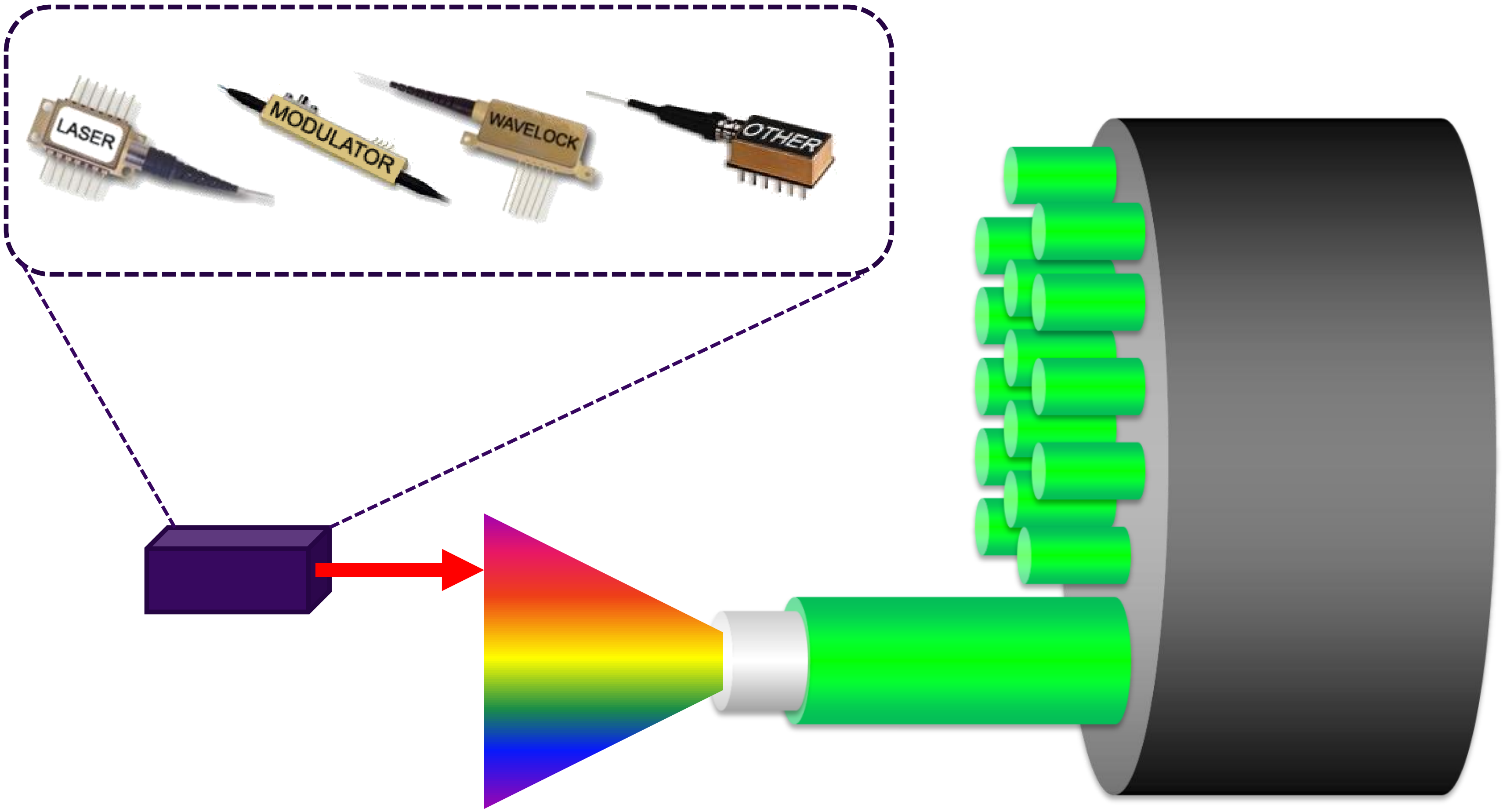
- From tens of components to billions of components on a single chip
- Fundamental building block is the “gate”
- Silicon is material of choice

# The success of DWDM historically
# *Most of this growth achieved without Photonic Integration*

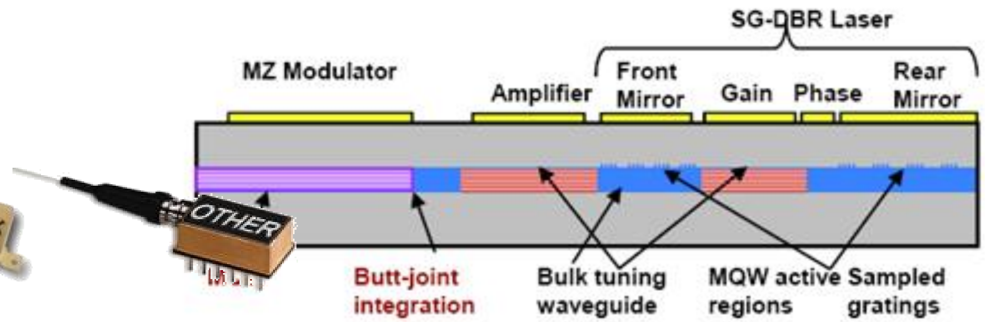



**IP Network Growth Expected to Scale WDM Networks >10Tb/s by 2020**

# Let’s take one wavelength



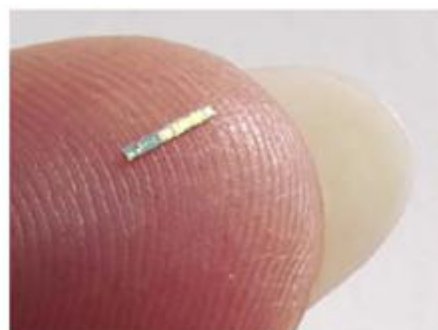
# Small Scale PIC:
# *Integrated Laser Mach Zehnder (ILMZ)*

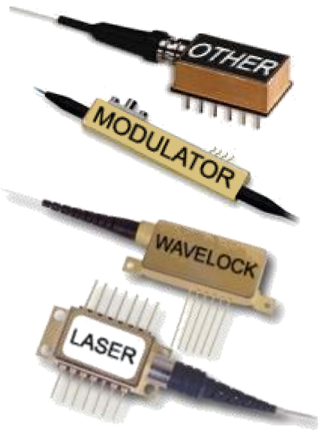

TOSA

ASIC
(Tunable Control)

ILMZ PIC



Source: JDSU


OTHER
MODULATOR
WAVELOCK
LASER

# Large Scale Photonic Integration

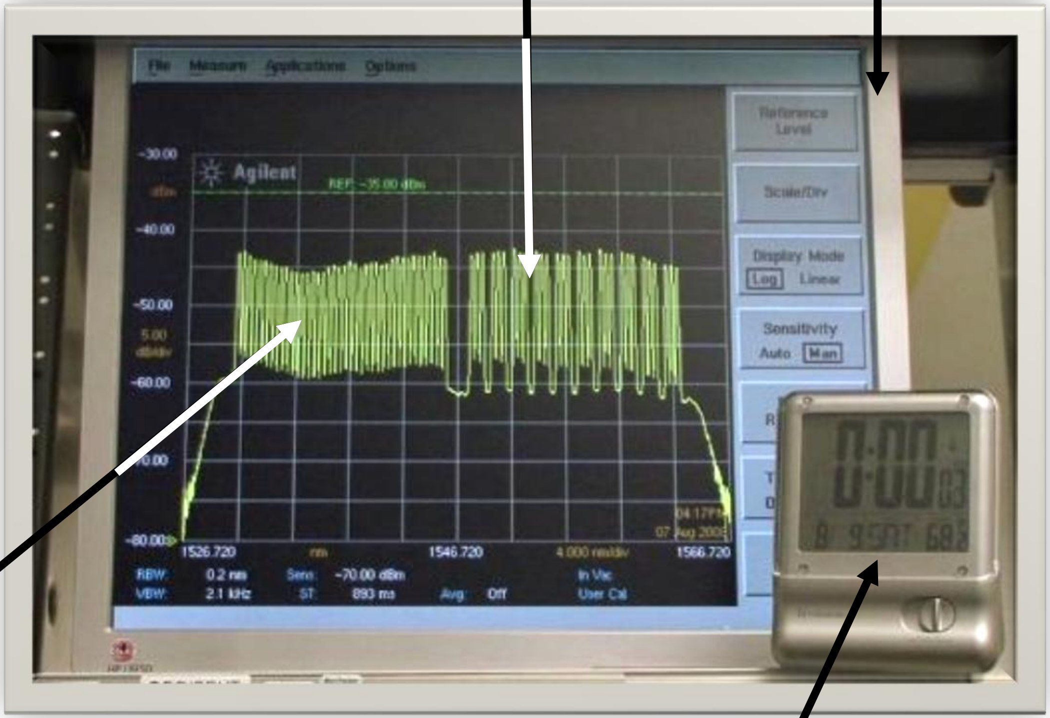

- Improves cost, space, power, reliability
- Makes digital processing economical
- Service ready capacity

# What are you going to see?

- Adding a single PIC-based line card, with 10x10Gb/s waves
- 100Gb/s of capacity for the same effort as one 10Gb/s transponder

"Gaps" for additional waves

Optical Spectrum Analyzer




Existing 10G waves on the fiber

Stopwatch



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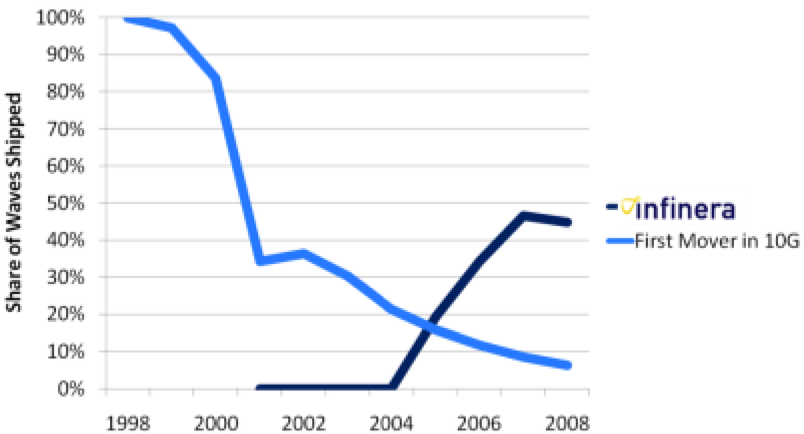
# Photonic Integrated Circuit Success

2004

*100G per chip*

PICs enabled a disruptive digital networking model



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# Why isn't everybody doing it?

- PIC first described in 1969
  - Very few large scale developments reach product status
  - Many academic projects, but little continuity of development
- Biggest commercial challenge is lack of R&D funding
  - Optical Vendor "dis-integration" circa 2000 – major vendors cannot subsidise PIC development through system sales
  - Optical component industry does not have enough R&D budget

| **Total transponder market** | **$2.1B** |
|---|---|
| Assume 12% R&D/Sales | $263M |
| Assume 1% for advanced technology projects | $21M |

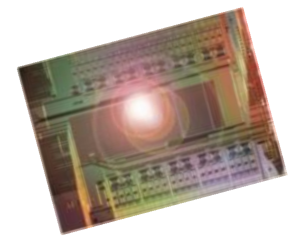
Source: Julie Sheridan, VP Engineering Finisar

# Next-gen Photonic Integrated Circuits

2004

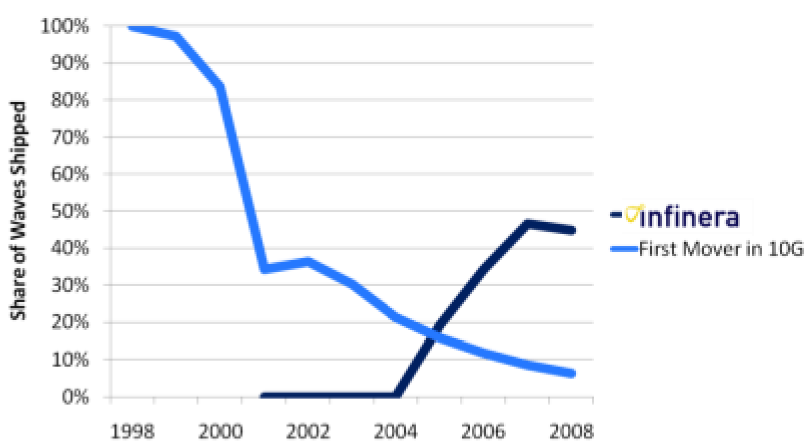
*100G per chip*

2009

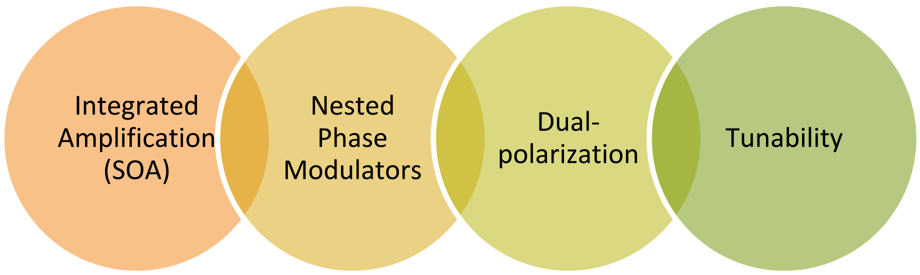


*400G per chip*

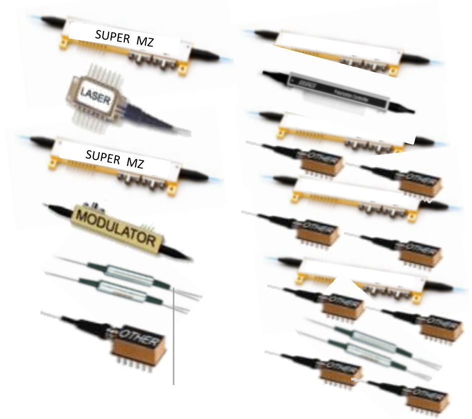
PICs enabled a disruptive digital networking model




Dramatic enhancements in integrated functionality



# Scaling to higher data rates

| Year | 1990 | 1995 | 1998 | 2008 |
|---|---|---|---|---|
| Datarate | ≈1G (Async) | 2.5G | 10G | 40G/100G |
| Modulation | NRZ | NRZ | NRZ | Phase Modulation (e.g. DQPSK) |
| Components Required |   |   |   |   |

**Beyond 10G, 4x increase in bits per wave requires ≈4x increase in components = minimal economic benefit**

# Why do I need Complex Modulation?

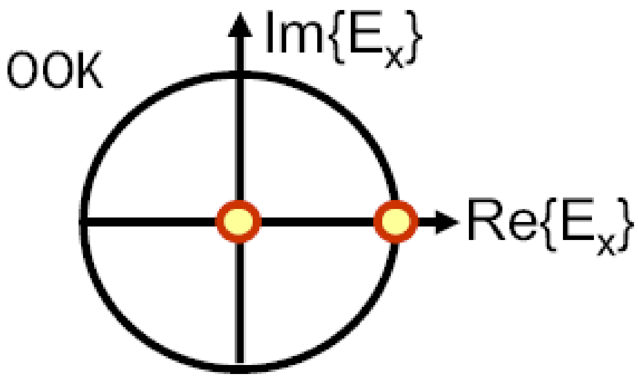
- Optical transmission is about:
  - Sending high data rates
  - Over very long distances
  - For very little money

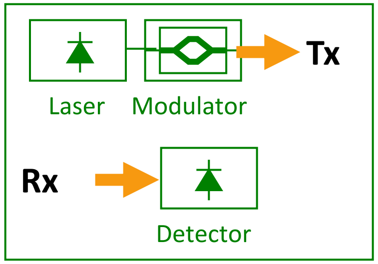
If you stress any one of these variables, the others will respond

- Our biggest problem is optical fiber:
  - Loss
  - Dispersion
    - Modal dispersion
    - Chromatic dispersion
    - Polarization mode dispersion
  - Non-linear effects
    - Self phase modulation
    - Cross phase modulation
    - Four wave mixing

For a given modulation type, the gross magnitude of these impairments scales roughly with the *square of the symbol rate*

# 1 bit per symbol: NRZ Modulation

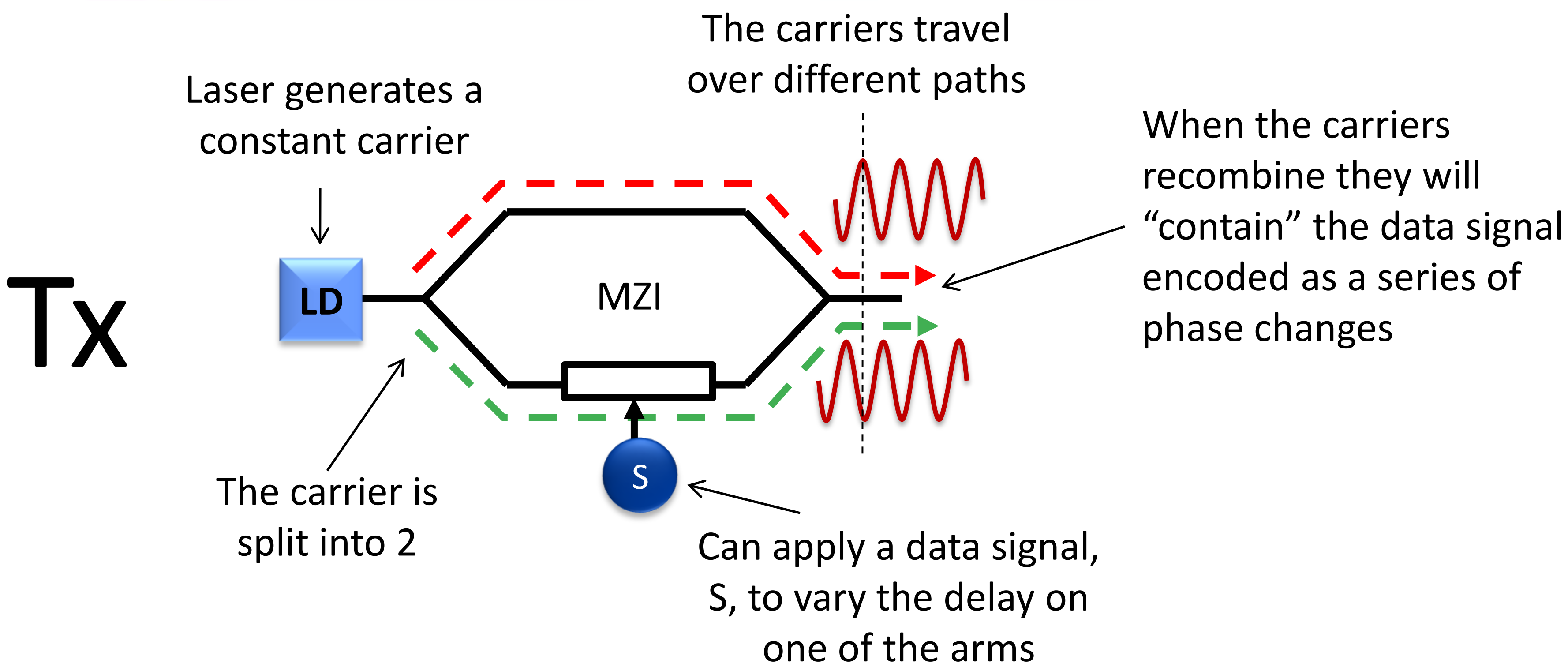



***NRZ***

- Simple modulation technique
- Easy to implement
- Low power use
- But very sensitive to fiber impairments as bitrate increases
  - This is what we're talking about with the "square" relationship
- Increasing power will trigger non-linear effects

# Using Phase to Apply a Signal




Rx

Q: How do we recover the data signal at the receiver?

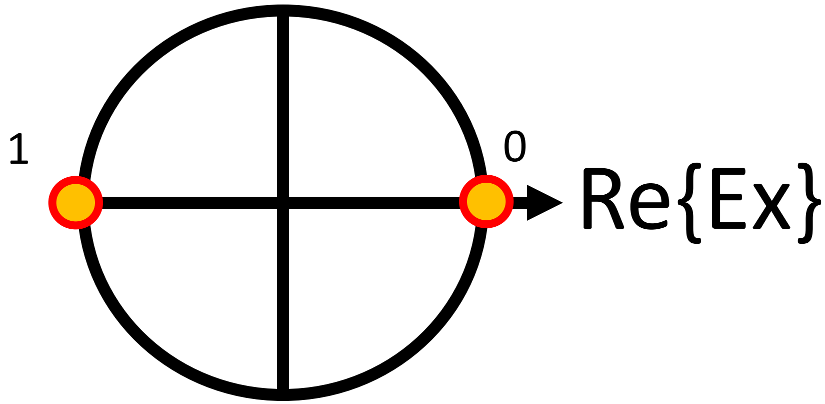
Hold that thought!

# Phase-Based Complex Modulation

- Two fundamental advantages:

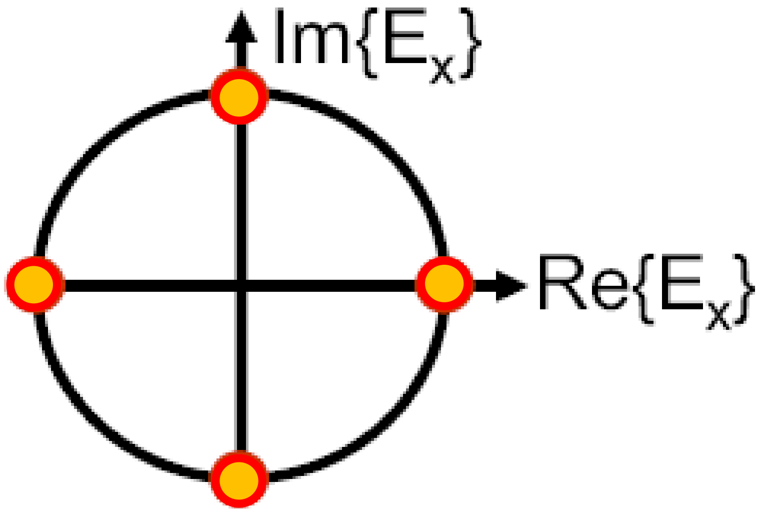
- Phase modulation tends to be more tolerant of fiber impairments like dispersion and non-linearities
- By using lots of phase states we can cram more bits into a single symbol
  - Impairments are related to the symbol rate, not the bit rate
  - Exactly the same as the complex modulation used on ADSL, WiMax etc.

# 1 bit per symbol: DPSK



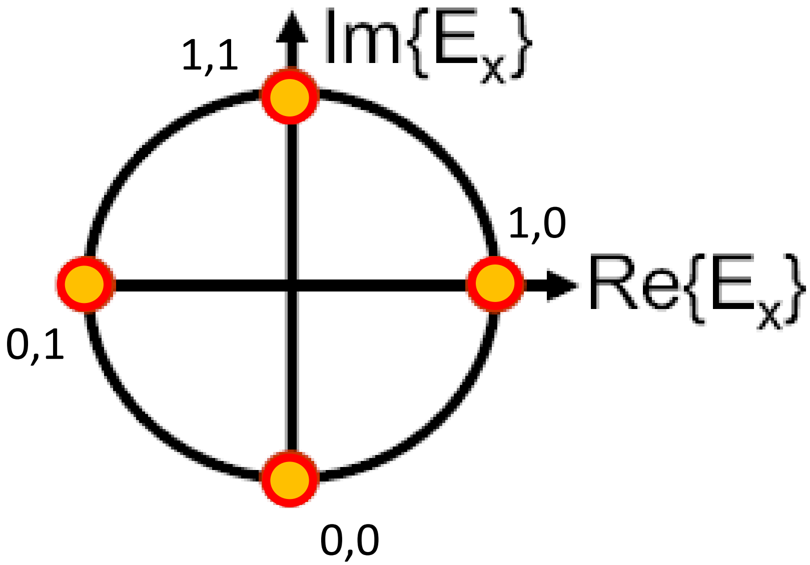

- Most basic phase modulation technique
- Differential technique allows phase slips to be ignored
- Used by OpNext & Mintera, and their OEMs
- AKA: BPSK, where local oscillator coherent detection is used

# 2 bits per symbol: Quadrature PSK




- Advanced modulation, 4 phase states = 2 bits
- More bits per symbol

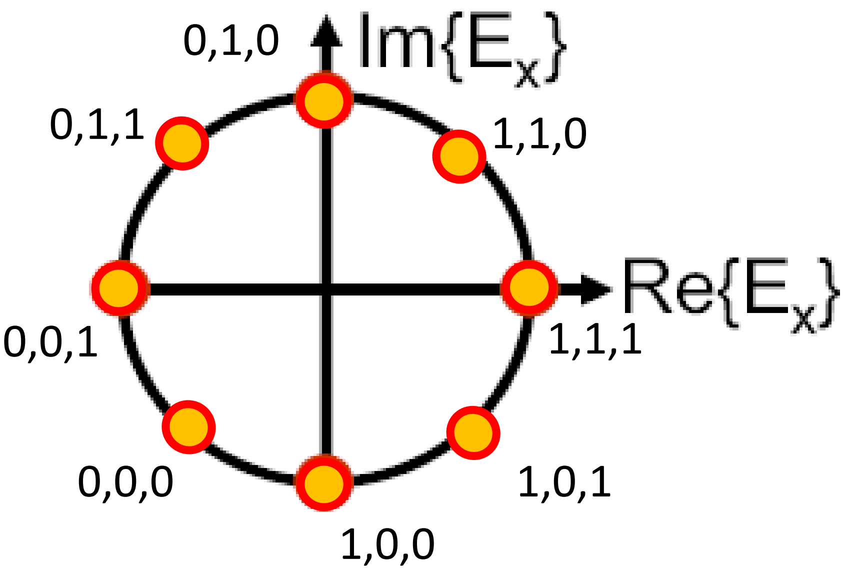
# 2 bits per symbol: Quadrature PSK




- Advanced modulation, 4 phase states = 2 bits
- More bits per symbol

# 3 bits per symbol: 8-PSK

## *…And higher orders of modulation*

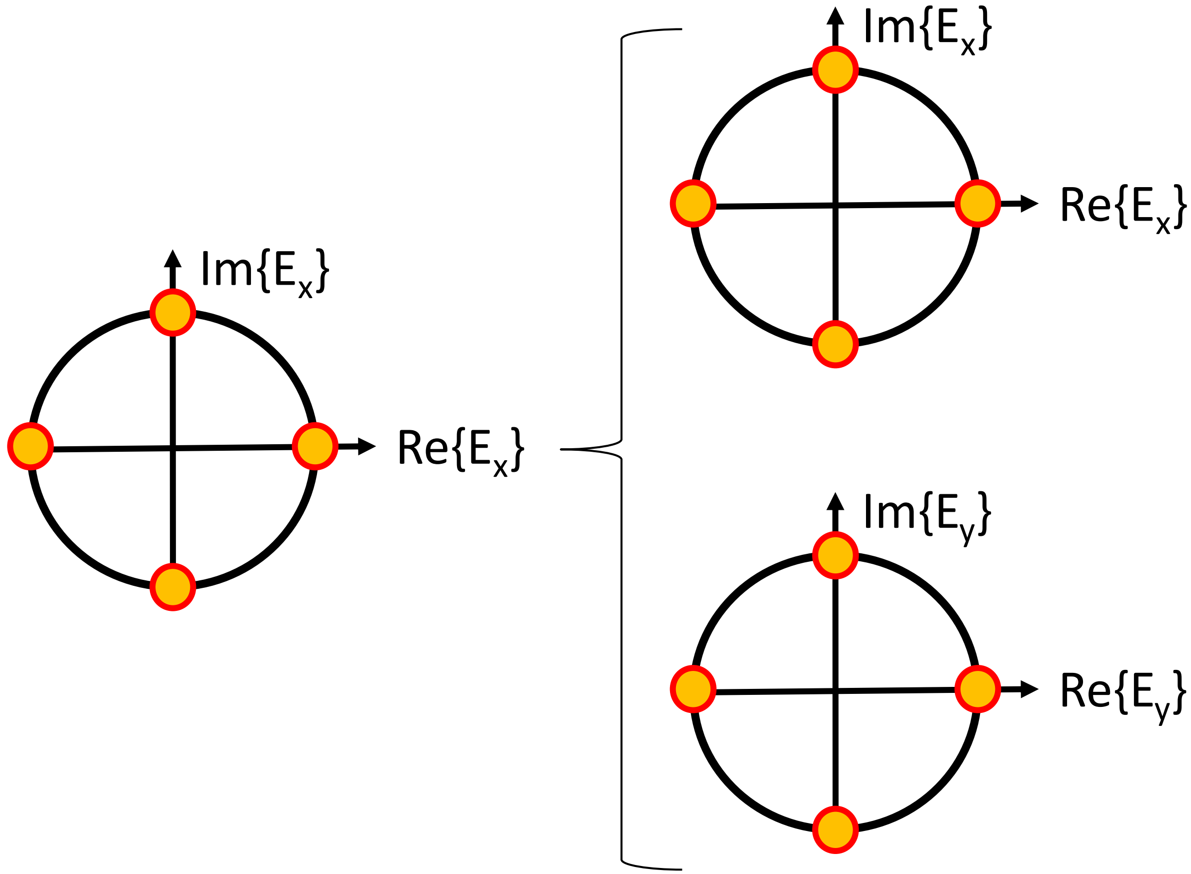



- 8 phase states = 3 bits
- Twice as complex, but only 50% more bits

For *discrete implementations*, 8-PSK seems to be *too complex*

# PM-QPSK, 4 bits per "symbol"

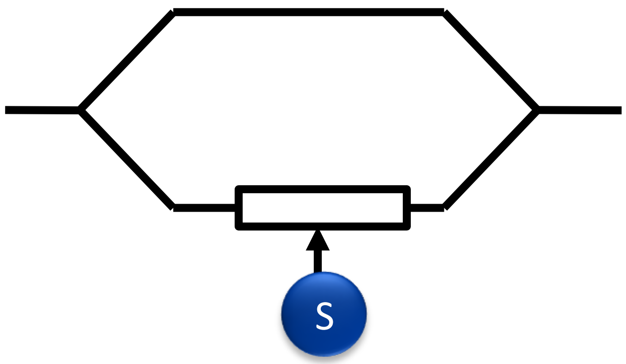
Two Polarizations




X-Polarization

Y-Polarization

# Implementing Phase Modulation Using Discrete Optical Components...



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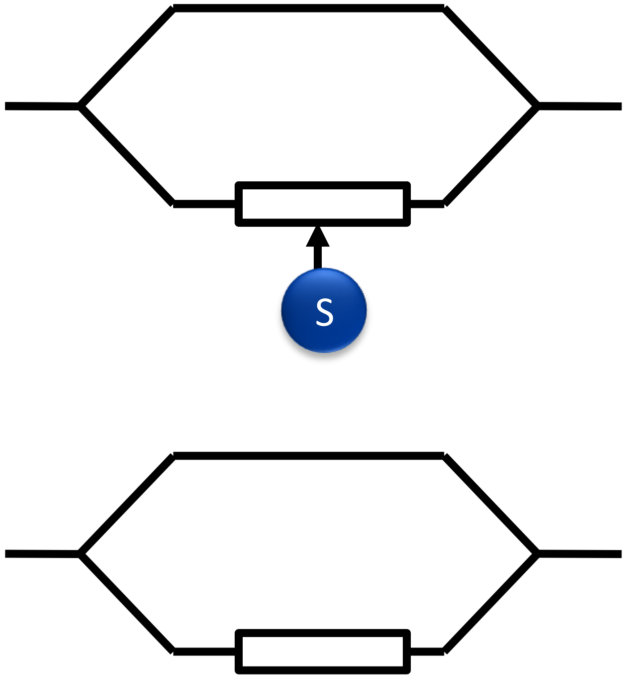
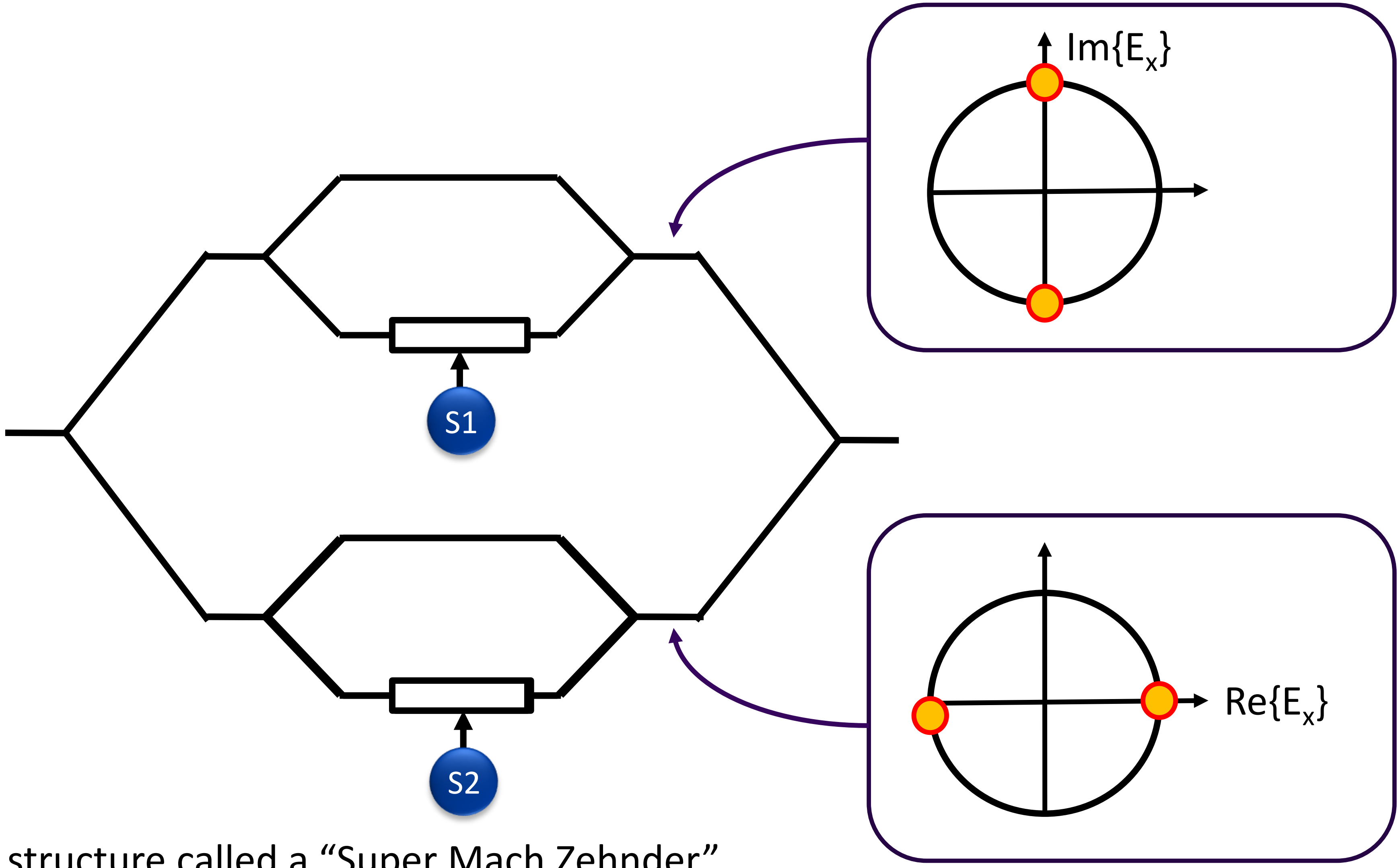
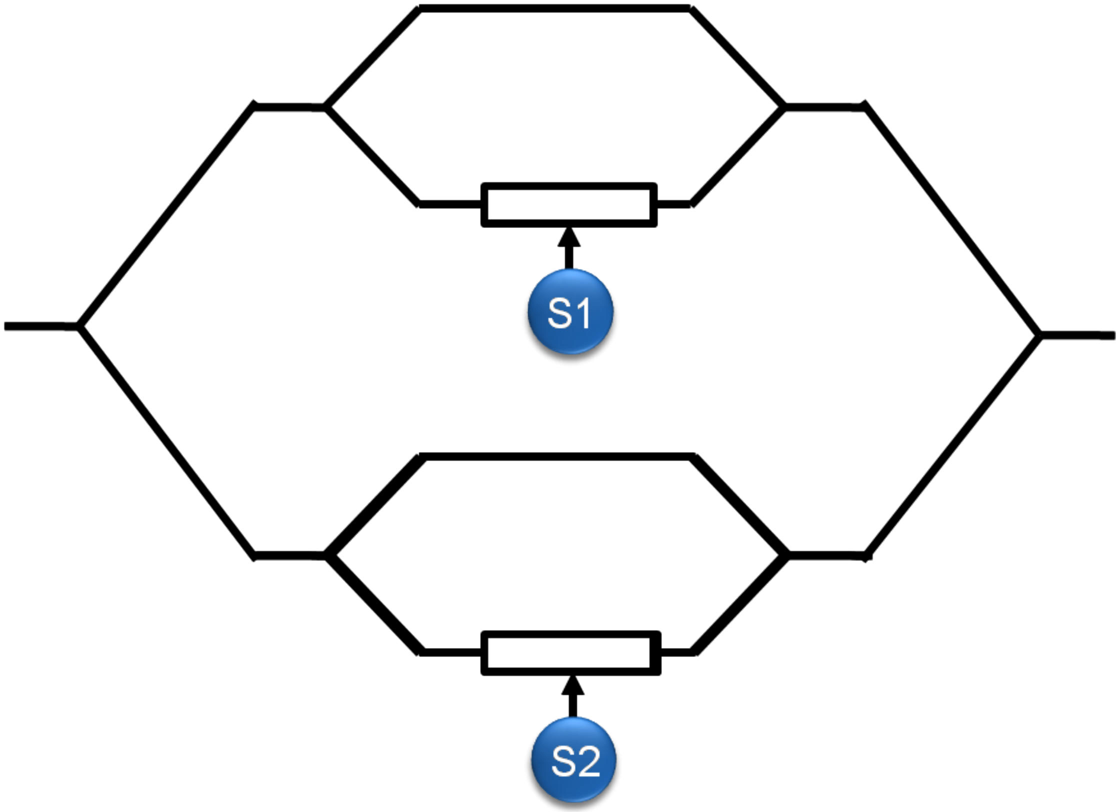


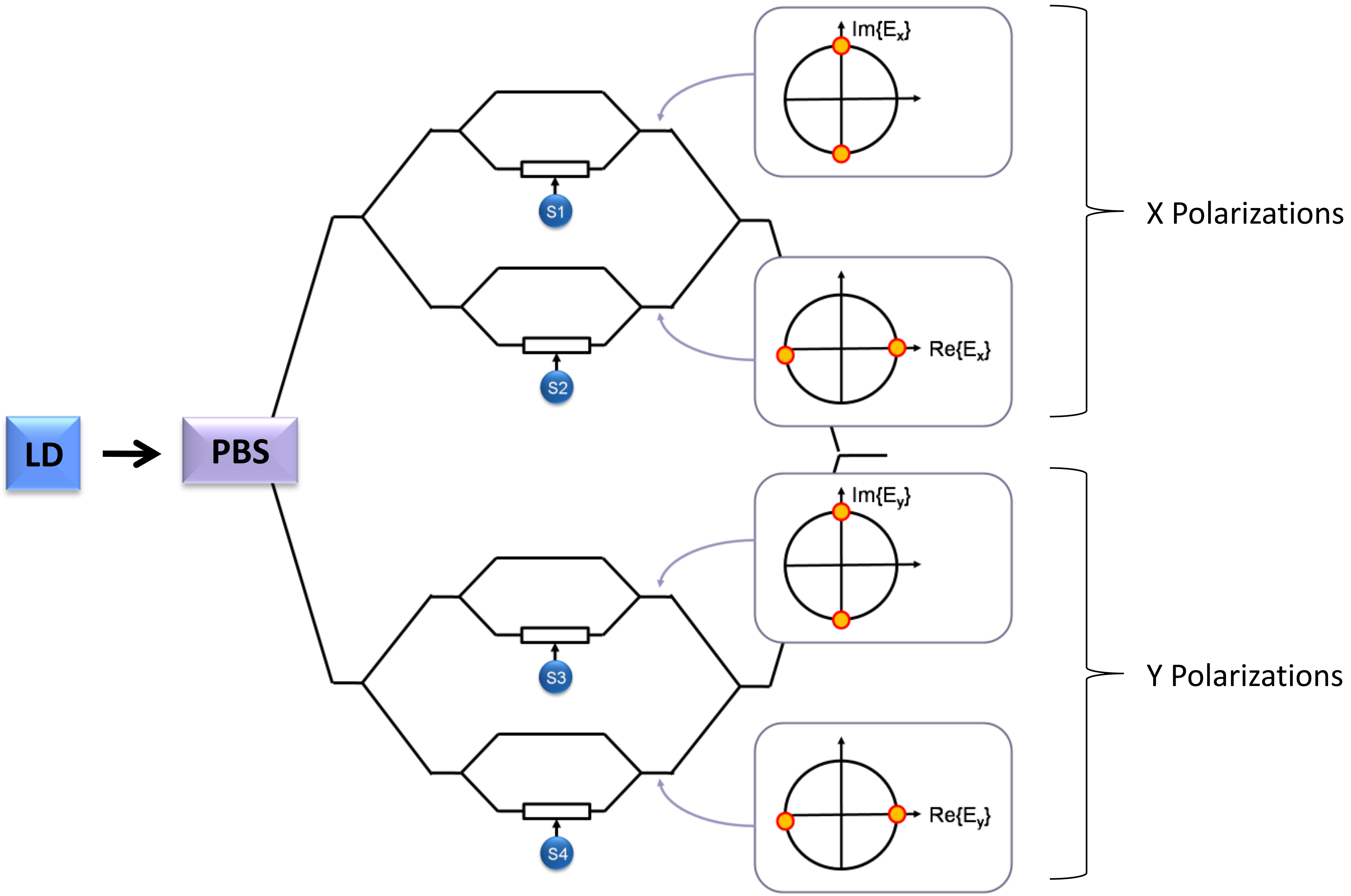
# This is QPSK...




This structure called a “Super Mach Zehnder”


S1
S2

# This is a *PM*-QPSK Transmitter

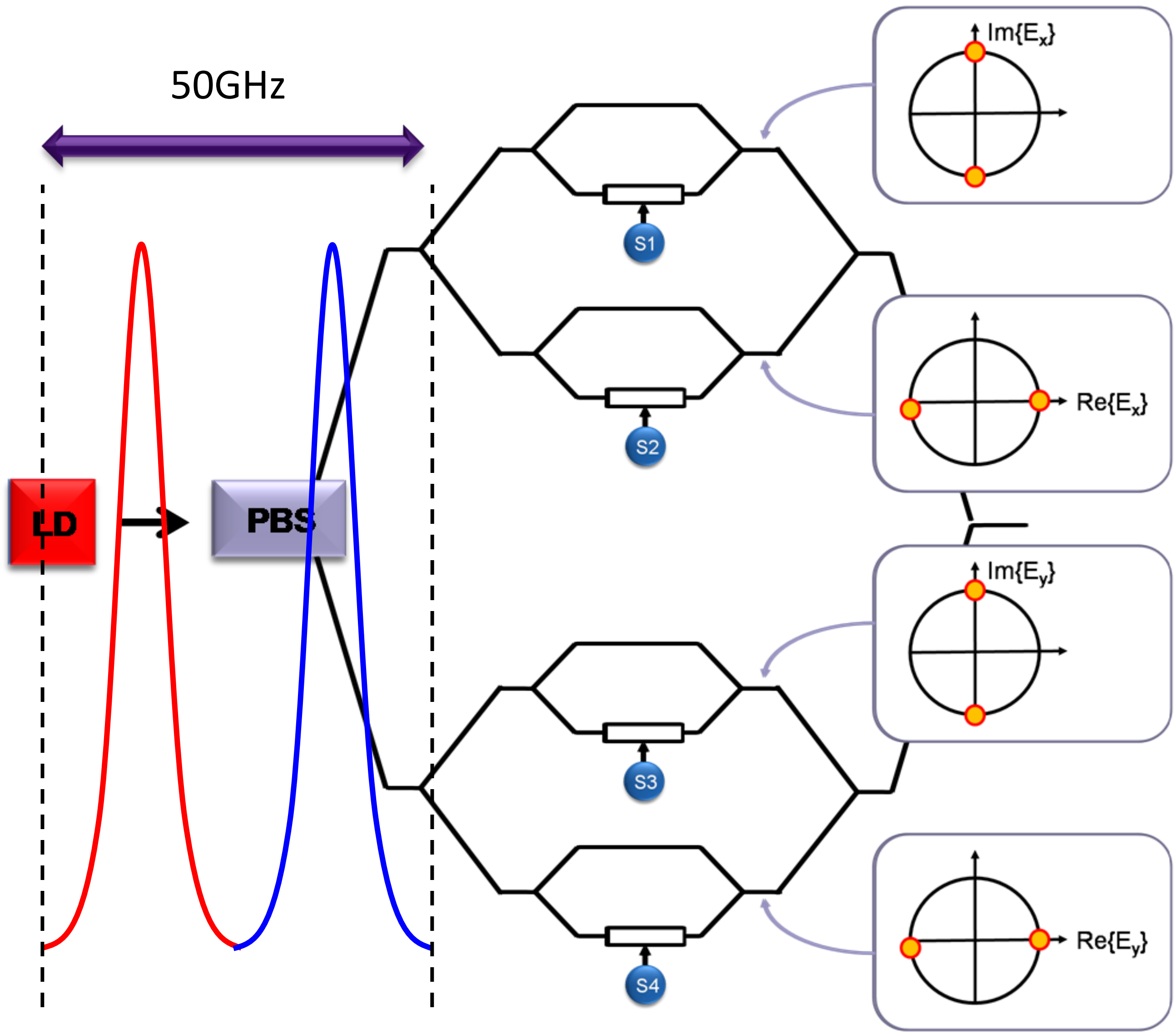


# What about 100G?

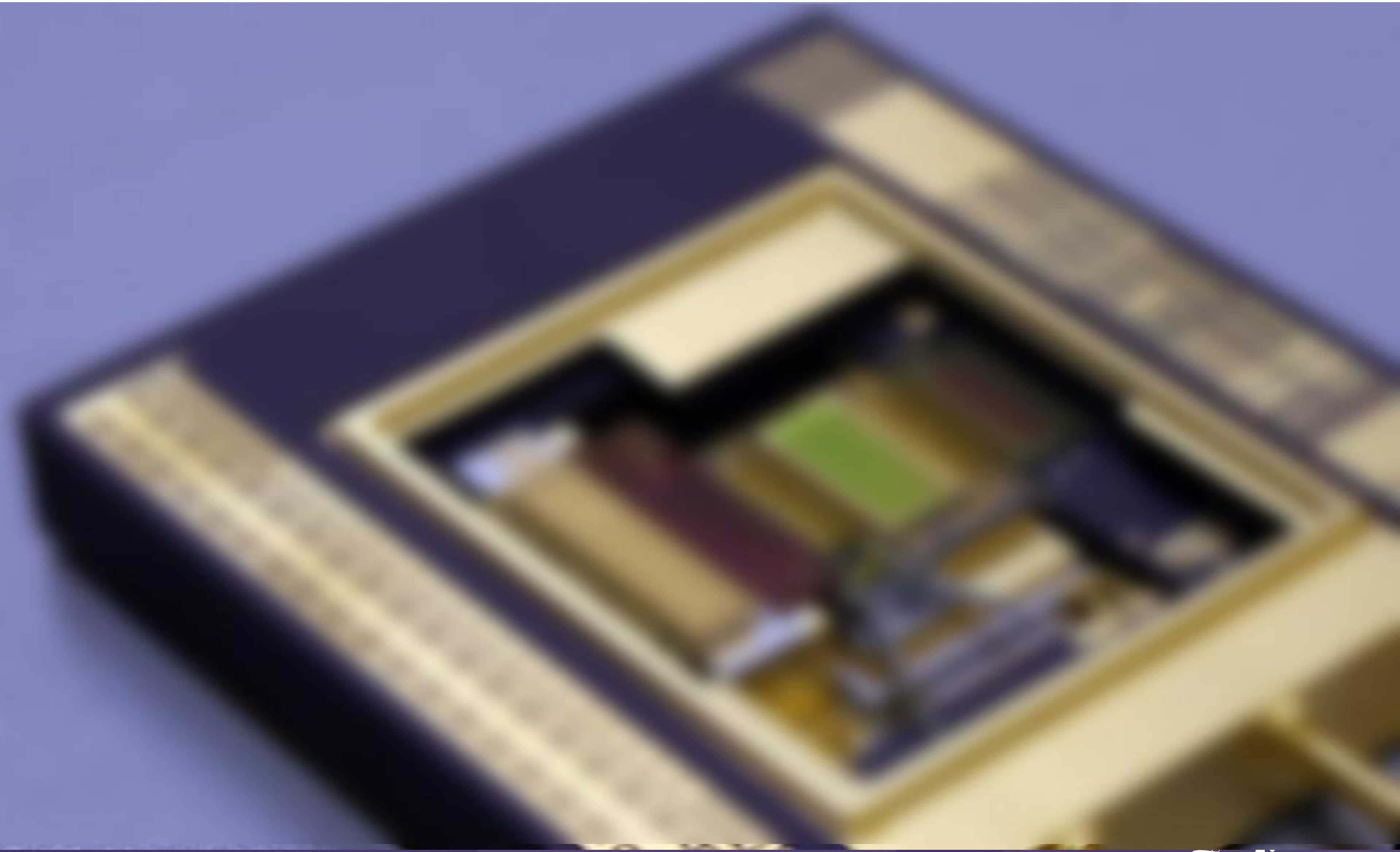
- Option 1: PM-(D)QPSK
  - Increase baud rate from 10G (+OH) to 25G (+OH)
    - Around 28G with OH
  - Places strain on electronics
  - Impact of baud rate then places strain on DSP algorithms in Rx
  - It's achievable, but will be expensive
- Option 2: Add more phases (8PSK, 16QAM, etc.)
  - Law of diminishing returns
  - Could be mitigated by Photonic Integration
  - Impact on OSNR → reach
- Option 3: Find another modulation property
  - Amplitude and phase tend to be mutually exclusive
  - Only 2 polarization states
  - *How about "spread spectrum"?*

What does this mean in the context of long haul optical transmission?

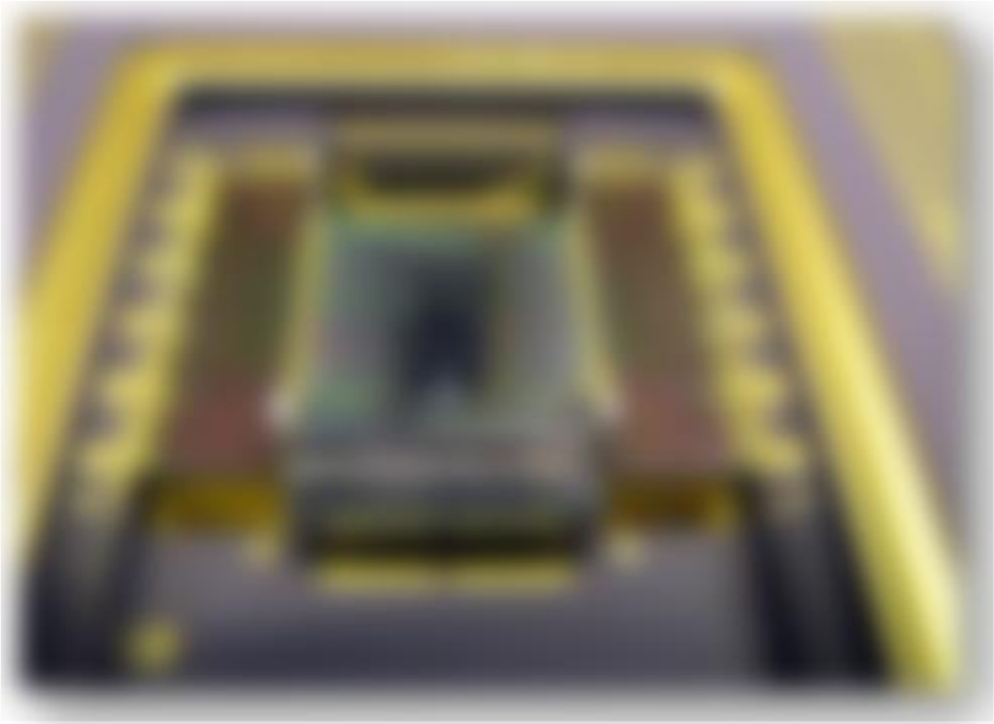
# This is a *DC*-PM-QPSK Transmitter



# 400G PIC Transmit Module



# 400G Receiver PIC Module

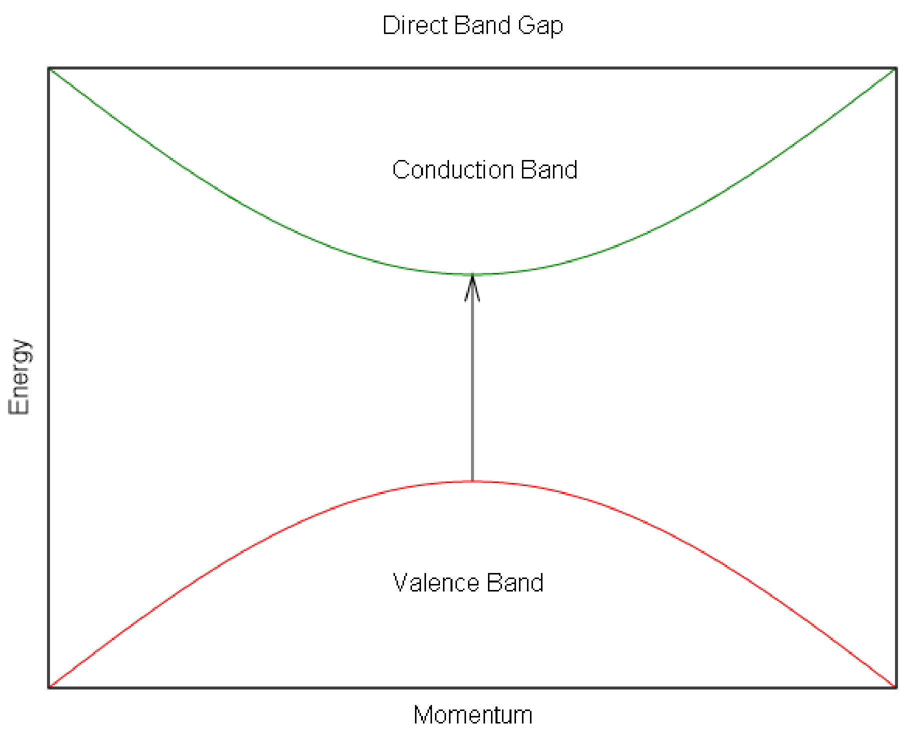


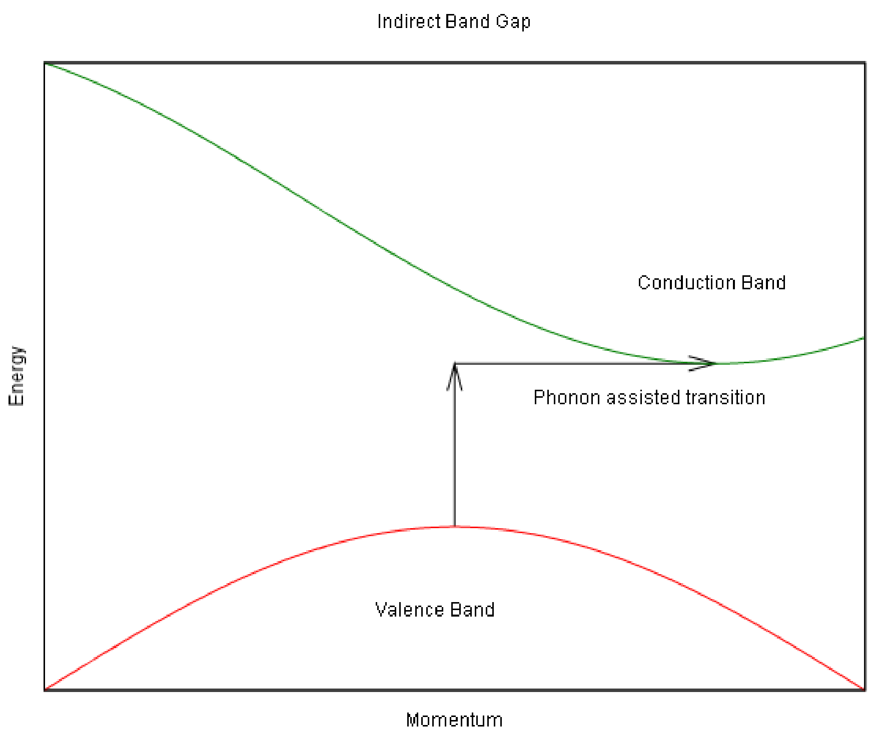
- 20 Delay Interferometers
- 10 Rotators, 20 polarizers
- 20 Polarization beam splitters
- 1x10 50 GHz  Flat Top Demux
- 220 precision couplers
- Tunable filters
- 160 photodetectors

# The right material for the job?

THE LURE OF
SILICON PHOTONICS

# A Quick Aside:
## *Direct and Indirect Bandgap Semiconductors*



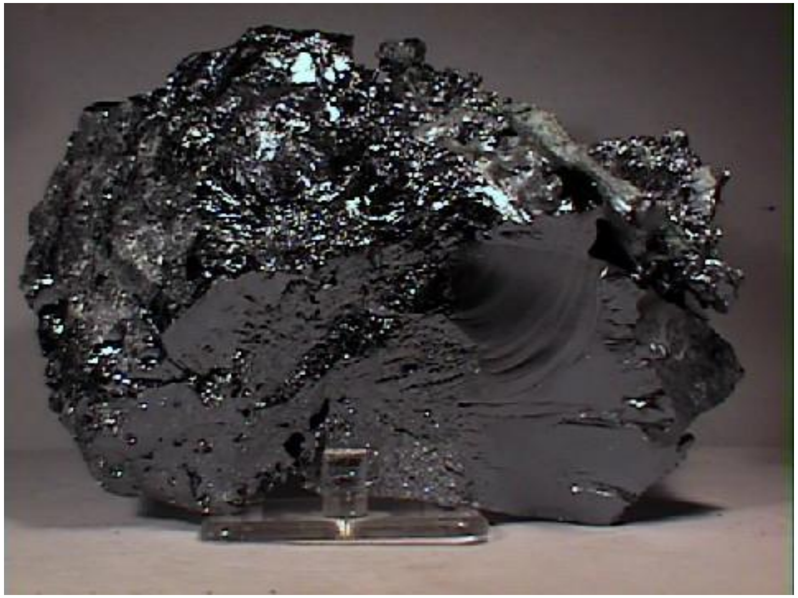

InP, GaAs, CdTe, CIGS

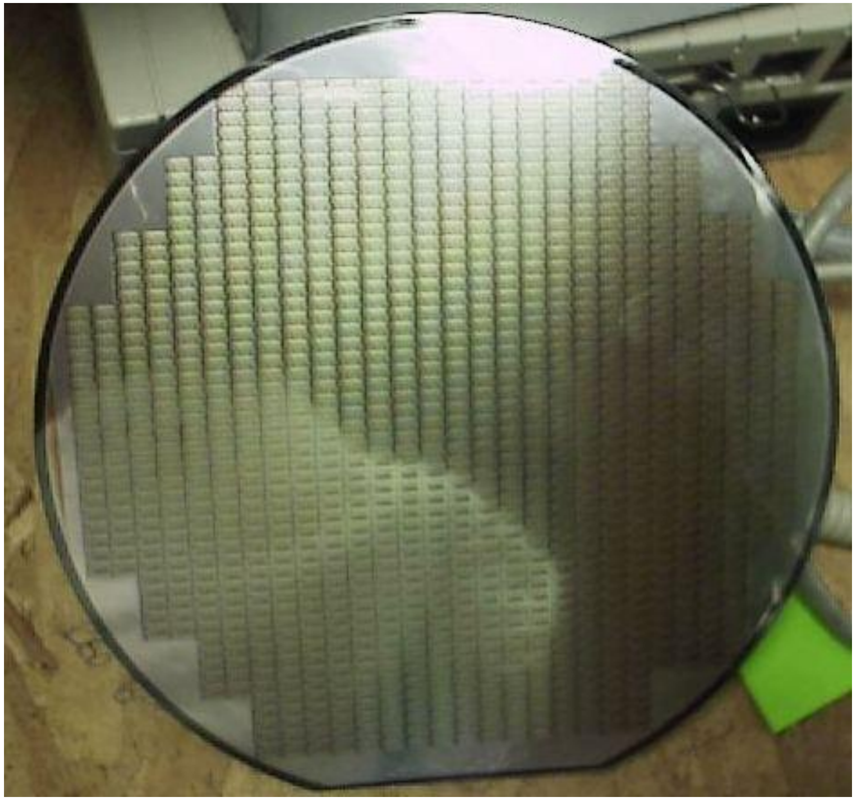
Si, Ge, AlAs

These make good lasers, photodetectors

…these don't

# But Silicon Is Great!





- Abundant (sand is $SiO_2$)
- Cheap
- Easy to work with
- Decades of production experience

There is a huge incentive to "make Silicon lase"

# Summary

- Photonic Integration is solving critical problems in:


Data Processing

Data Communications

- At the very beginning of its technology cycle

*The best is yet to come!*

# Thank You!

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