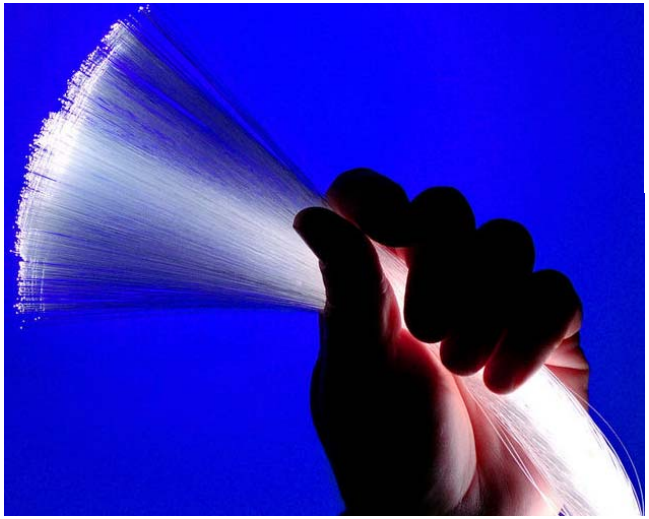
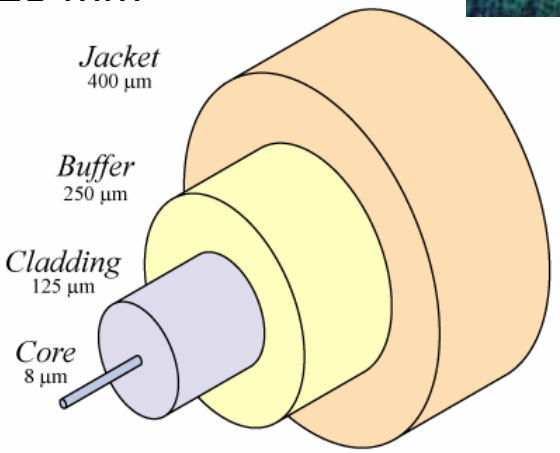
Communication Photonics

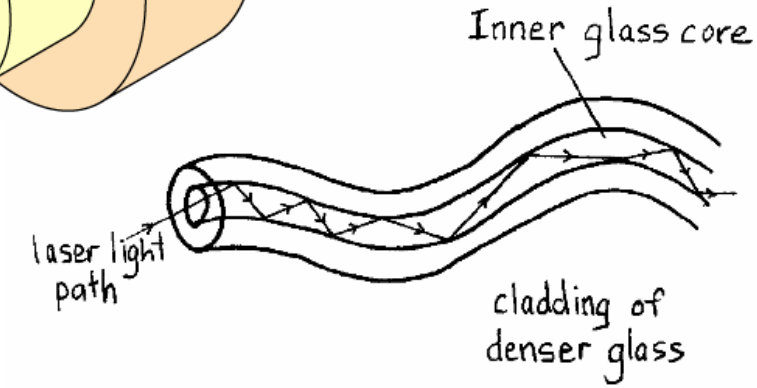
OptiComp Corp

Optical Fiber

- Operates by reflection of light at interface of cladding and core
- Optical fiber loss: 0.2-0.5 dB/km
  - ⇨ RF cable loss: 50-1000 dB/km
- Optical fiber diameter: 0.125 mm
  - ⇨ RF cable diameter: 3-25 mm

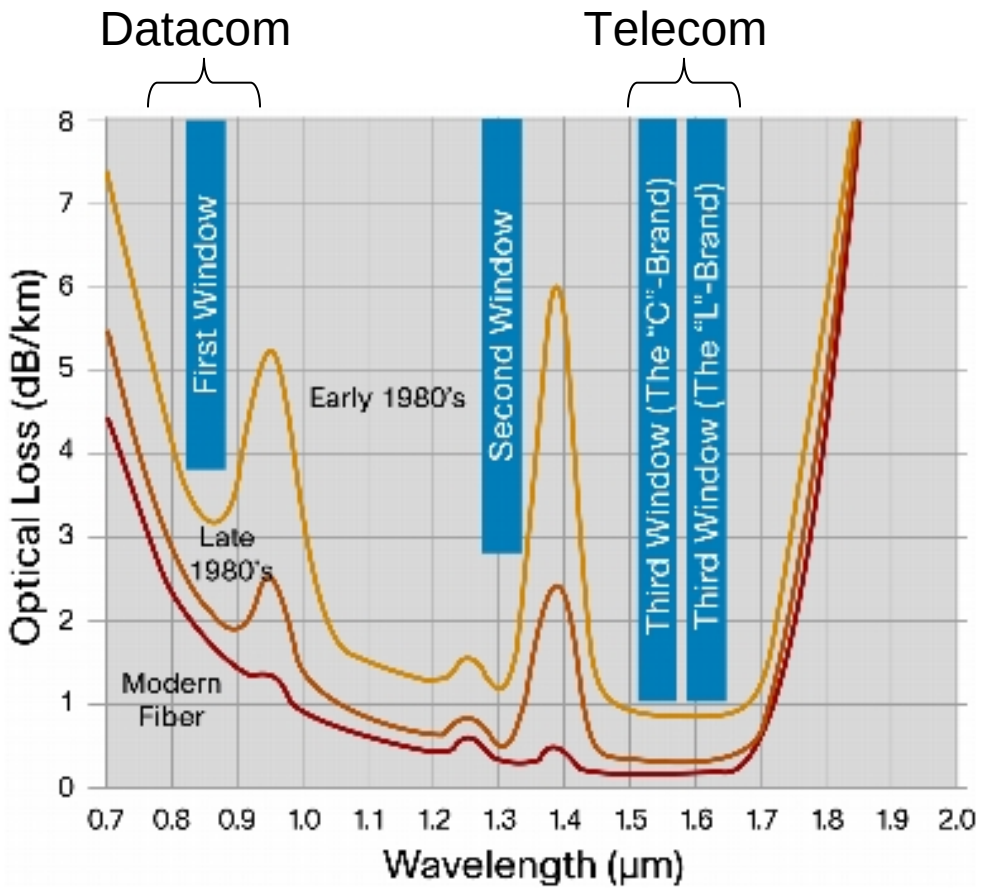






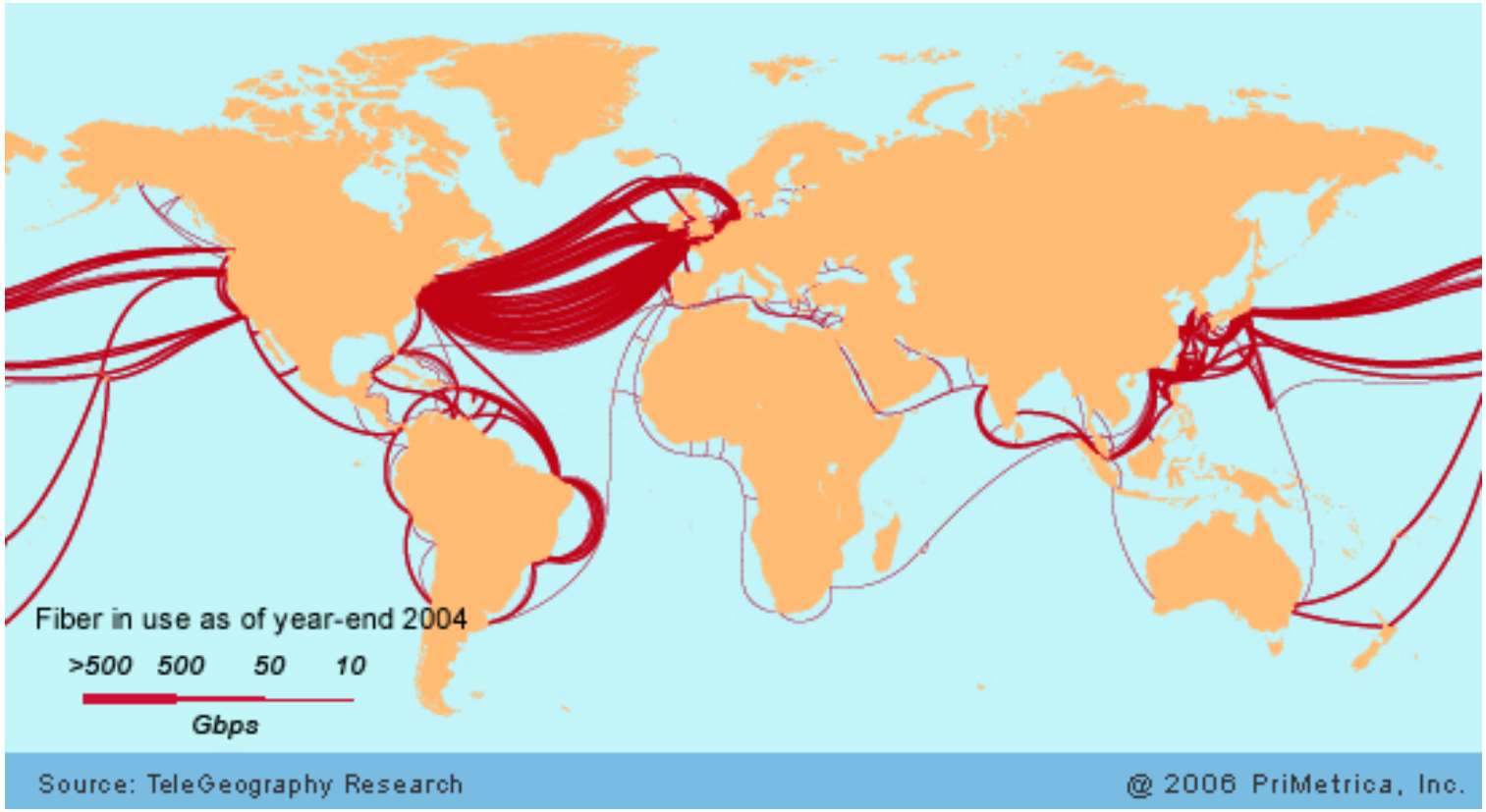
Optical Signal and Fiber Bandwidth

- Optical carrier frequency 195 THz
  - ⇨ 100,00 time higher than GSM cellular phone transmission frequency
- Spectral bandwidth: 10 THz (10,000,000 MHz)
  - ⇨ Every person in China can call every person in India over single optical fiber



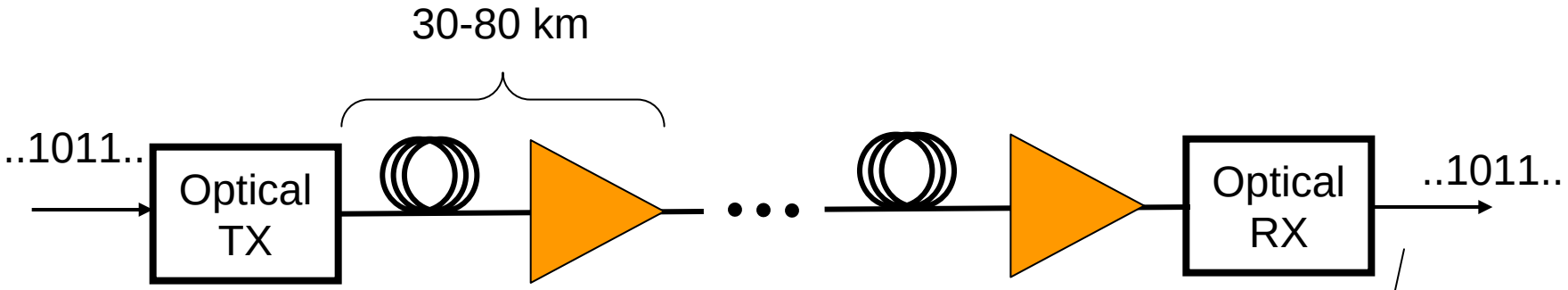
Fiber Optics for Telecom

- More bandwidth than RF satellite and RF coax cable
- Latest Transatlantic fiber optic cable (TAT-14) can support 200 million phone calls
- Last transatlantic copper cable (TAT-7) could support
  - ⇨ 4,000 phone calls

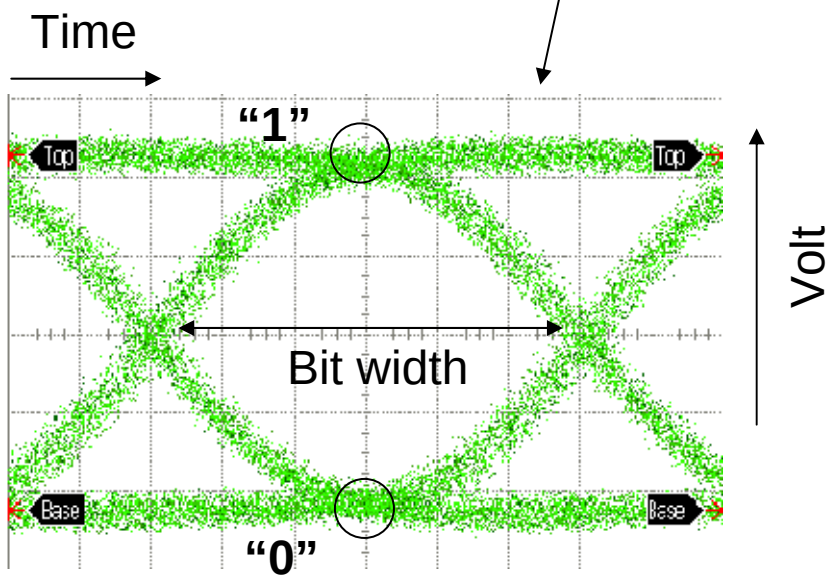


Typical Optical Communication Link

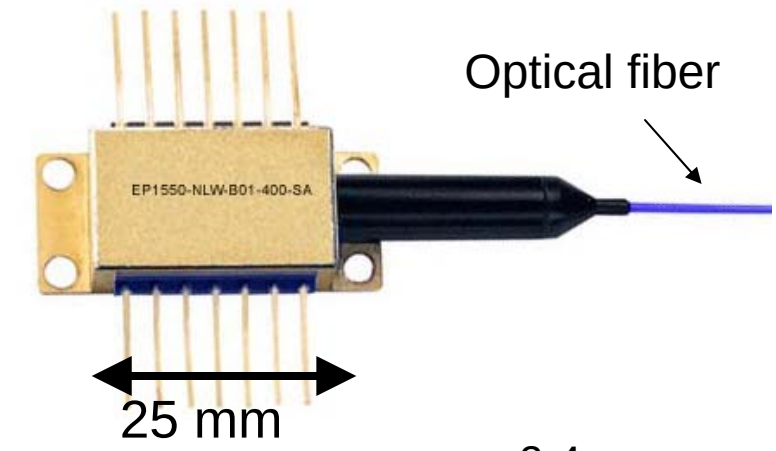
- Simplest modulation scheme: ON-OFF modulation of light
- Receiver is a “square-law detector” with no concern for optical frequency
- Typical data rates are 2.5 to 40 Gbps



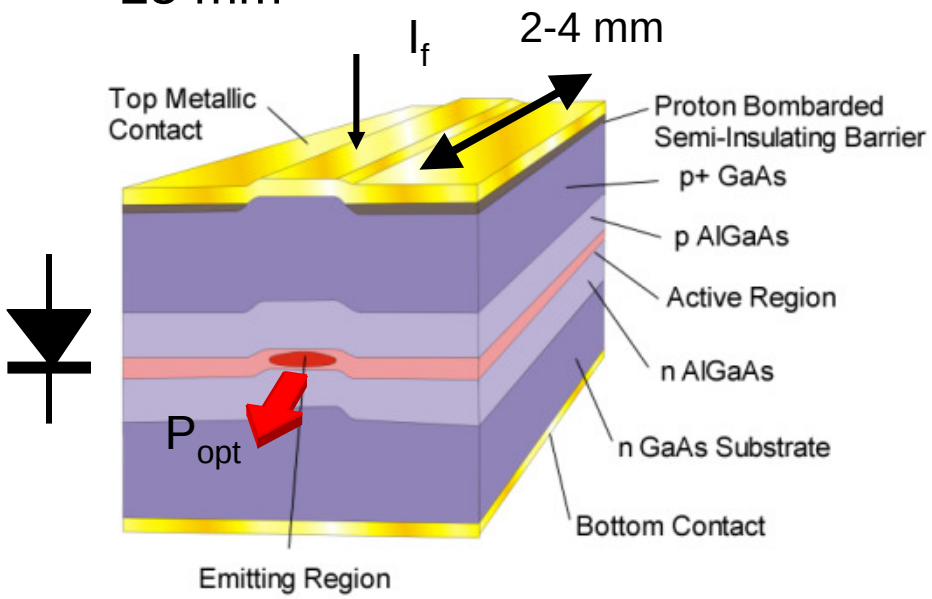
- Metric of transmission quality is “eye diagram” after optical receiver

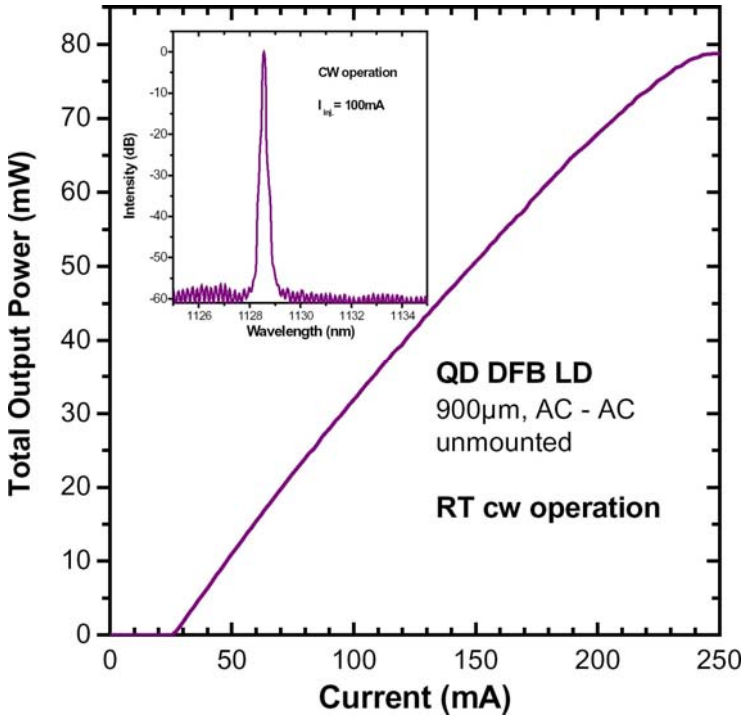


Optical Laser Source



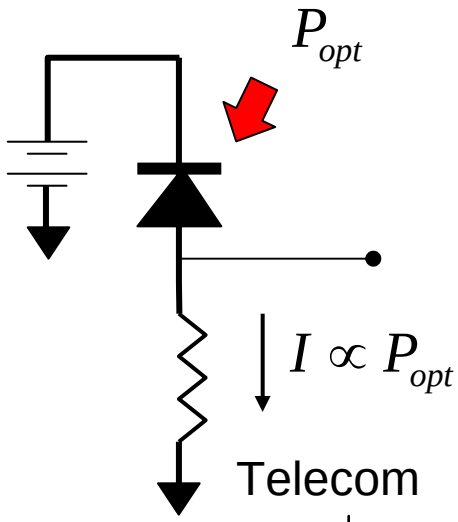
- Multiple quantum-well InGaAs heterojunction edge-emitting laser diode (LD)
- Laser emission is 1500 to 1650 nm
- Output power is proportional to input current

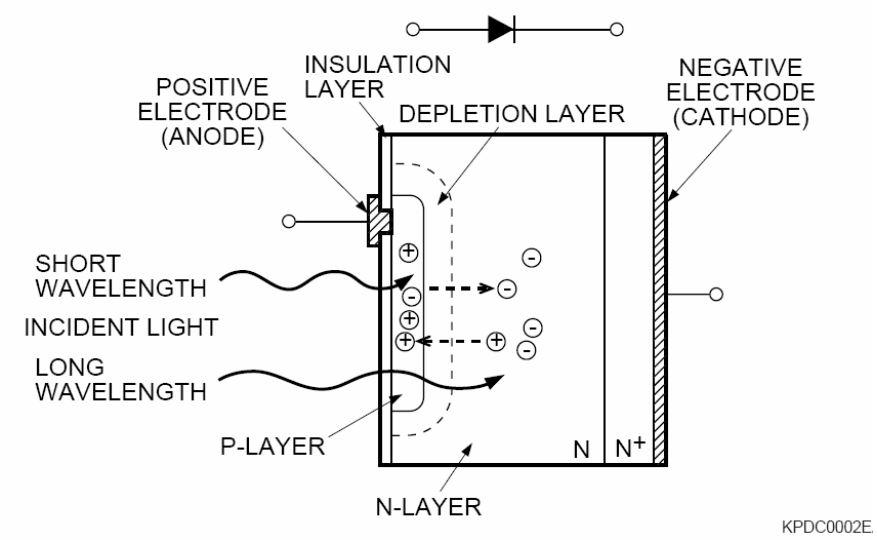


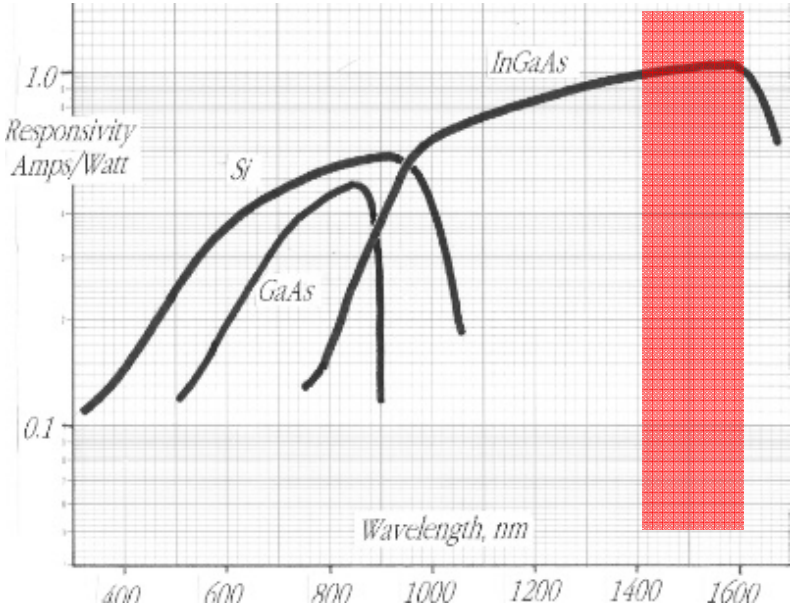


Optical Receiver

- "Square-law detector" - output electric current is proportional to input optical power
- p-i-n photodiode (PD) junction where an electron-hole pair (EHP) is generate for each photon absorbed
- Photodiode is not wavelength sensitivity

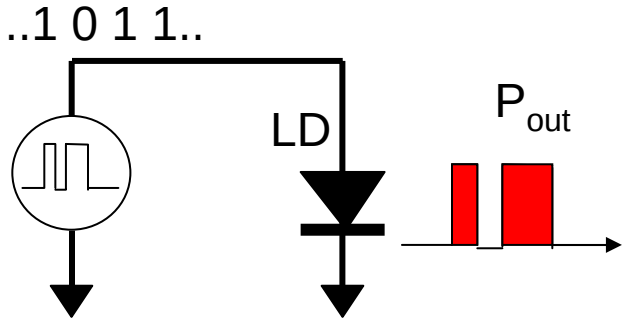




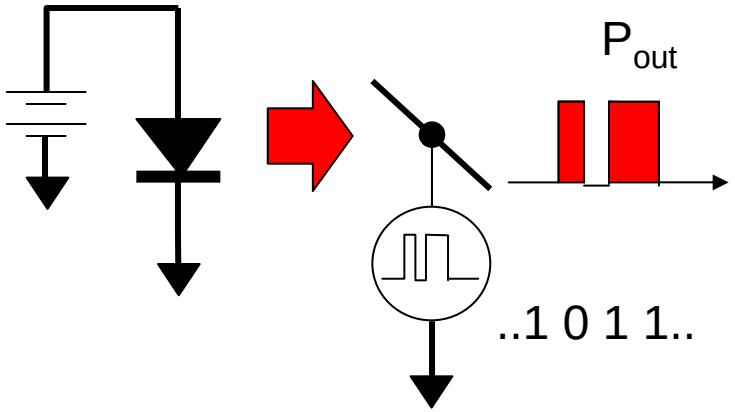


Data Modulation Methods

- Direct modulation
  - ⇨ Laser diode current is turned ON and OFF
  - ⇨ Preferred method but limited to <10 Gbps



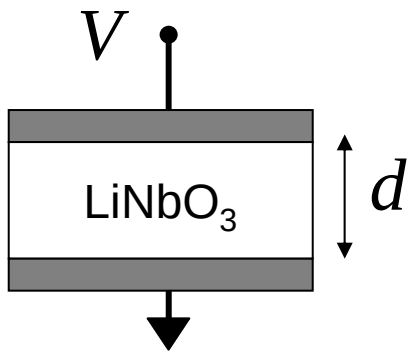
- Indirect modulation
  - ⇨ Laser is ON all the time
  - ⇨ Light is modulated with external electrically controlled shutter



Lithium Niobate Modulator

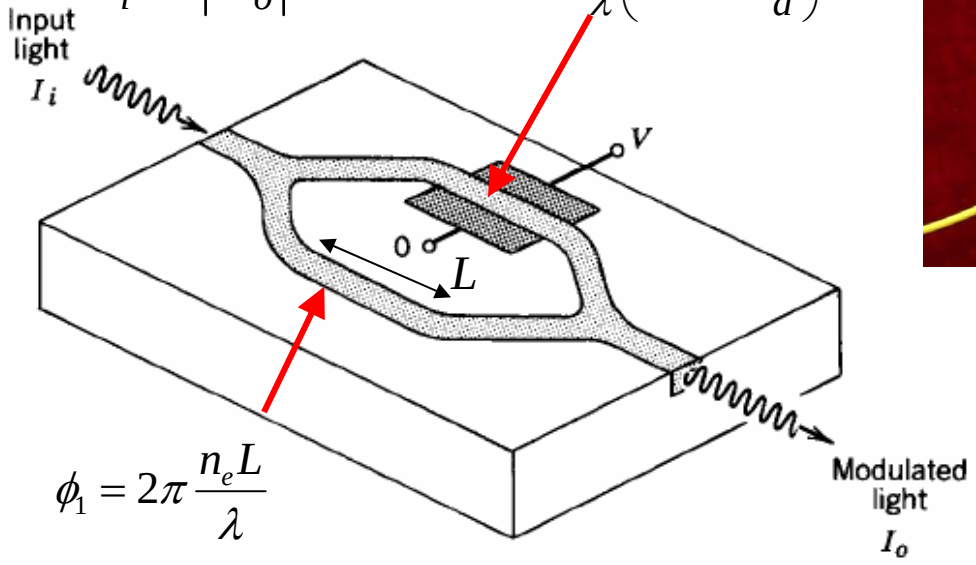
- For Gbps data rate, mechanical shutters are much too slow
- Lithium Niobate ($LiNbO_3$) is electro-optic material where applied voltage changes refractive index

$$n = n_e + \Delta n' \frac{V}{d}$$

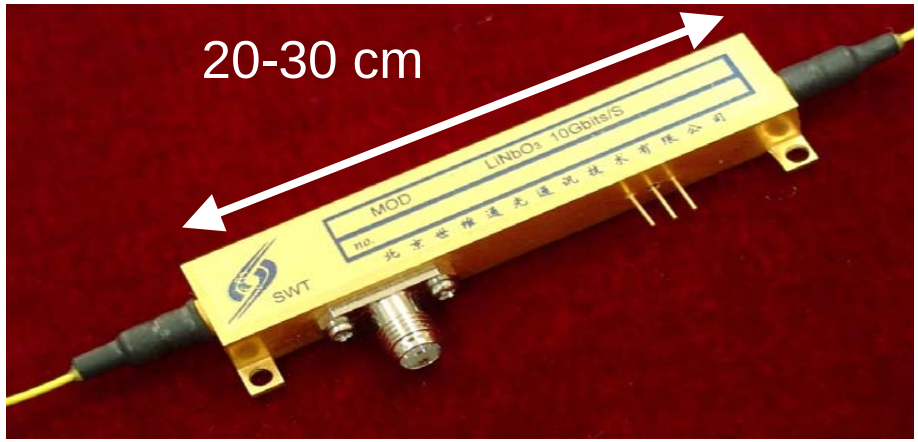


Mach Zehnder Interferometer

$$I_i = |E_o|^2 \qquad \phi_2 = 2\pi \frac{L}{\lambda}\left(n_e + \Delta n' \frac{V}{d}\right)$$



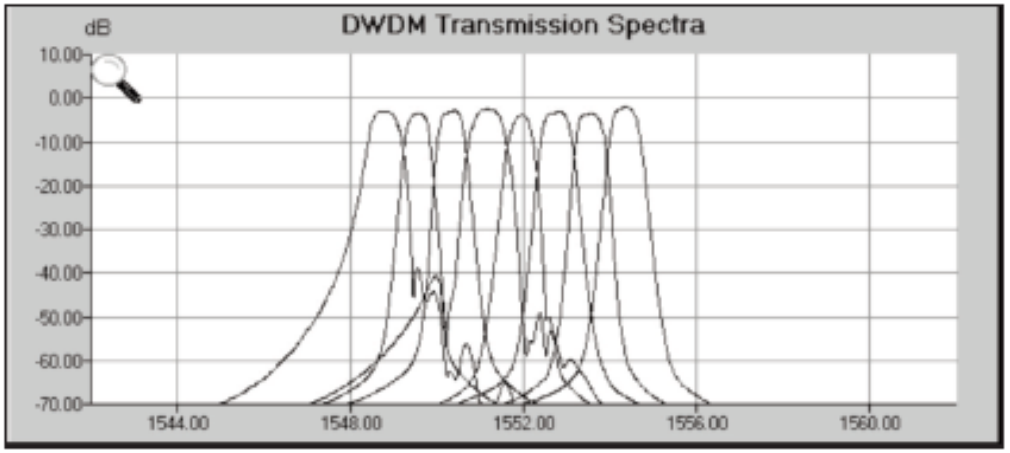
$$\phi_1 = 2\pi \frac{n_e L}{\lambda}$$

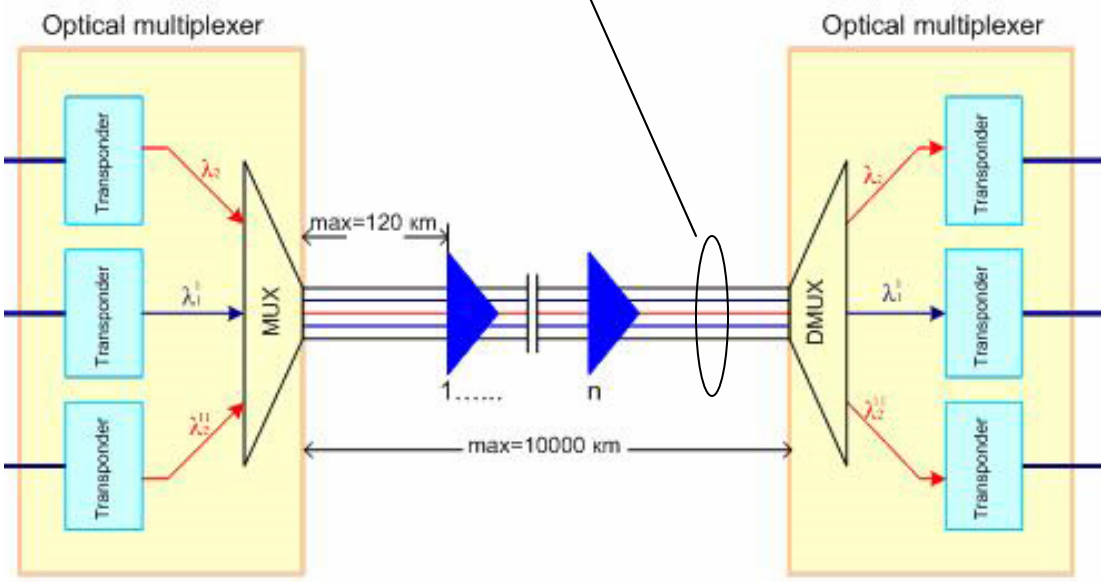


$$I_o = \left|\frac{E_o}{2} + \cos(\Delta n' \frac{V}{d})\frac{E_o}{2}\right|^2$$

Wavelength Division Multiplexing

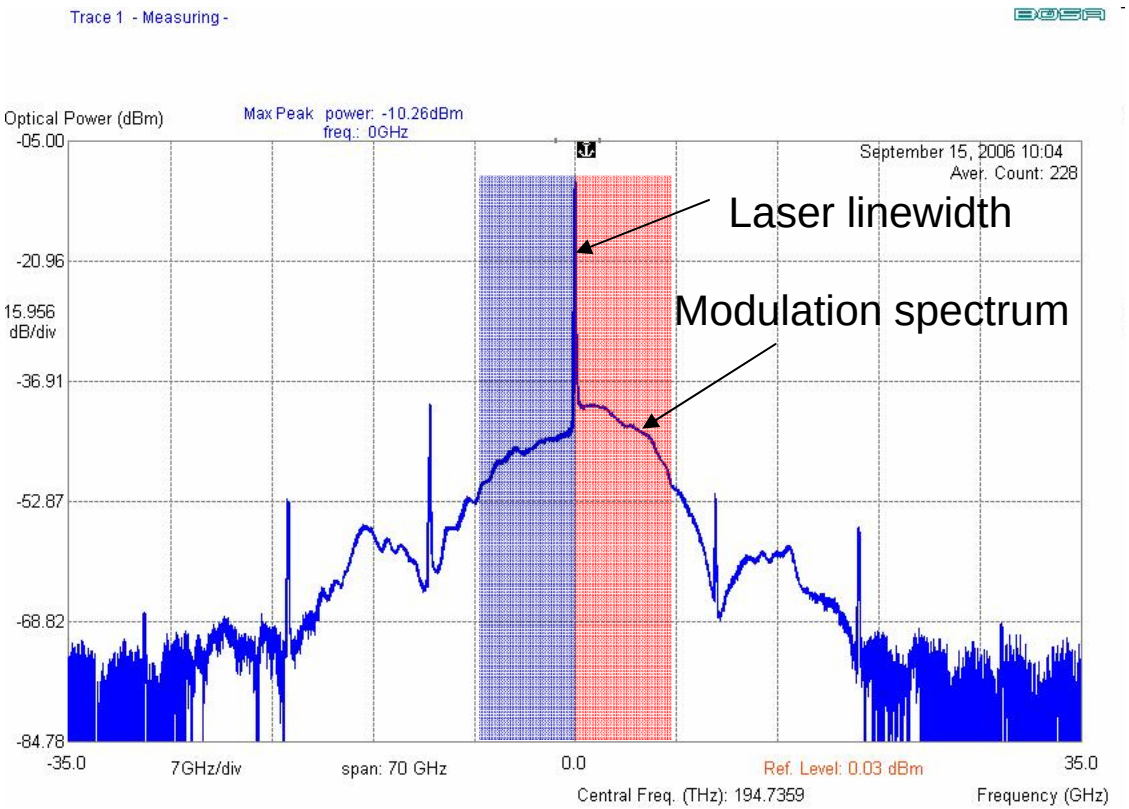
- Electronics is limited to 40 Gbps, but fiber bandwidth is 10 Tbps
- Also, maximize use of existing fiber
- Multiple channels are created by use of different optical wavelengths
  - ⇨ Typically 8 to 64 channels
- State-of-the-art demonstrated >1,600 Gbps over a single fiber





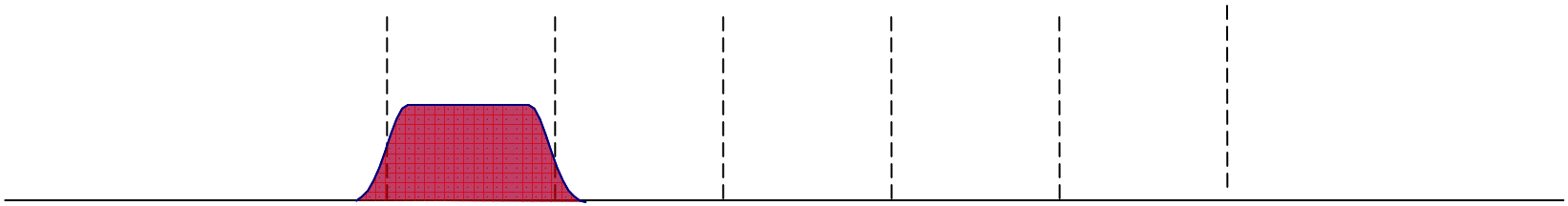
Laser emission spectrum

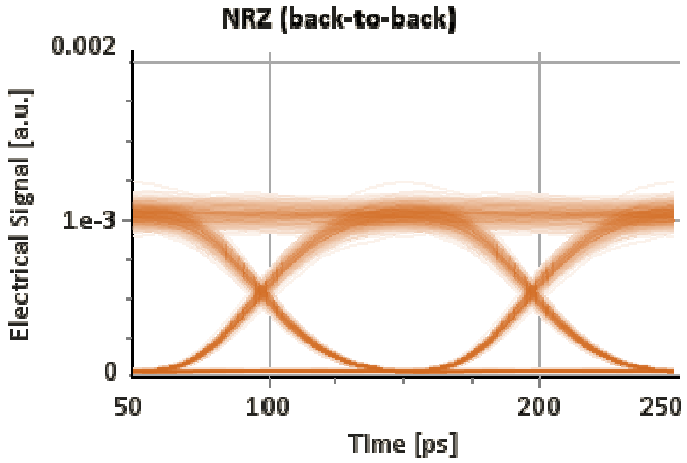
- Laser light is not perfect sine wave with zero spectral width
- Noise in laser produces approximately 0.1 to 0.2 nm wide “linewidth” (spectral width)
- Data modulation increases width of laser spectrum
- Final width of laser light can be 0.2 to 0.3 nm wide

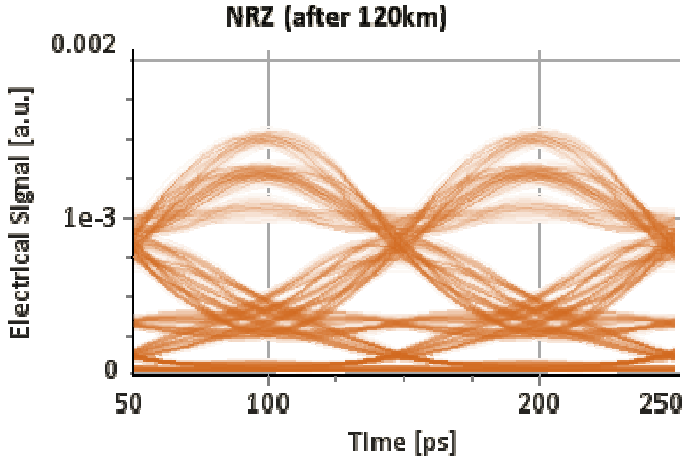


Group velocity dispersion

- Limitation on fiber transmission is not attenuation but group velocity dispersion (or “chromatic dispersion)
- Group velocity dispersion (GVD) - Speed of light at one wavelength is slightly different than another
- Spreading of optical pulse by GVD produces interference among neighboring data bits or “intersymbol interference” (ISI)

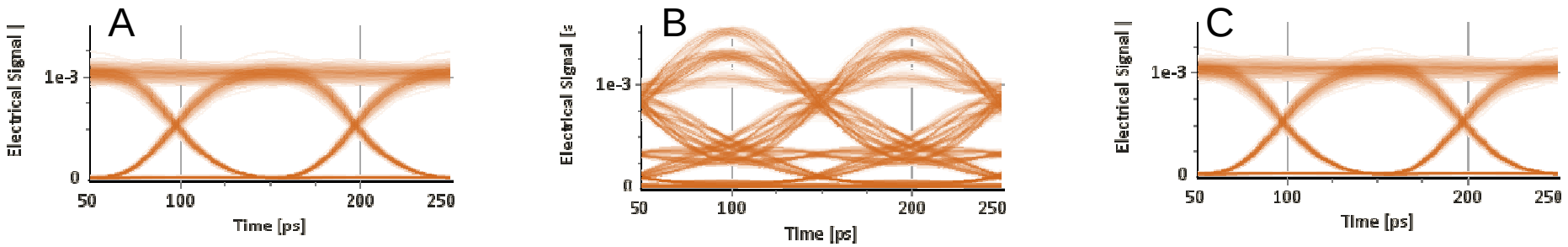


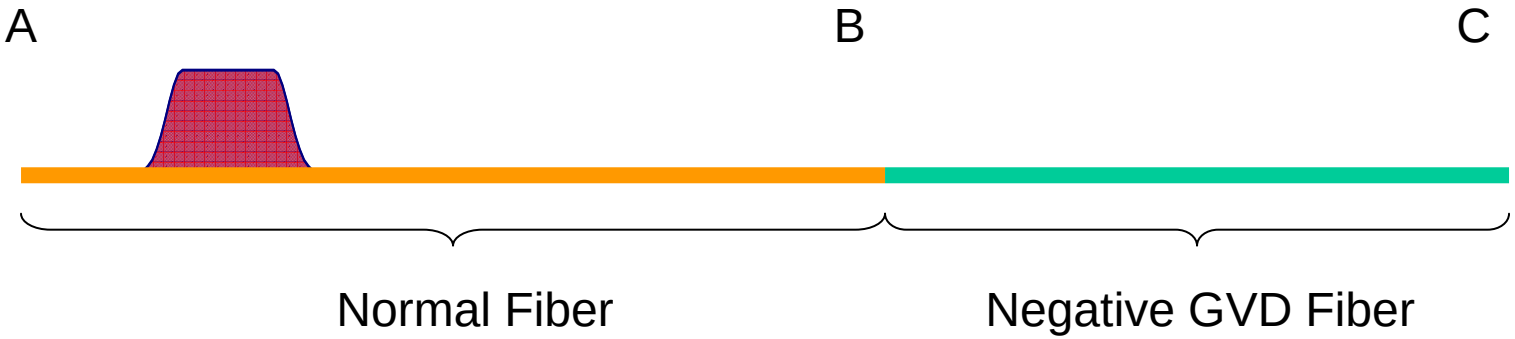




Chromatic dispersion compensation

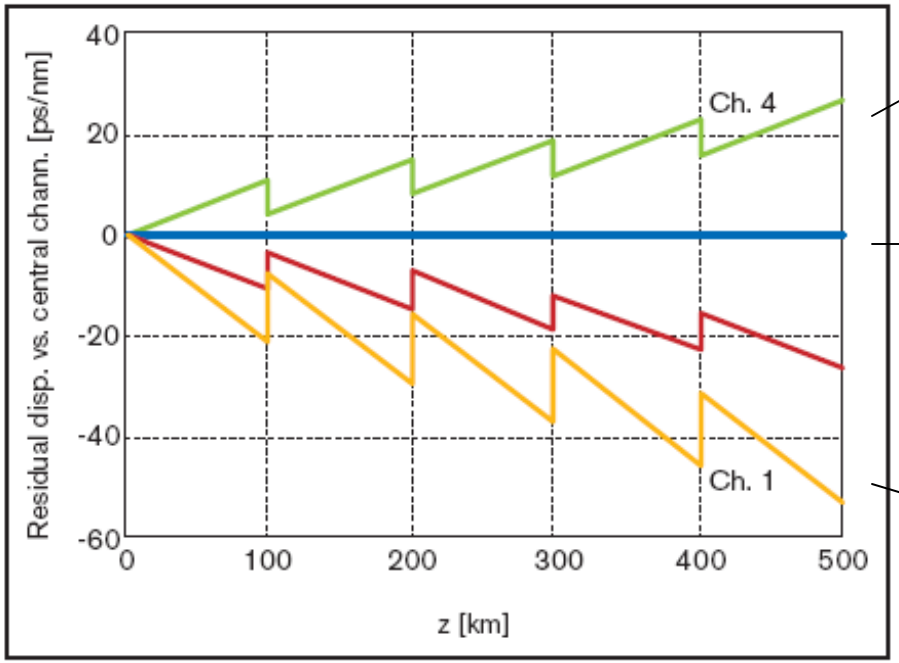
- Chromatic dispersion is linear effect and can be reversed
- Special dispersion compensating fiber has opposite GVD so that pulse spreading is reversed

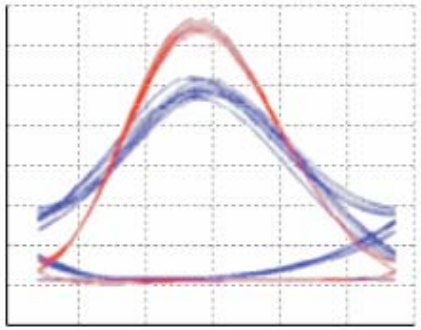


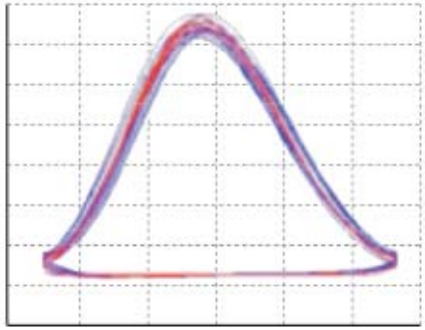


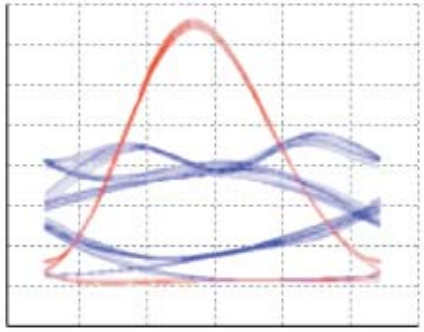
Chromatic Dispersion with Legacy Fiber

- At >10Gbps, GVD cannot be fixed perfectly at all wavelengths in old telecom fiber
- 1000's km of fiber already installed in and between US and Europe
  - ⇨ Too expensive to replace
- New modulations are being used to reduces ISI



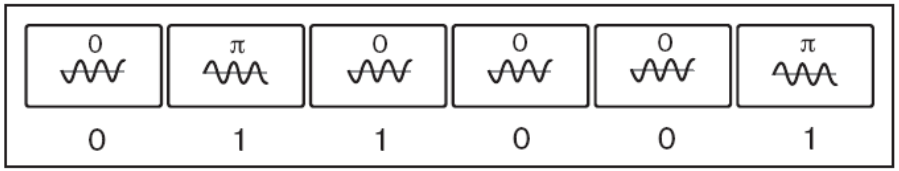




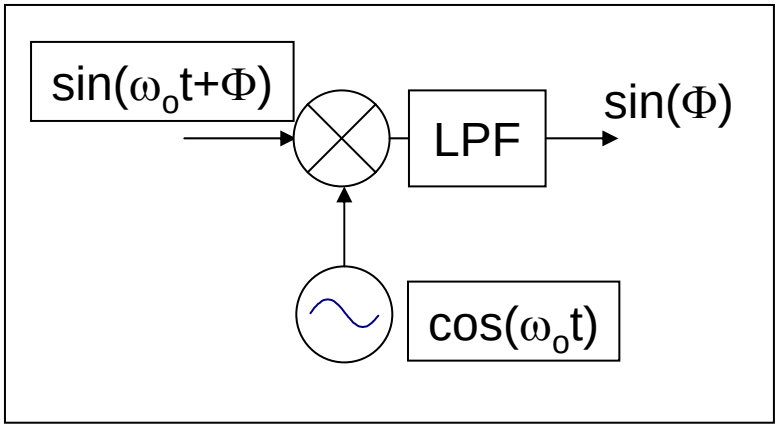


Differential Phase Shift Keying

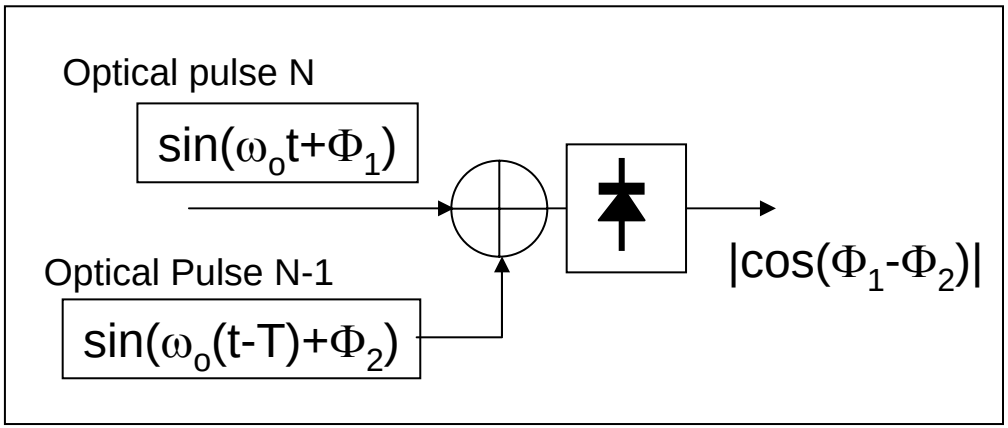
- Differential phase shift key (DPSK) is new solution for chromatic dispersion at 40 Gbps and beyond
- DPSK is less sensitivity to effects of chromatic dispersion
- Precise local oscillator is impossible with semiconductor laser so differential PSK is required
- DPSK has become commercial, DQPSK is being studied



Standard homodyne receiver



Optical delay interferometer receiver



Optical waveguide for non-Telecom use

- Better bandwith and thinner than RF copper cable
- Does not emit EM radiation or get interference between other electrical systems or radio signal (fading)
  - ⇨ Cellular and cordless phones
  - ⇨ Sensitive scientific instruments
  - ⇨ Solar activities
  - ⇨ High power lines
  - ⇨ Integrated circuits
- Difficult to intercept or block communication signals than radio links
  - ⇨ High security communication lines

Datacom Fiber Links

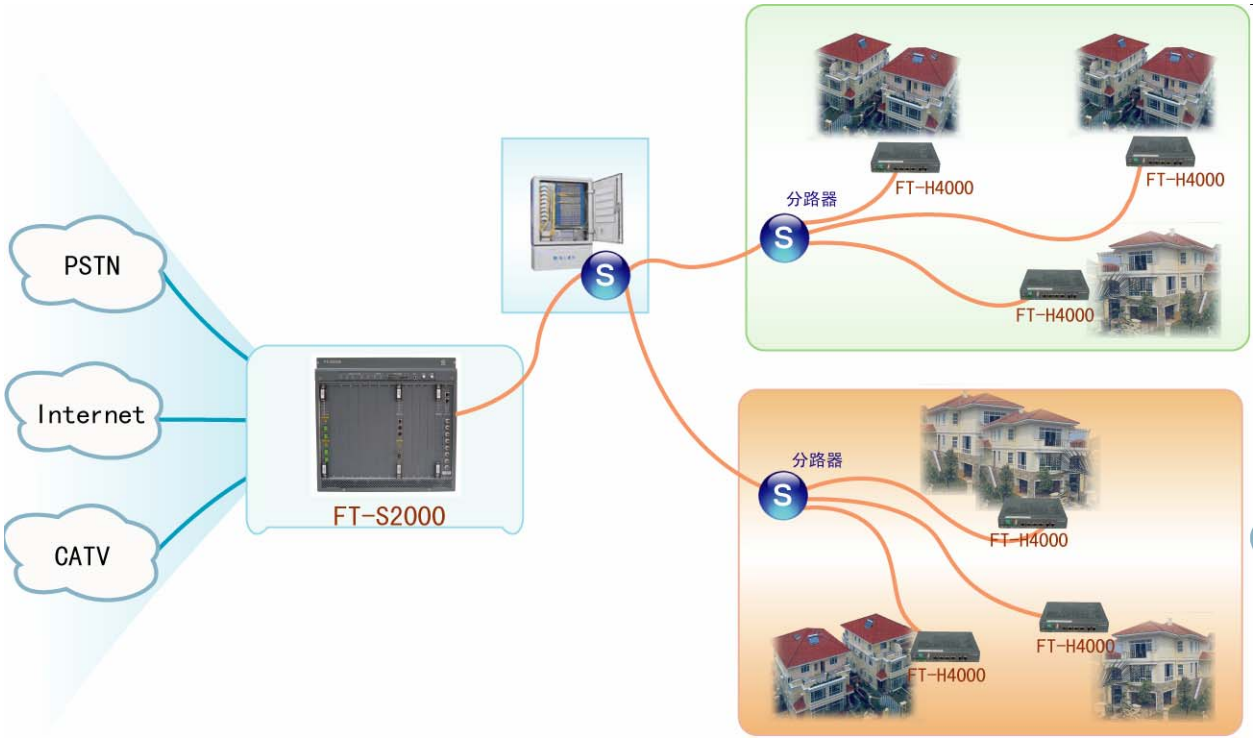
- Storage networks and supercomputing systems are requiring Tbps data rates
- Cost is more important than maximizing fiber bandwidth

MareNostrum (Barcelona) 62TFlops
About 5000 fiber cables
50 Tbps

MareNostrum central switch racks:
About 1700 fiber cables/rack today

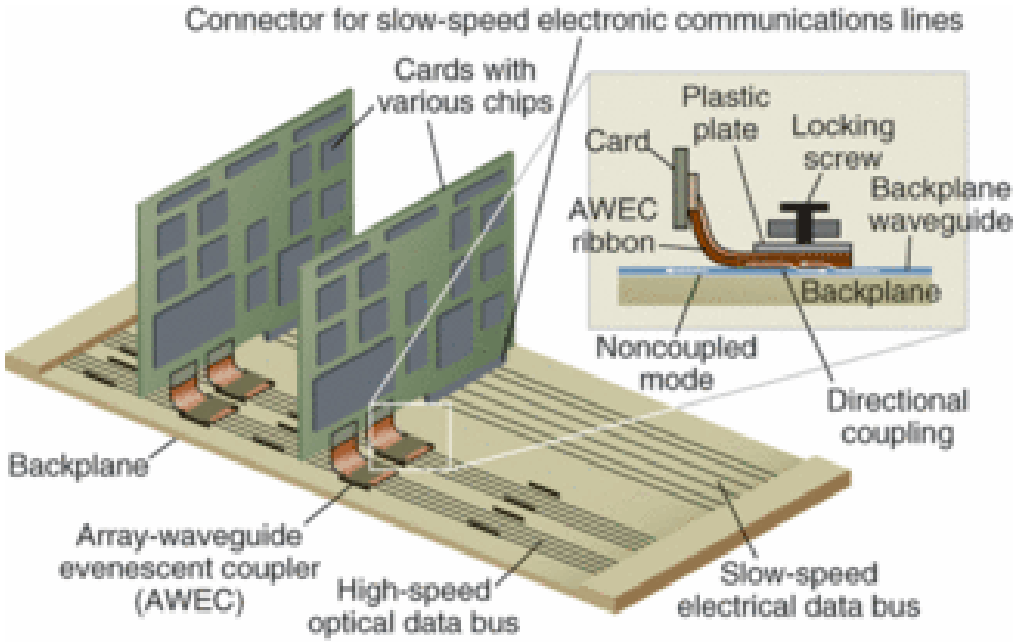
Fiber to the Home

- Europe, Asia and US are providing cable, telephone and 100 Mbps Internet service over single optical fiber
- High Definition TV (HDTV) and Video on Demand (VOD) over Internet
  - ⇨ US, Europe, Asia are transitioning to HD TV service which is higher quality than standard TV, but requires 6x more bandwidth
  - ⇨ Standard CATV copper cable cannot support additional bandwidth



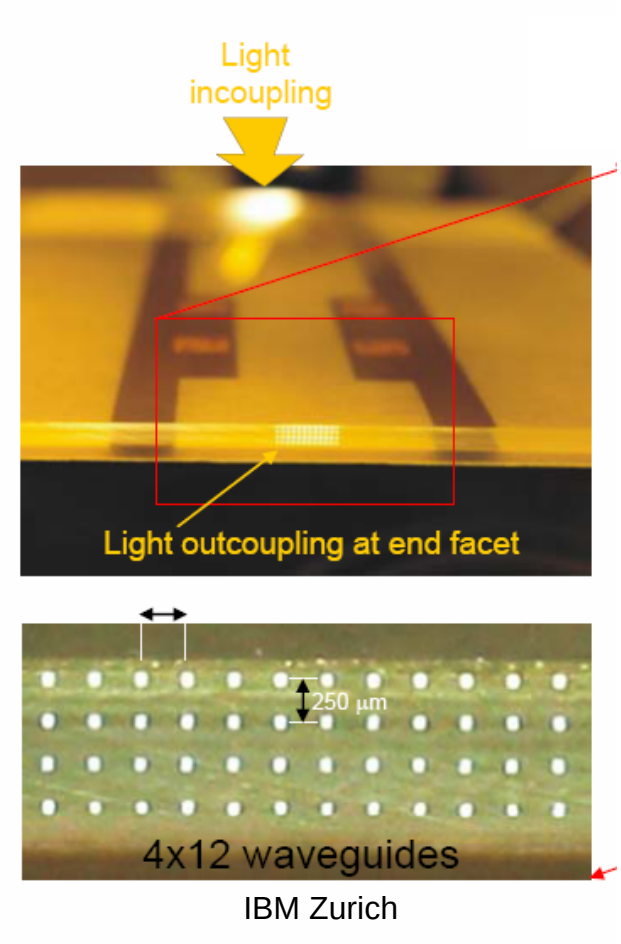
Optical backplane

- Network server require Tbps bandwidth from board to board
- Technology development underway to make optical backplane in network server

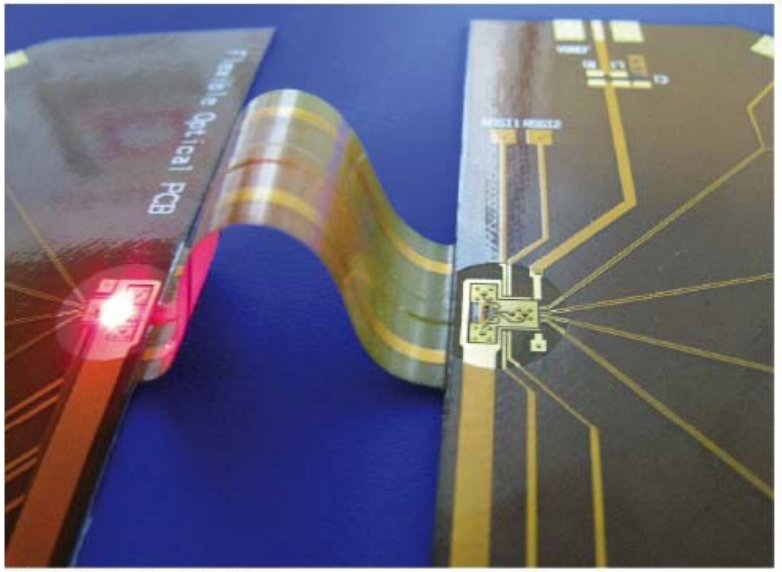


Embedded Optical Waveguides

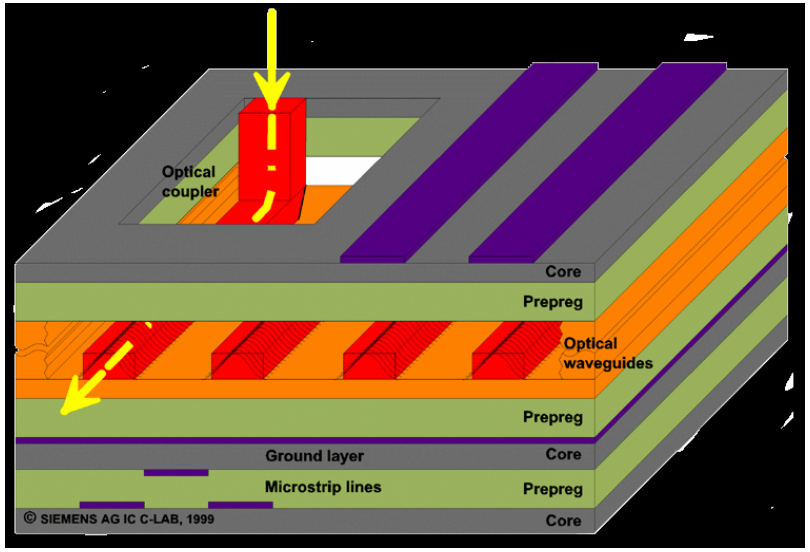
- Plastic optical waveguide fabricated into PCB layers for computers and mobile phones



IBM Zurich

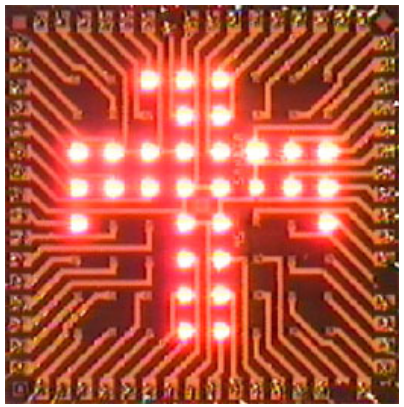


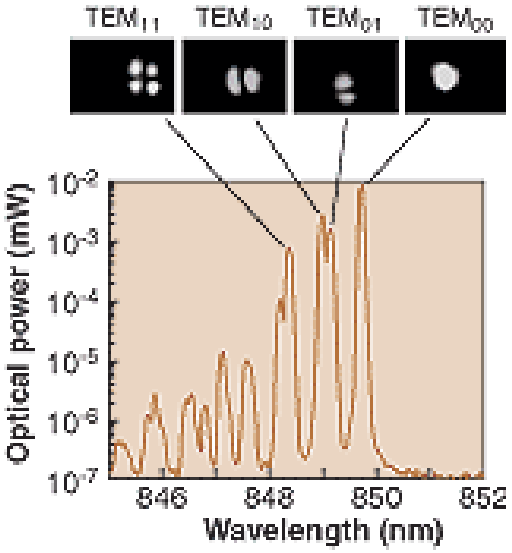
Flexible Optical PCB Korea Photonics Technology Institute

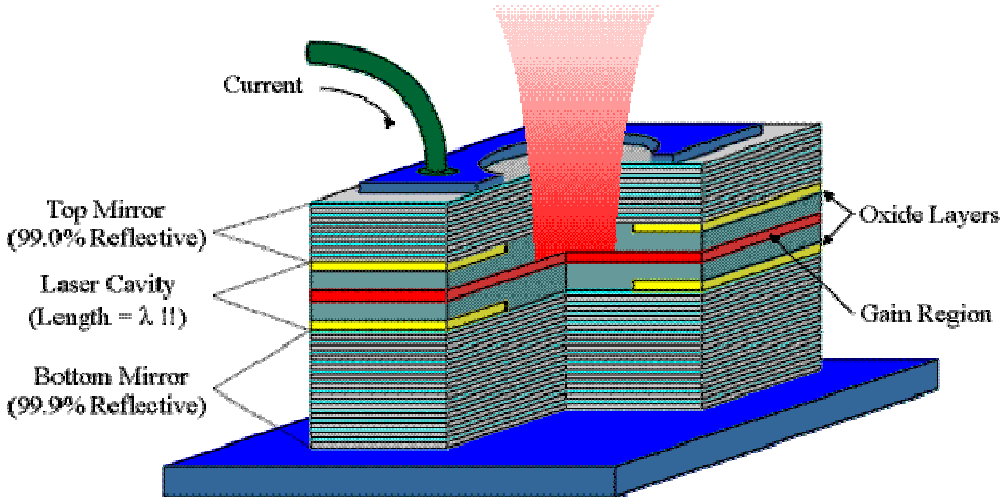


Vertical Cavity Surface Emitting Laser

- VCSELs are excellent for high-speed datacom optical links
- Commercial VCSEL can modulate at 10 Gbps
- Easier to fabricate compared to DFB laser diodes in large quantities

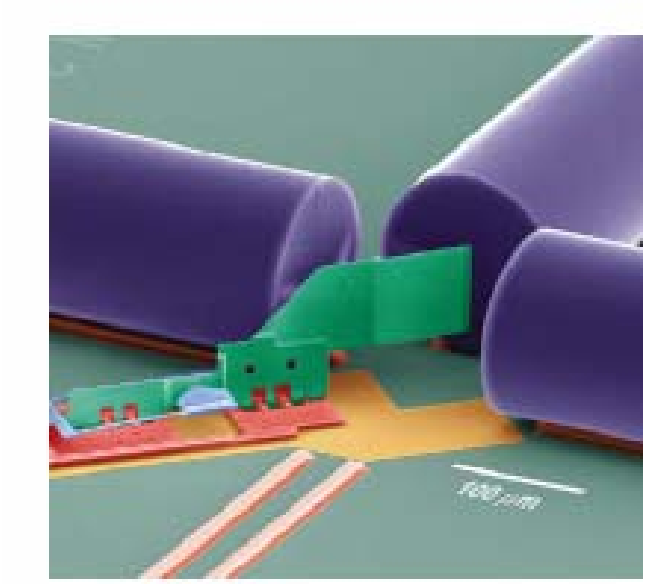


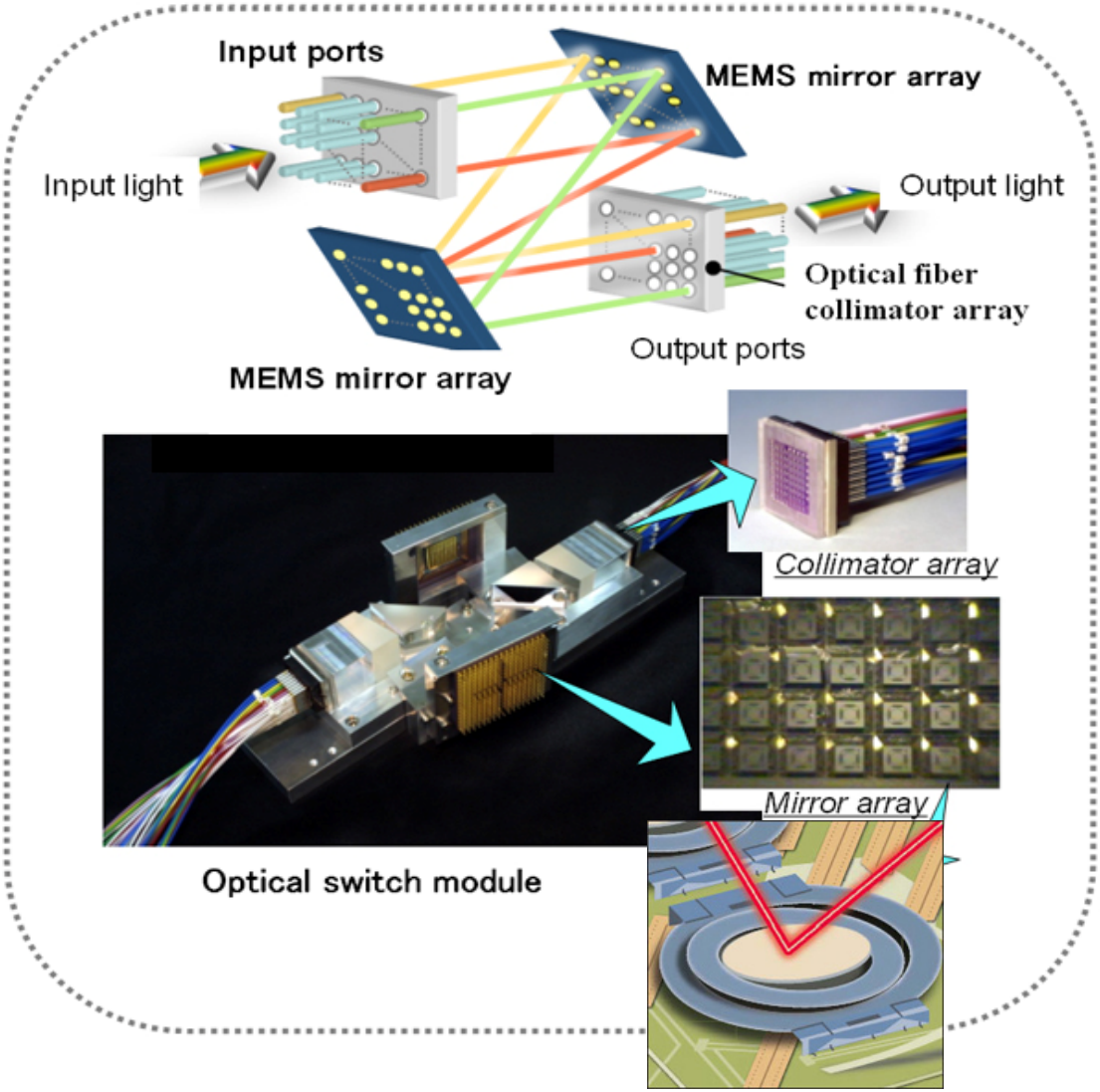




MEMS Optical Switch

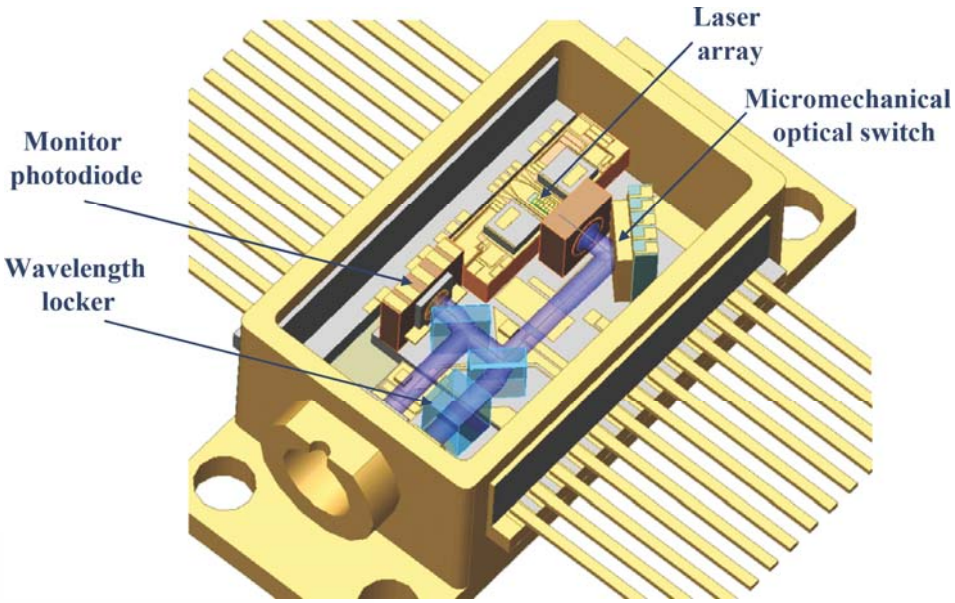
- Reroute optical signal from one fiber to another



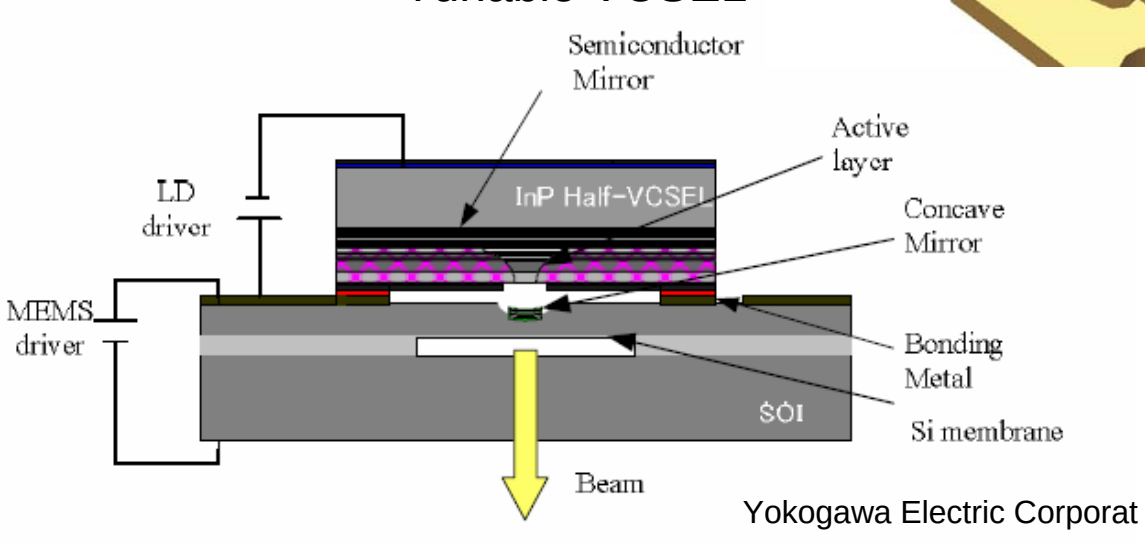


Tunable Lasers with MEMS

Tunable DFB



Tunable VCSEL



Yokogawa Electric Corporat

Silicon photonics

- Majority of optical devices are made of glass, glass arsenide (GaAs) and indium gallium arsenide (InGaAs)
  - ⇨ Silicon is limited to electric signal processing

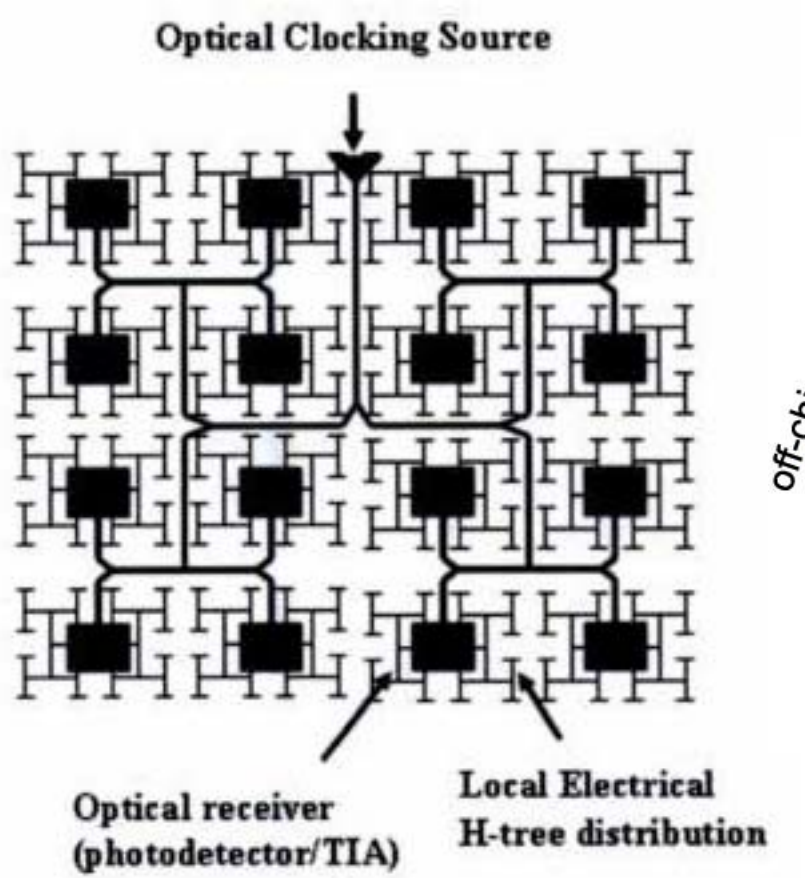
- "Holy Grail" of optical communication is silicon photonics

- Optics that is integrated on top of silicon IC to improve silicon electronic speed and performance
  - ⇨ Important for improved computer performance

- Optics made with silicon semiconductor to take advantage of low cost of silicon fabrication
  - ⇨ Silicon wafer processing is much more mature than InGaAs or GaAs
  - ⇨ Lasers
  - ⇨ Detectors
  - ⇨ Modulators

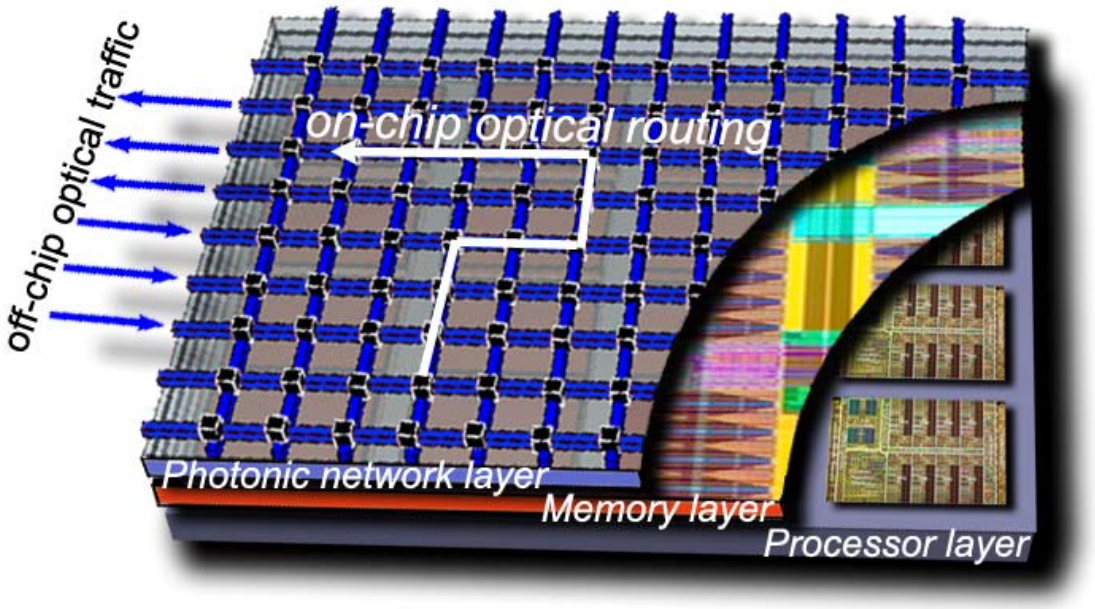
On-chip optical routing

- Parasitic capacitance and inductance of copper traces has become limiting factor in CPU speed
  - ⇨ Intel Pentium design cannot exceed 3-4GHz
- Electronic network layers does not interfere with photonic network layers



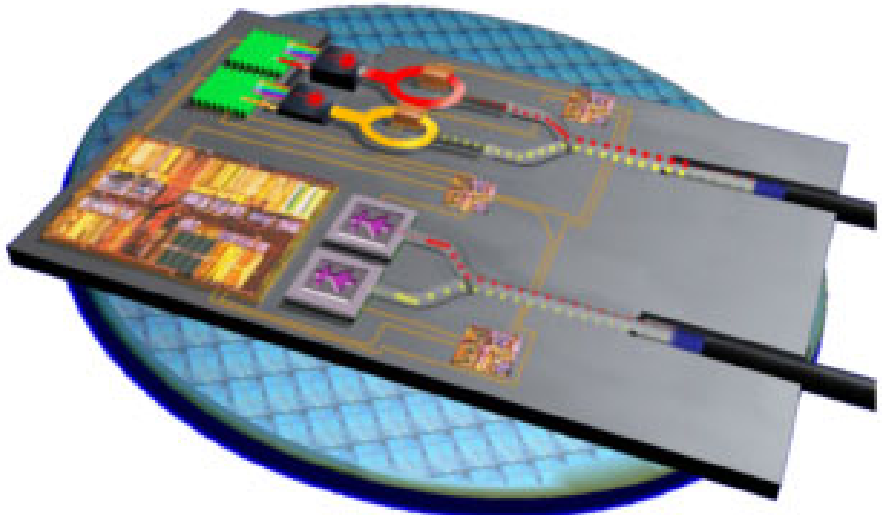
Silicon photonics by Lorenzo Pavesi, David J. Lockwood

IBM Whitepaper

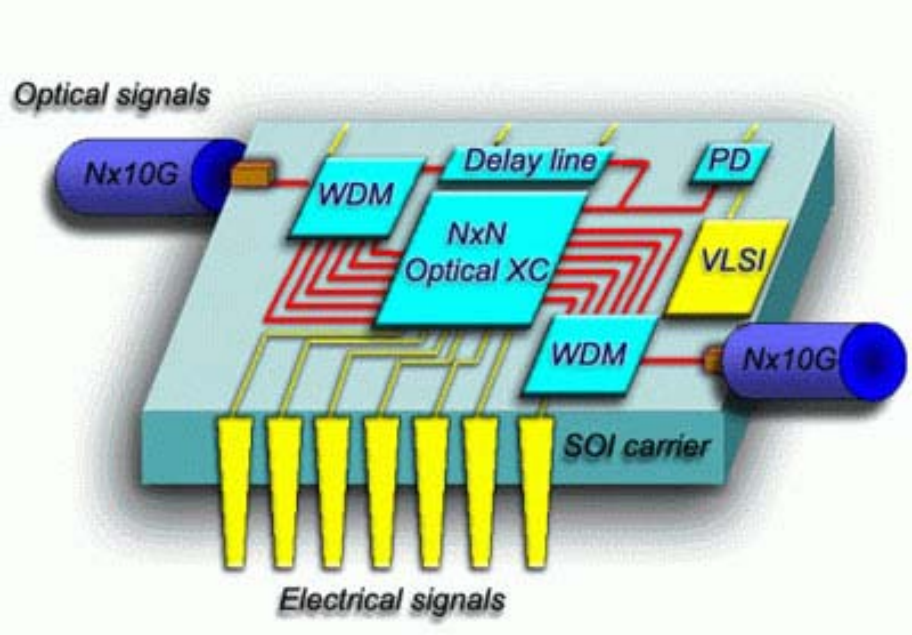


Silicon-based photonics

- Optoelectronics are 100x more expensive than silicon devices
  - ⇨ Primarily InGaAs and glass
- Current technology requires laser, modulator, photodiodes to be fabricated and packaged separately
- Silicon processing is much more advanced than InGaAs
- Integrated optics will bring cost down

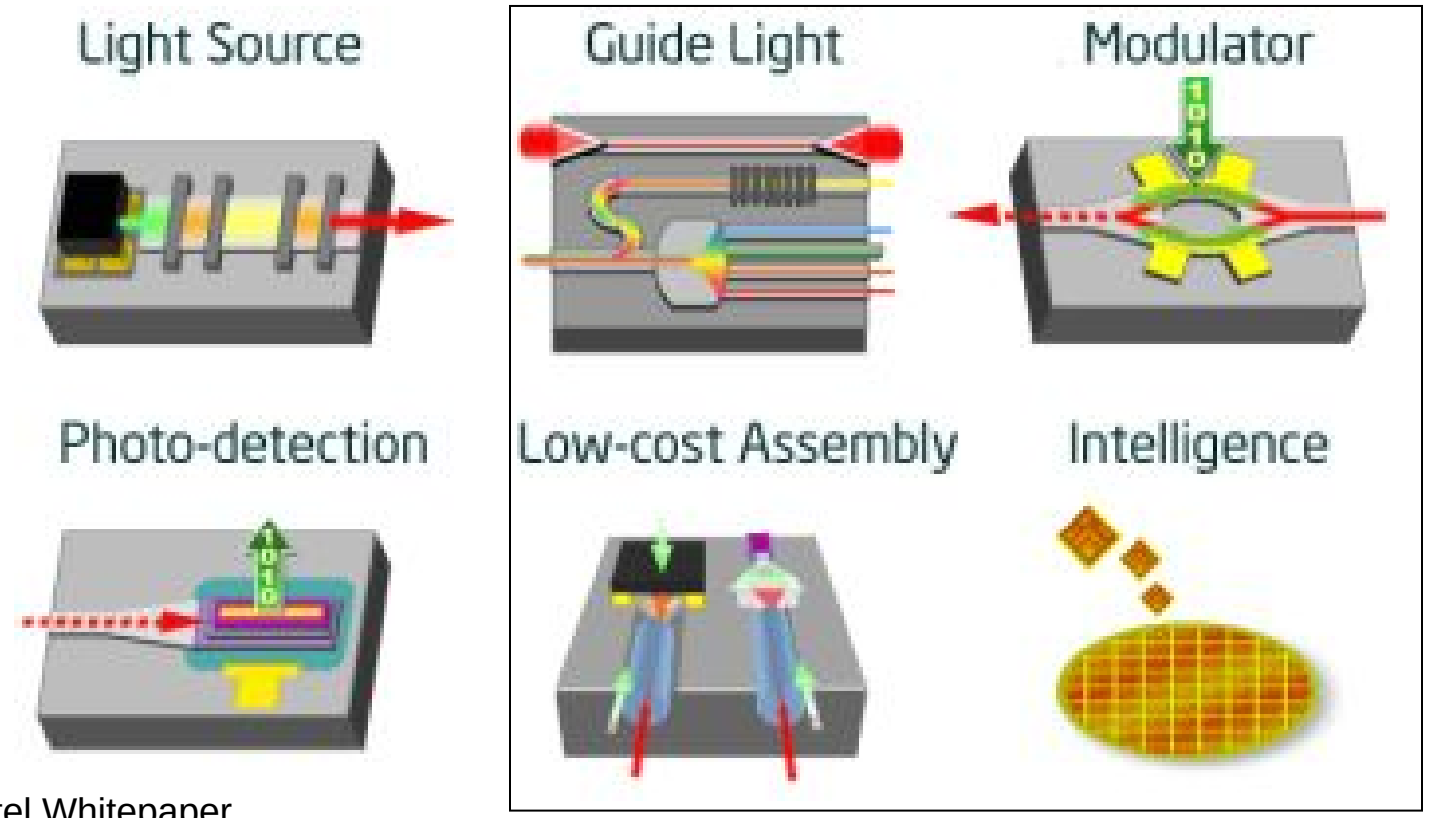


Intel Whitepaper



Intel's Vision of Silicon Photonics

- Silicon is inexpensive and easy to integrate with
- Silicon not ideally suited for high speed optical communications
  - ⇨ Indirect bandgap of silicon is bad for lasers
  - ⇨ Silicon PD is too slow and wrong wavelength for telecomm



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Conclusion

- New world economy is dependent on delivery and processing of vast amounts of information
  - ⇨ Business
  - ⇨ Governments
- Future of wired communication is fiber optics
  - ⇨ Transcontinental
  - ⇨ Intercontinental
  - ⇨ Computer to Computer
  - ⇨ Chip-to-Chip
- Wireless communication also depends on fiber optics
  - ⇨ Central office to core network
- High performance computing will rely on optical communications
  - ⇨ Improve microprocessor performance
  - ⇨ Increase supercomputing capabilities to study science, medicine, economy, energy, environment, etc.