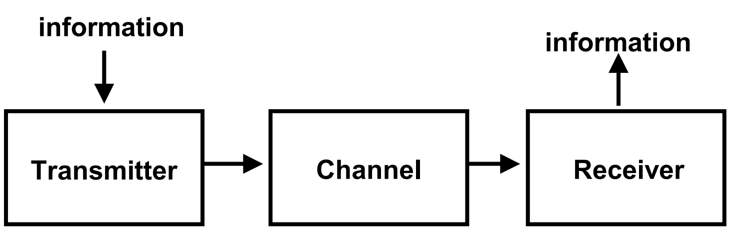
Introduction to Integrated Photonic Devices

- Class: Integrated Photonic Devices
- Time: Wed. 1:10pm ~ 3:00pm.
  Fri. 10:10am ~ 11:00am
- Classroom: 資電106
- Lecturer: Prof. 李明昌(Ming-Chang Lee)

Block Diagram of a Communication System



- **Transmitter:** A device converts the information into a suitable signal transmitting in channels.
- **Channel:** A medium bridges the distance between the transmitter and receiver. (EM wave →air, electronic signal →wire or cable, optical wave → fiber).
- **Receiver:** A device extracts weaken signal from the channel and amplifies it. The signal eventually is converted to its original information.

Three Mileage Stones in Developing Optical Communication

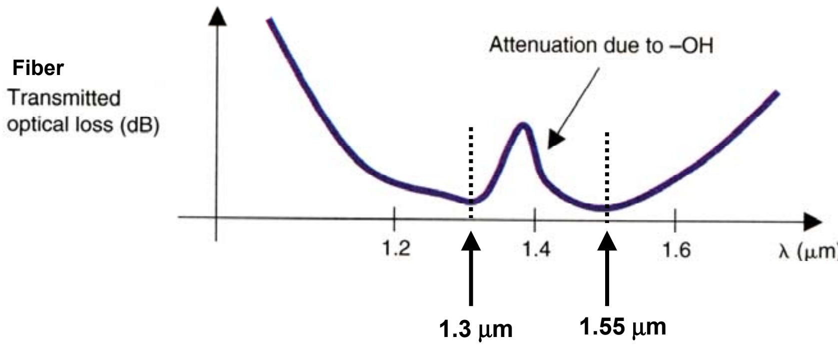
- Laser (optical source) --- 1960s
  - From gas laser to semiconductor laser (diode laser, hetero-junction laser,…)
- Low-Loss optical fiber --- 1980s
  - 1000dB/km → 20dB/km → 0.2dB/km
- Semiconductor manufacturing --- 1990s ~
  - Silicon, III-V, II-VI, silica,…
  - Integrated optical devices

Advantage of Optical Interconnect

- Immunity from electromagnetic interference (EMI)
- Safety in combustible environments
- Security from monitoring
- Large bandwidth
- Low-loss transmission
- Small size, light weight
- Inexpensive
- Major disadvantage: difficult to use for electrical power transmission

Optical Communication Wavelength

Stamatios V. Kartalopoulos,



- **What is the capacity of optical communication?**

Speed of light

$$\Delta f = \frac{c}{\lambda^2}\Delta\lambda$$

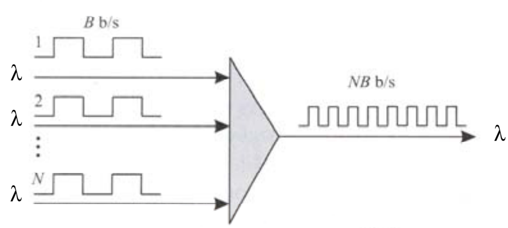
Suppose $\Delta\lambda$ is 0.05 µm, the bandwidth is

$\boxed{\text{6.24 THz}}$ (much higher than electronic device)

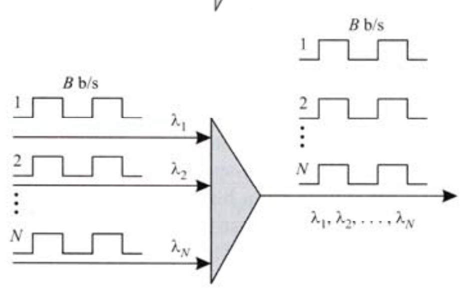
Multiplexing Techniques

To fully utilize the bandwidth, two multiplexing techniques are developed.

OTDM: Optical Time Division Multiplexing

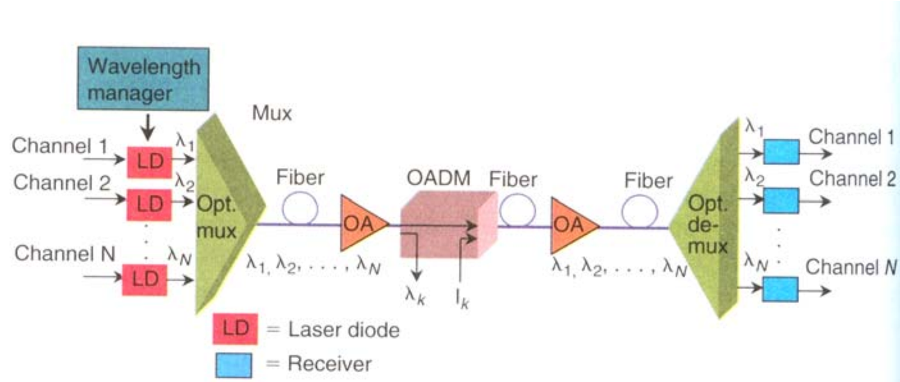


WDM: Wavelength Division Multiplexing



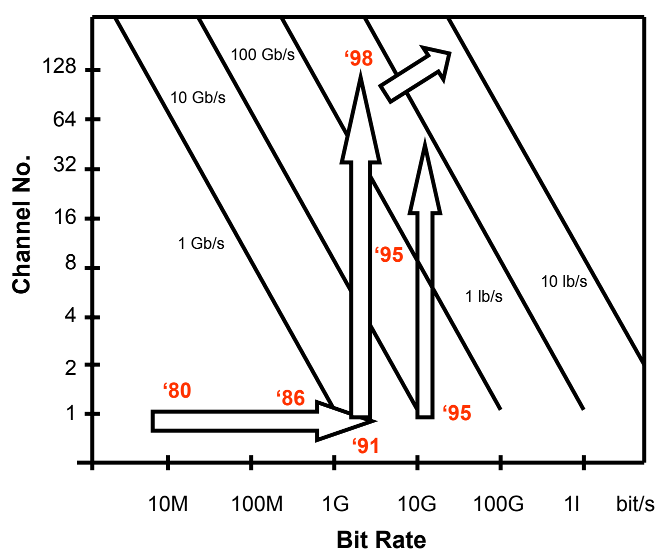
Rajiv Ramaswami, “Optical Networks”

A DWDM Point-to-Point Optical Link

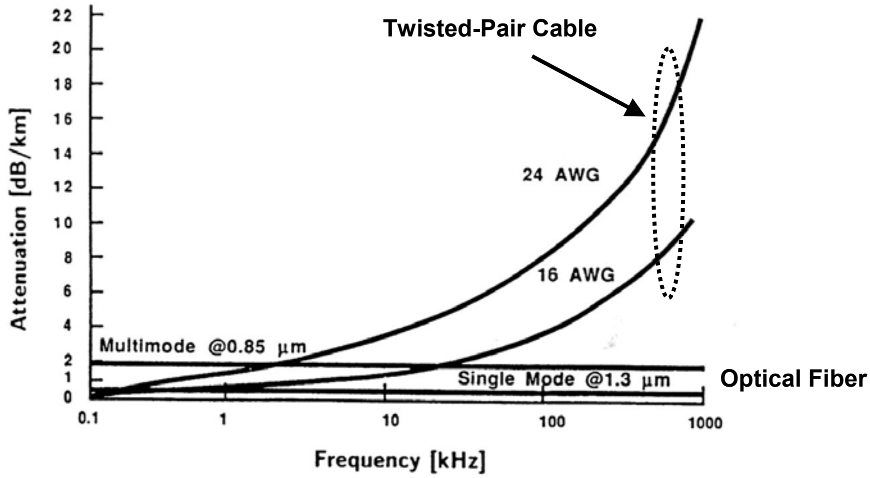


- **Laser diode, Reciver, Optical Mux/Demux, Optical amplifier, …**

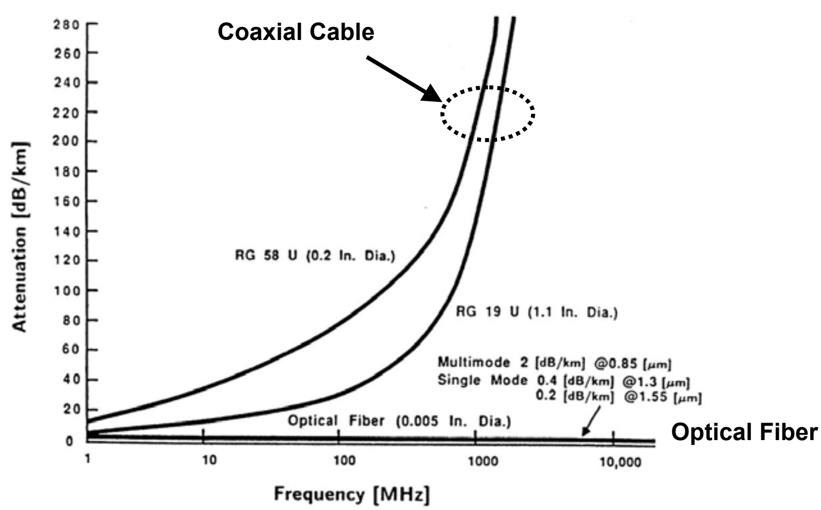
Per-Fiber Capacity Trends



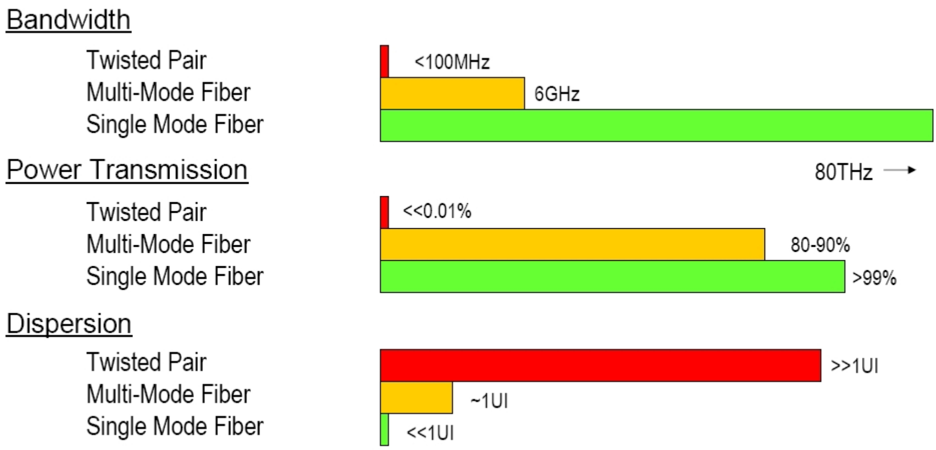
Optical Fiber vs. Twisted-Pair Cable



Optical Fiber vs. Coaxial Cable



Benchmark between Optical Fibers and Twisted-Pair Cable



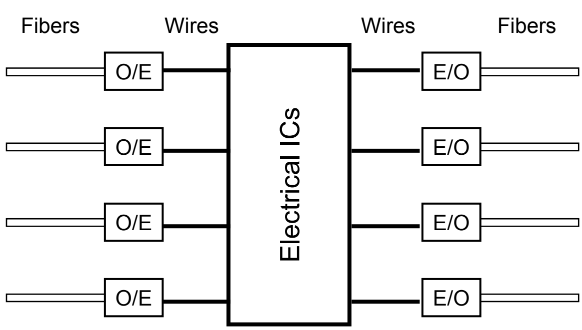
Source: Luxtera Inc.

- **Singlemode fibers have unlimited capacity, low loss and low dispersion**

Optical Signal Processing

- **With the development of network communication, the transmitted signals need further processed such as switching, add-drop multiplexing, …**

I. Processing in electronic domain



Switching, Add-drop Multiplexing
Wavelength Conversion, Signal Reshaping…

Optical Signal Processing

II. Processing in optical domain (discrete component)

De-multiplexer

2×2 switch

Attanuator

Thorlab Ltd.

Isolator

Summary of Components in Optical Integrated Circuits

- Passive components --- linear optics
  - Waveguides/Couplers
  - Switches (optical interconnect, wavelength selective switches)
  - Filters (add-drop filters, MUX/DEMUX)
  - Dispersion compensators (chromatic dispersion, polarization dispersion)
  - Attenuator
  - Gain equalizer
  - Isolators/Circulators

Summary of Components in Optical Integrated Circuits

- **Active components --- optoelectronics, nonlinear optics**
  - Amplifiers
  - Lasers
  - LED
  - Modulators
  - Detectors
  - Wavelength converters

Passive vs. Active

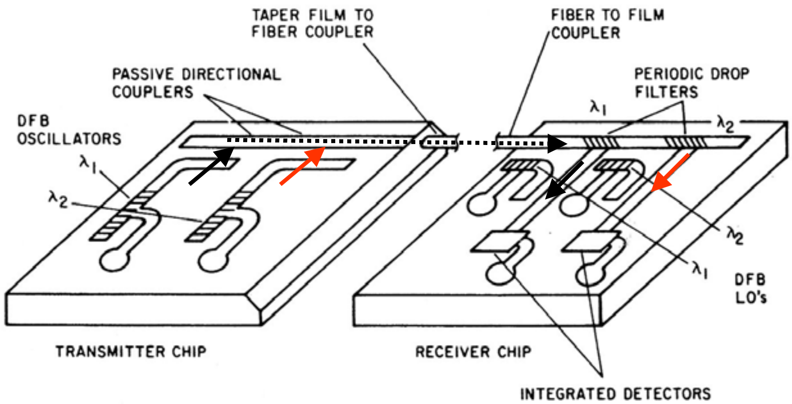
Passive Materials

- Quartz (SiO_2)
- Lithium Niobate ($LiNbO_3$)
- Lithium Tantalate ($LiTaO_3$)
- Tantalum Pentoxide
- Niobium Pentoxide
- Silicon
- Polymers

Active Materials (light source)

- Gallium Arsenide (GaAs)
- Gallium Aluminum Arsenide (GaAlAs)
- Gallium Arsenide Phosphide (GaAsP)
- Gallium Indium Arsenide (GaInAs)
- Gallium Indium Arsenide (GaInAs)
- Other Compound III-V and II-VI

Monolithic Integrated Optical Communication System



- The signals are processed in optical domain
- All the optical components are integrated on a single chip

Evaluations of Optical Integrated Circuits

Advantage

- Compared with electrical ICs
  - Increased bandwidth
  - WDM
  - Could be low power consumption
  - Data transparent
- Compared with discrete optical components
  - Batch fabrication economy
  - Smaller size
  - Improved optical alignment
  - Immunity to vibration
  - Low power consumption

Disadvantage

- High cost of developing new fabrication technology

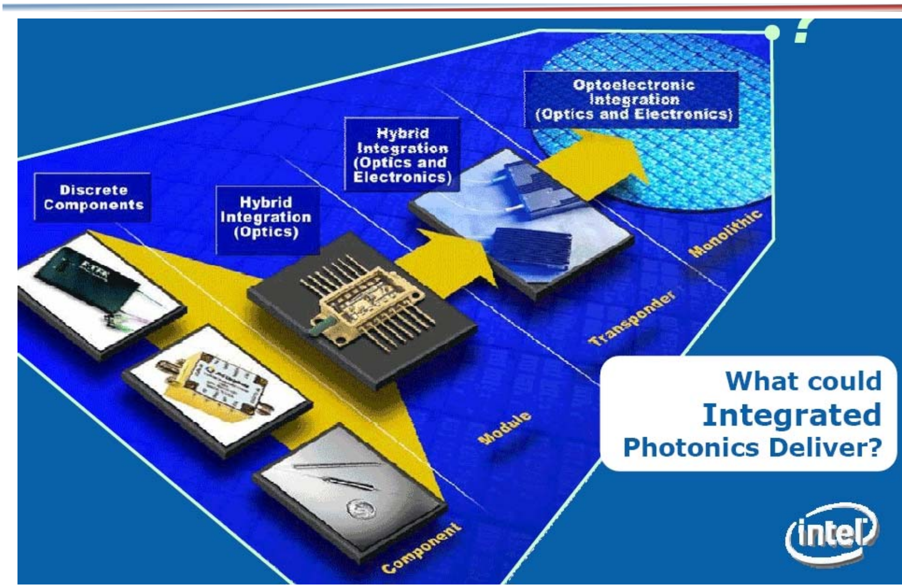
Hybrid and Monolithic Integration

Hybrid: Combination of different OICs substrates (active and passive components/materials)

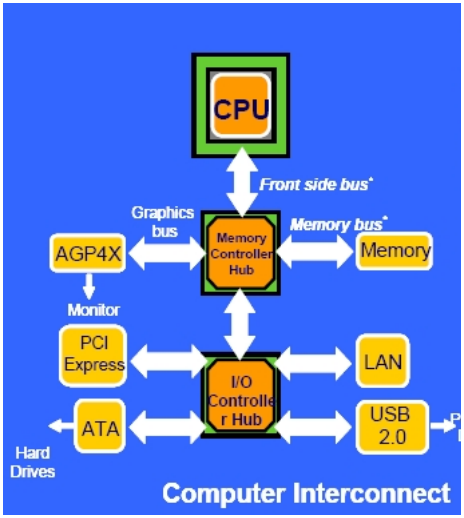
Monolithic Integration: Integration of different OICs on a single substrate

	Hybrid	Monolithic Integration
Pros	• Well-developed Fabrication • Reliability of each component	• Compactness • Self-alignment, Immunity to vibration • Cost reduction
Cons	• Assembly or Packaging • Alignment	• Challenging to fabrication

Roadmap of Optoelectronic Integrated Circuits



Integrated Photonics: Short-Distance Optical Interconnect

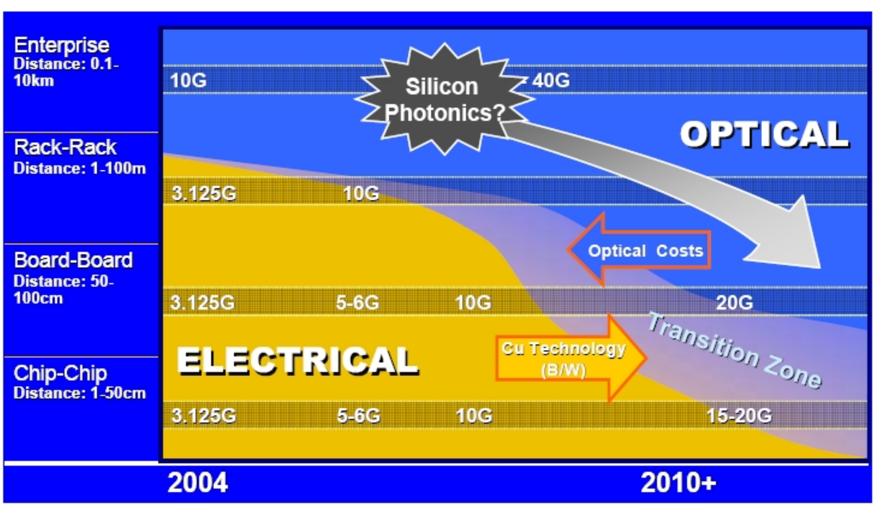


Source: Intel

- Process power will be divided into several processing units --- CPU, graphic processor, memory controller, math processor, etc.
- Each processing unit requires large bandwidth for connection
  - 1-Tflop CPU requires 1000Gb/s bandwidth
  - 1 graphic processor requires 80Gb/s
- Issue:
  - Loss in copper wires
  - Heat dissipation due to high speed clock

PC interconnect speed should keep with the number of transistors

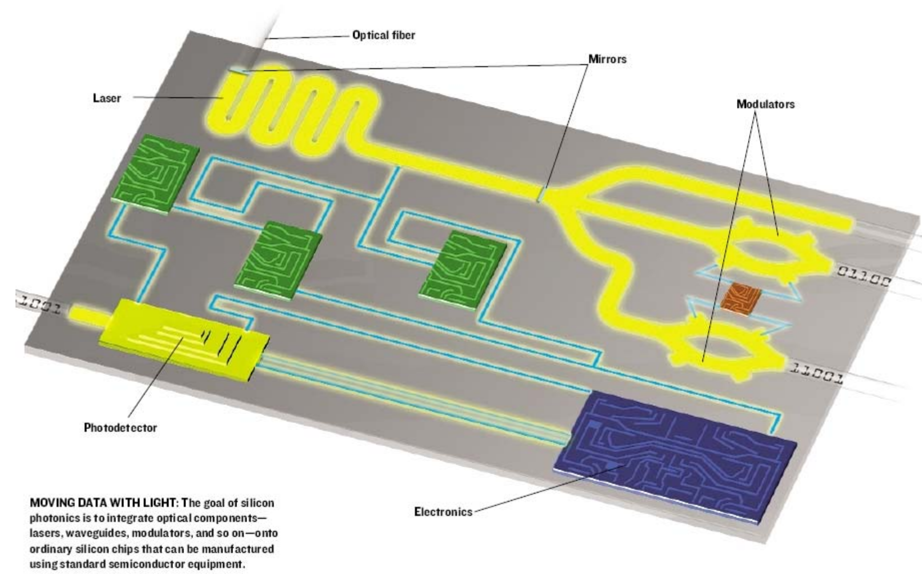
Market Transition from Electrical to Optical



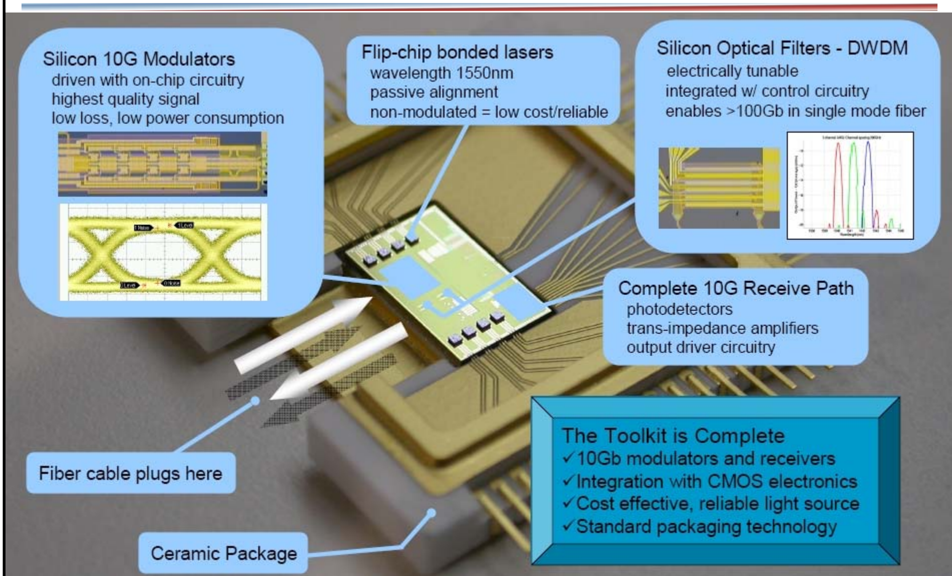
The upper limit of copper connection (electrical): Source: Intel

10-40 Gb/s for PC board material at < 1m distance

Intel Proposed Silicon Photonics

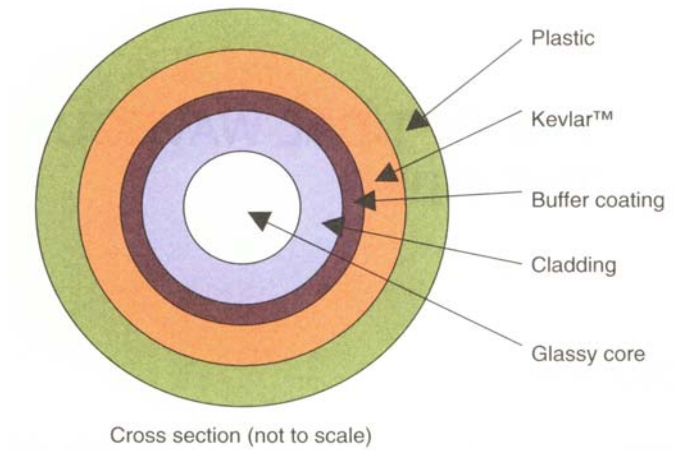


Commercialized CMOS Optical Transceivers --- Luxtera Inc.



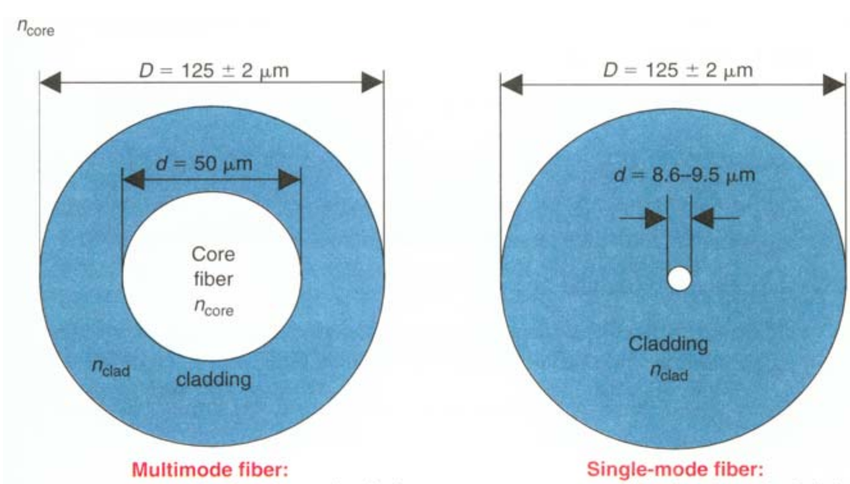
Source: Luxtera Inc.

Fiber Structure



Stamatios V. Kartalopoulos," Introduction to DWDM Technology

Fiber Dimension



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