


AN OVERVIEW OF OPTICAL FIBER FUNDAMENTALS

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IDEAL CABLES

- ▶ A cable is the path (channel) between the transmitter and the receiver.
 - ▶ An ideal cable should have:
 - ▶ Minimal Attenuation
 - ▶ Broad Frequency Response
 - ▶ Minimal Dispersion
 - ▶ Minimal Latency
 - ▶ Favorable Physical Properties
 - ▶ Predictable
 - ▶ Repeatable
 - ▶ Consistent
 - ▶ Universal
 - ▶ Reasonable Cost
- 
- A series of three parallel white diagonal lines extending from the bottom right towards the top right of the slide.

BASIC DEFINITIONS

▶ Optical Fiber

- ▶ Glass filament of coaxial construction that conducts light via total internal reflection

▶ Core

- ▶ The center, the axial part of an optical fiber serves as the light transmission area of the fiber. The core has an index of refraction greater than the surrounding cladding.

▶ Cladding

- ▶ Glass surrounding the core of an optical fiber that has an index of refraction less than the core

▶ Total Internal Reflection

- ▶ When the outer medium has a lower index of refraction than the core, a distinct angle exists for which no light is refracted. Light is completely reflected back into the core material. Maximum light can be transmitted through the light guide only if total internal reflection occurs at the core-cladding interface.

▶ Single Mode Fiber (SMF)

- ▶ SMF allows for only one pathway, or mode, of light to travel within the fiber. The core size is typically $8.3\text{ }\mu\text{m}$. Usually used for long distances.

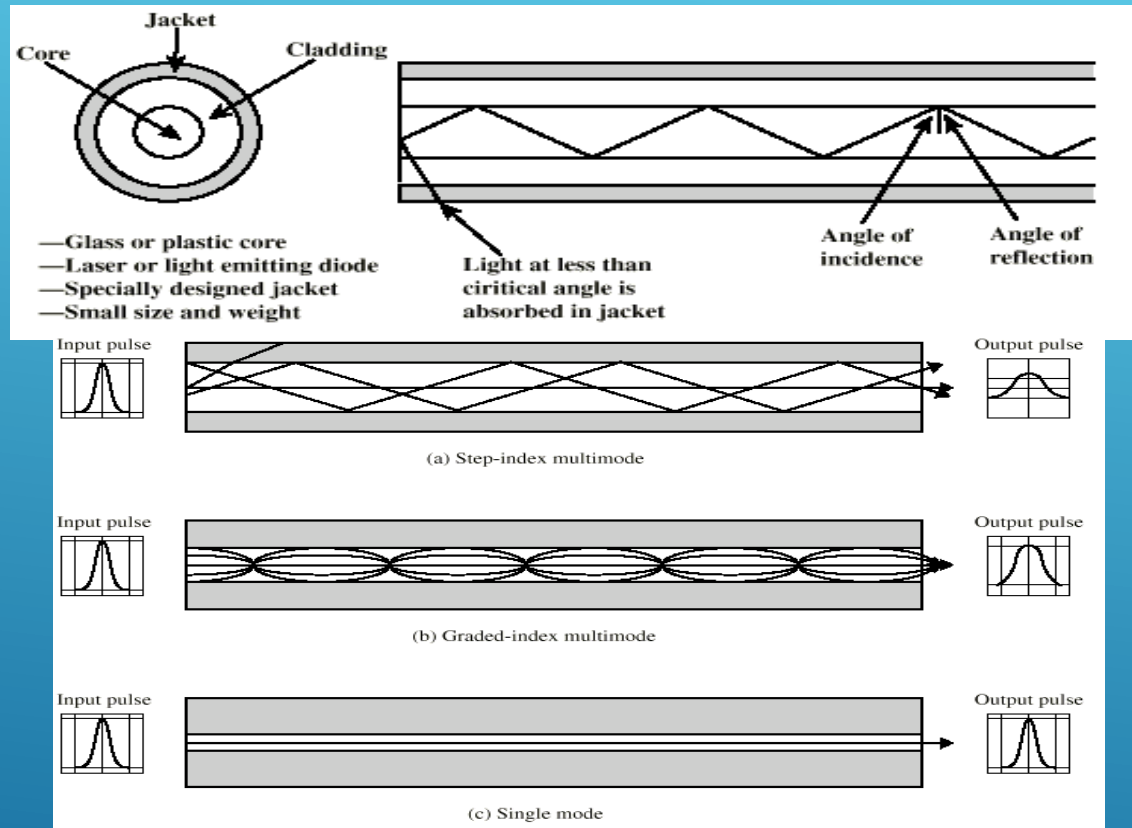
▶ Multimode Mode Fiber (MMF)

- ▶ MMF allows more than one mode of light. Common MM core sizes are $50\text{ }\mu\text{m}$ and $62.5\text{ }\mu\text{m}$. Multimode fiber is better suited for shorter distances.

Practical Concerns

- The primary cost of most optical networks is the optical interfaces; NOT the cables.
- A MMF network is more economical because it can be used with inexpensive connectors and LED transmitters, making the total system cost lower.
- This makes MMF fiber a better choice for shorter distance applications such as within a data center.
- A SMF network requires more expensive transmitters and receivers to couple light within the small core area.
- SMF is typically used in carrier networks and supports distances of 40 km.

FIBER TYPES



- ▶ For **step index multimode fibers**, the index of refraction is constant within the core and constant within the cladding. Step index fibers have a constant index profile over the entire cross section.
- ▶ **Graded index multimode fibers** have a non-linear, rotationally symmetric index profile, which falls off from the center of the fiber outwards. The index of refraction is reduced from the middle outwards. The rays travel in a spiral form around the optical axis.
- ▶ **Single mode fibers** support one confined transverse mode in which light propagates inside the fiber.

Clad fibers are an absolute necessity for transmitting light over long distance. If cladding were not used, the environment (atmosphere, gases, dirt) would be the cladding material. Absorption would drastically reduce the transmitted luminous flux. For total internal reflection, a portion of the energy in the electric field penetrates the cladding and is known as the evanescence field. Typically the penetration depth is 5 times the respective wavelength. Cladding material requires high optical performance because a significant portion of the energy is transmitted in it.

FIBER PERFORMANCE MEASURES

► Dispersion

- Modal – core radius $\gg \lambda$
 - Measured in MHz – km at a specific transmission λ
 - Function of Δ between longest & shortest guided light path (typical good quality, 2000 Mhz-km for MMF)
 - Note: SMF does NOT exhibit modal dispersion

► Chromatic

- Different spectral components of a transmitted pulse travel at different velocities (function of transmitter)

► Attenuation (dB per km)

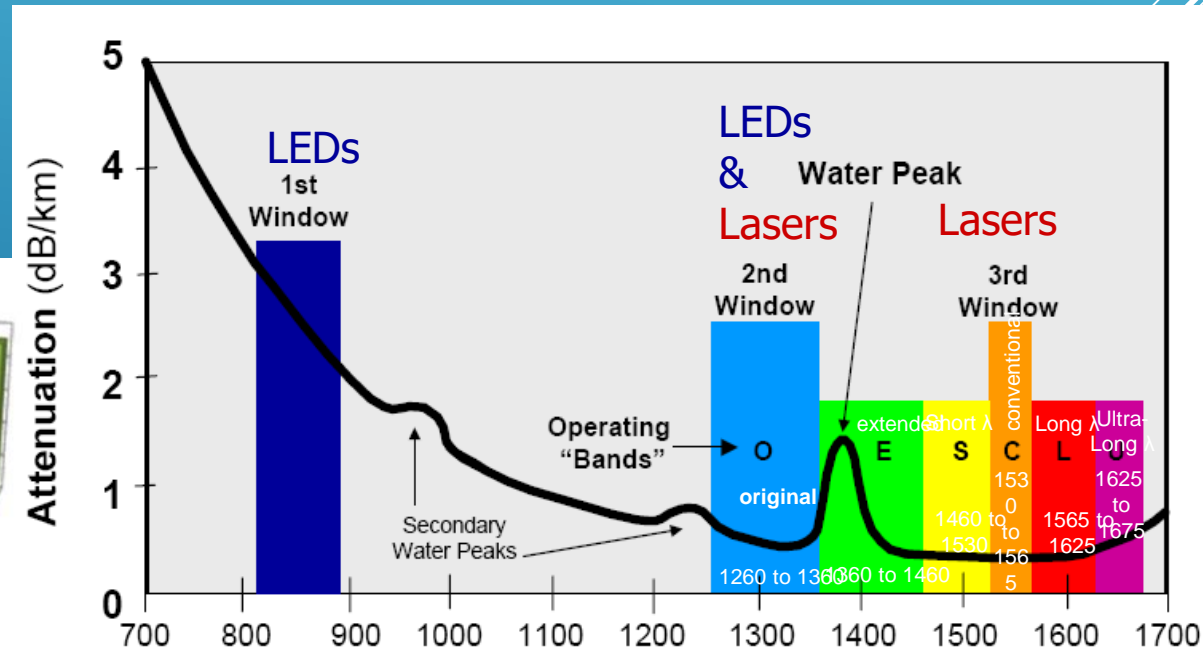
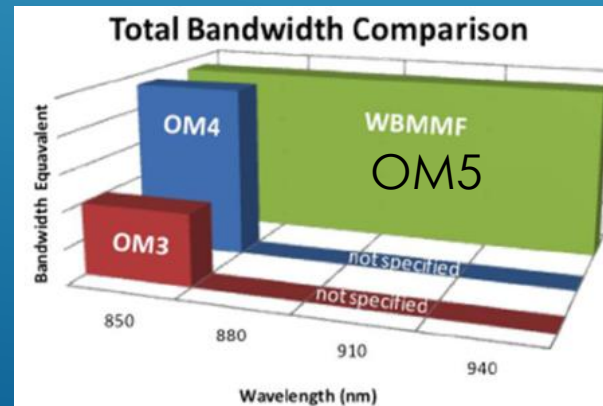
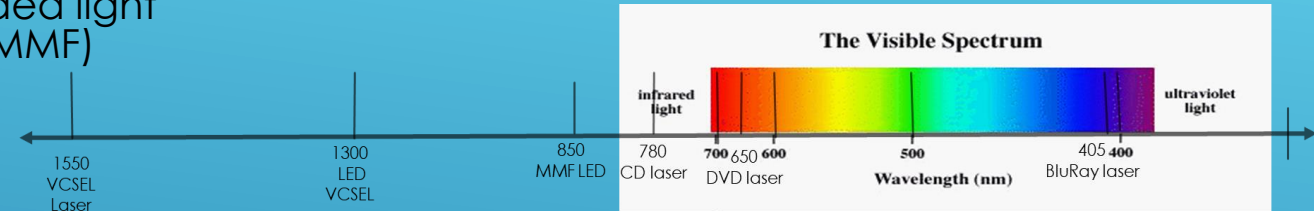
- Most feasible λ 's are designated as “Windows”

► Propagation Velocity (function of index of refraction of fiber core)

- $N_{vp} = 5.085 \mu s$ per Km

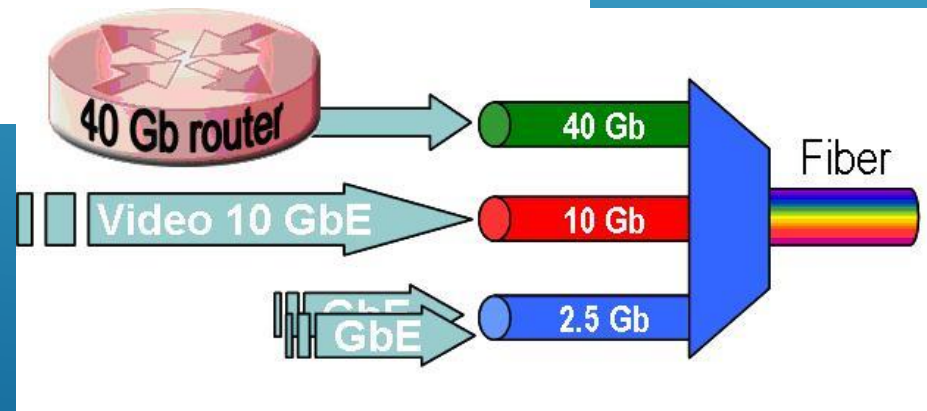
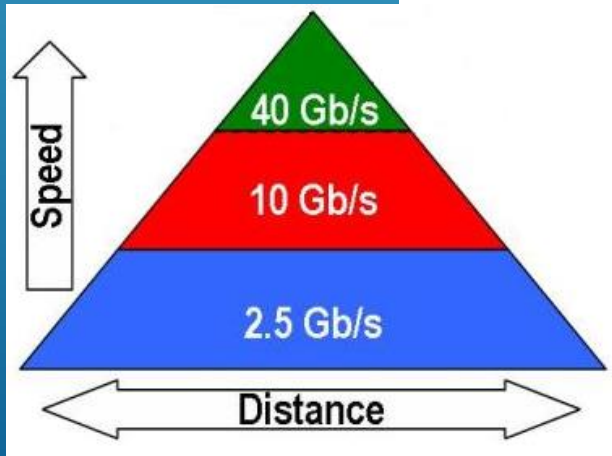
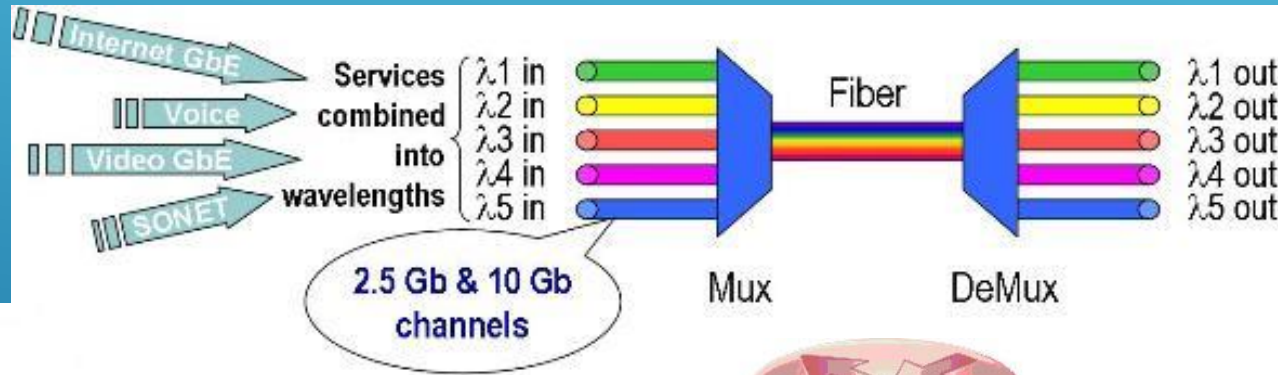
► Mechanical

- Tensile Strength
- Bend Radius



WAVELENGTH DIVISION MULTIPLEXING

- ▶ Wavelength division multiplexing (WDM) combines different wavelengths (colors, λ) in a single fiber and at the opposite end then separates them again
- ▶ Multiplies capacity of a single fiber by the number of λ 's used
 - ▶ CWDM is coarse WDM. Uses only a few well-separated λ 's
 - ▶ DWDM is dense WDM. Uses up to 256 λ 's, requires high precision transceivers

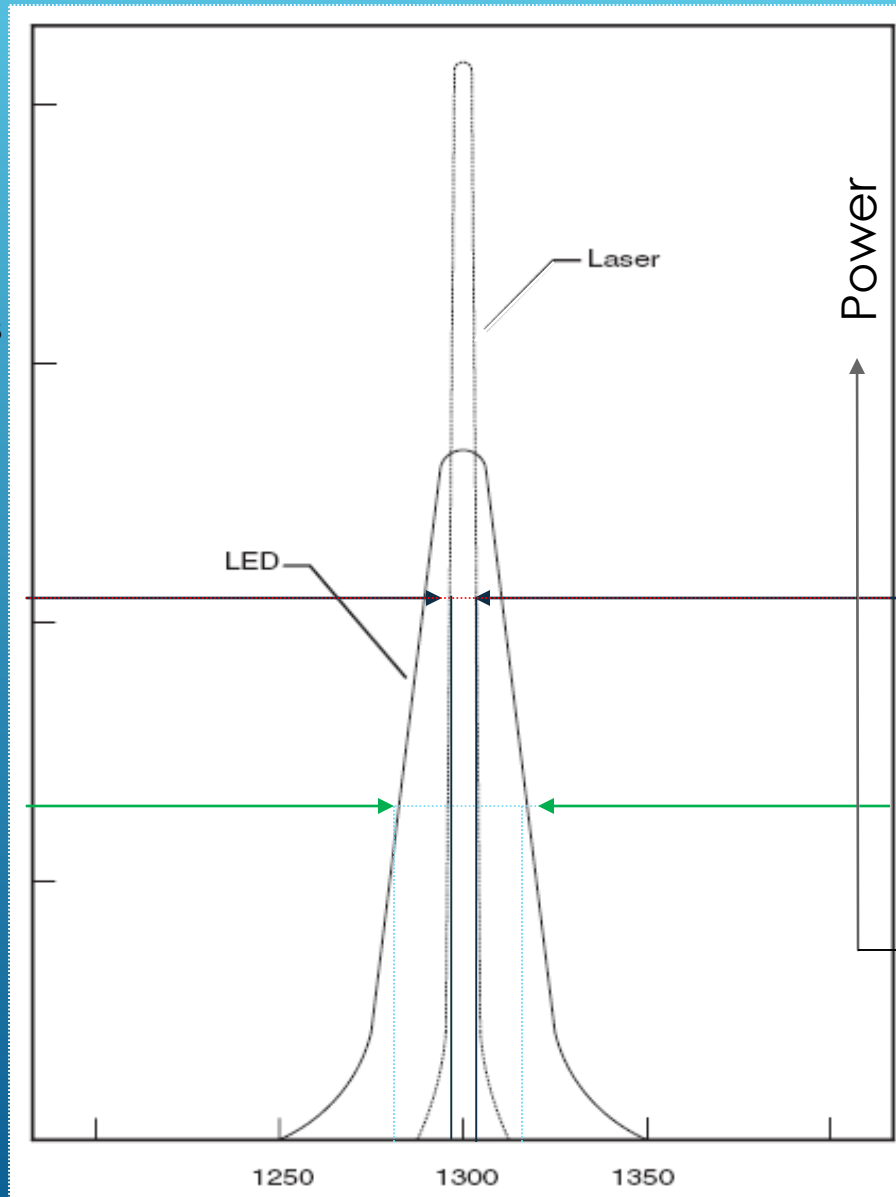


FIBER OPTIC TRANSMITTER COMPARISON

The total power emitted by a transmitter is distributed over a range of wavelengths spread around the center wavelength. This range is the spectral width.

Spectral width is measured in nanometers.

Spectral widths vary from narrow for lasers (several nanometers) to wide for LEDs (from tens to hundreds of nanometers) depending on the type of source used. Wide spectral widths lead to increased dispersion of light pulses as the light pulses propagate through an optical fiber.

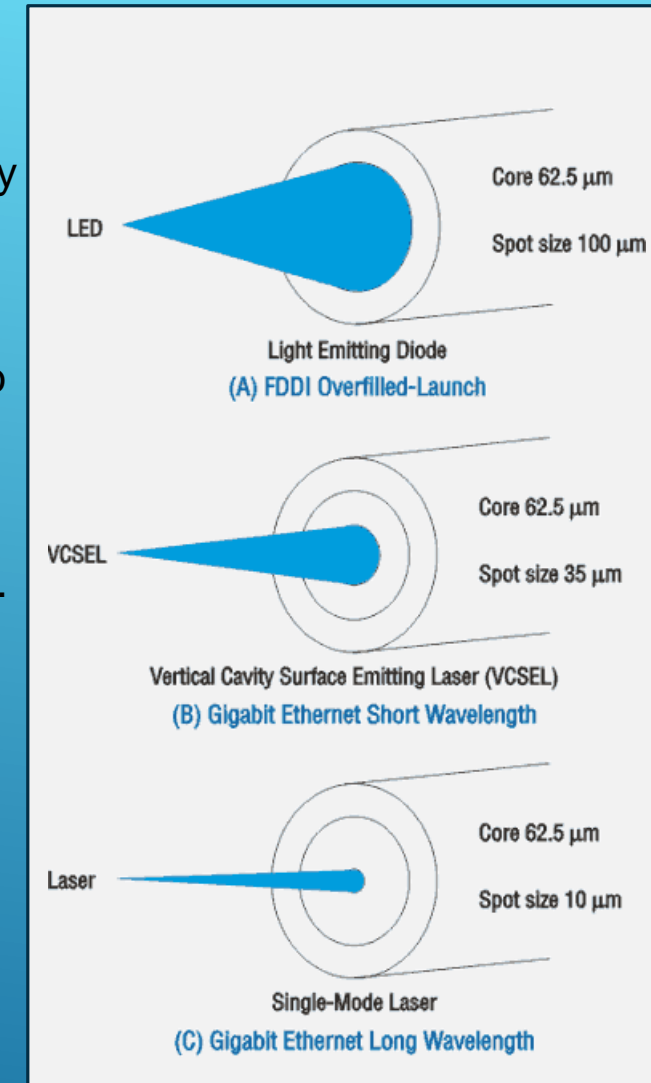


Spectral width is usually given as the range of wavelengths emitted with an intensity level greater than or equal to one half of the peak intensity level or full width half maximum (FWHM) spectral width.








Laser Spectral Width

LED Spectral Width

Measured in μW



COMBINATION OF TECHNIQUES

Transmission	40GbE Tx Rx	100GbE Tx Rx	400GbE Tx Rx
10G parallel lanes			N/A
25G parallel lanes	N/A		
10G or 25G with WDM and/or parallel lanes			
Note: Multiple lines represent parallel lanes and line with multiple colors represents WDM (multiple wavelengths within same lane).			

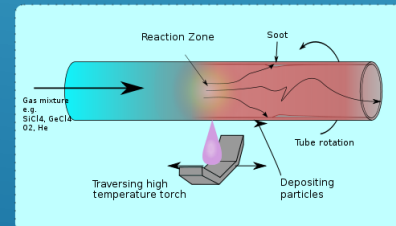
- Would require 40 fibers in each direction.
- Connector issues

FIBER MANUFACTURING

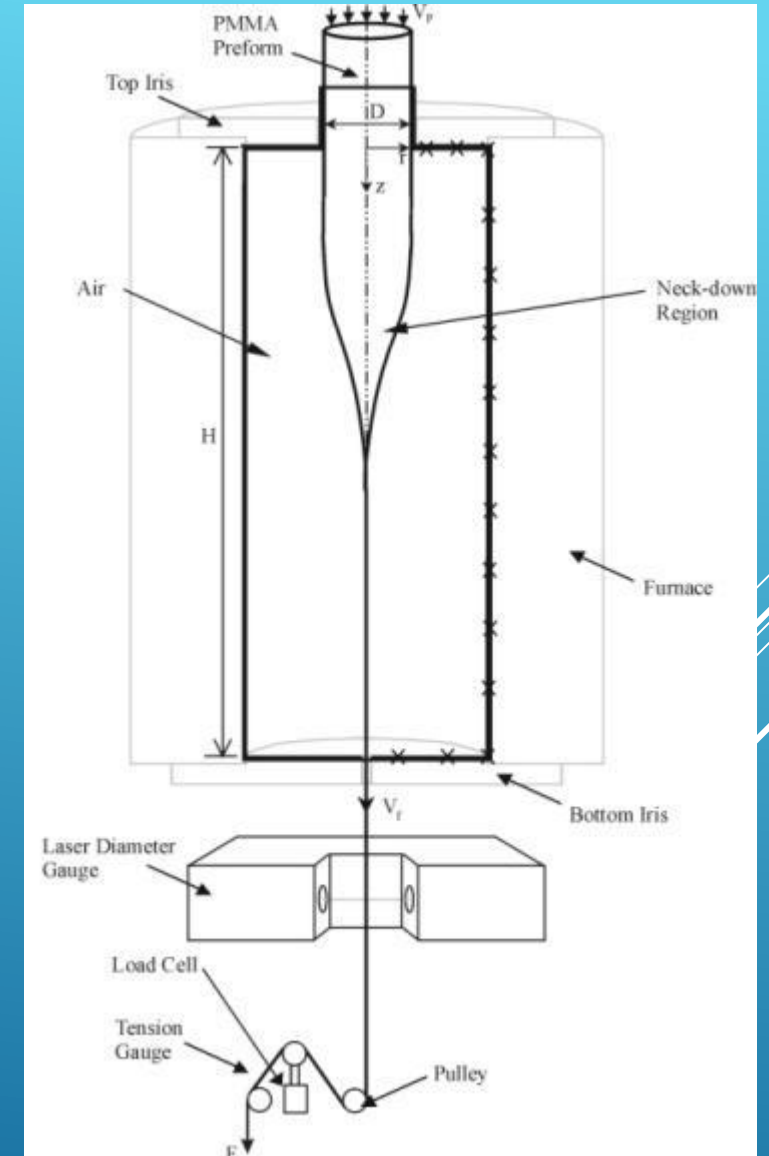
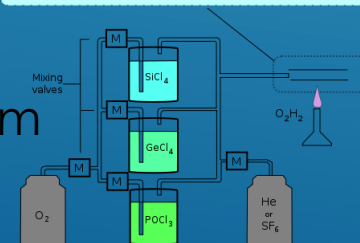
- ▶ A **Preform** is a cylindrical glass blank that provides the source material from which the glass fiber will be drawn in a single, continuous strand.
- ▶ Making a preform involves a chemical process known as Modified Chemical Vapor Deposition (MCVD). This process involves bubbling oxygen through various chemical solutions including germanium chloride (GeCl_4) and silicon chloride (SiCl_4).
- ▶ The bubbling chemicals produce gas that is directed into a hollow, rotating tube made of synthetic silica or quartz. A torch is moved up and down the rotating tube, resulting in very high temperatures that cause the gas to react with oxygen to form silicon dioxide (SiO_2) and germanium dioxide (GeO_2). These two chemicals adhere to the inside of the rotating tube where they fuse together to form extremely pure glass.
- ▶ The **drawing process** begins by lowering one end of the preform into an in-line furnace that produces heat in a range of 3,400 to 4,000 degrees Fahrenheit. As the lower end of the preform begins to melt, it forms a molten glob that is pulled downward by gravity. Trailing behind the glob is a thin strand of glass that cools and solidifies quickly.
- ▶ The equipment operator threads this glass strand through the remainder of the devices on the tower, which include a number of buffer coating applicators and ultraviolet curing ovens. Finally, the operator connects the fiber to a tractor mechanism. The tractor device pulls the glass strand from the preform at a rate of 33 to 66 feet per second. The actual speed at which the tractor pulls the strand is dependent upon the feedback information the device receives from a laser micrometer that continually measures the fiber's diameter.
- ▶ At the end of the run, the completed fiber is wound onto a spool.

Testing

- ▶ Refractive index profile
- ▶ Fiber geometry inspection, including core, cladding and coating
- ▶ Tensile strength
- ▶ Bandwidth capacity
- ▶ Attenuation at different wavelengths
- ▶ Chromatic dispersion
- ▶ Operating temperature and humidity range



Preform



Drawing Tower