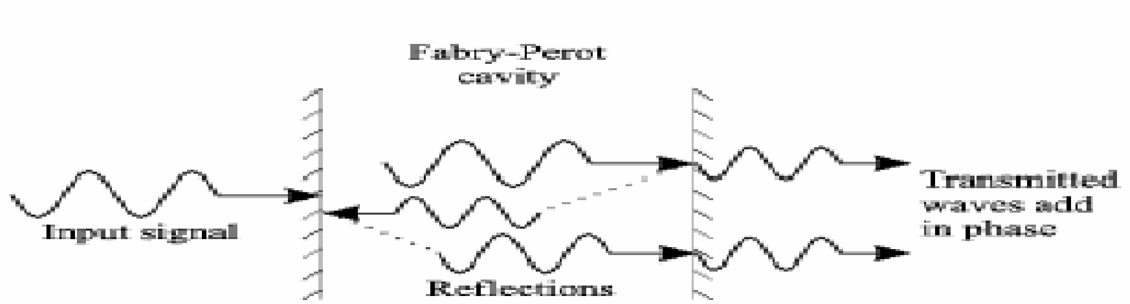
LASERS Revisited

Lasers

- Laser is essentially an optical amplifier enclosed within a reflective cavity that causes it to oscillate via positive feedback.
- Semiconductor lasers use semiconductor as the gain medium, whereas fiber lasers typically use erbium-doped fiber as the gain medium.
- WDM sources typically have output powers between 0 and 10 dBm.

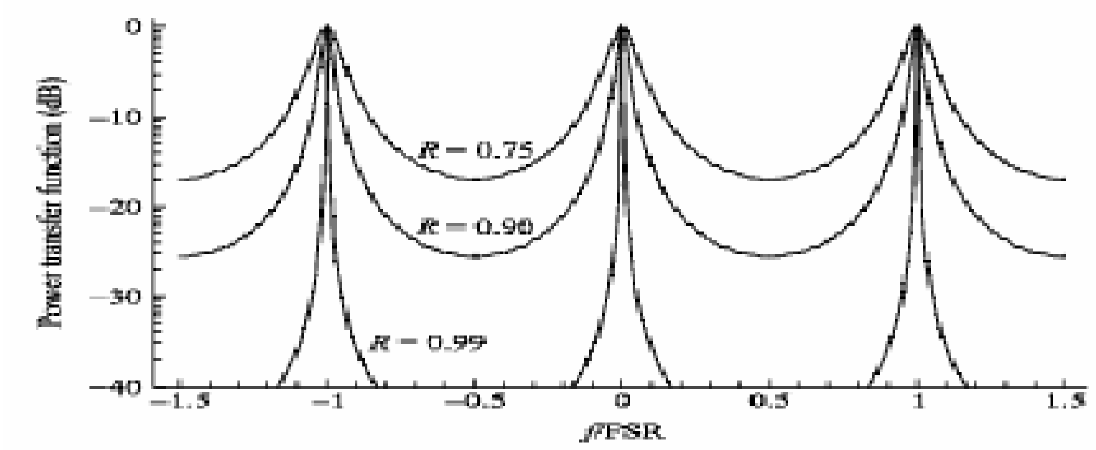
Fabry-perot lasers

- A Fabry-Perot filter consists of the cavity formed by two highly reflective mirrors placed parallel to each other
- This filter is also called a Fabry-Perot interferometer or etalon.
- Fabry-Perot filters have been used for WDM applications in several optical network testbeds
- There are better filters today, such as the thin-film resonant multicavity filter
- Fabry-Perot cavity is also used in lasers
- Compact Fabry-Perot filters are commercially available components
- Their main advantage over some of the other devices is that they can be tuned to select different channels in a WDM system



Principle of Operation

- Principle of operation is explained in the previous figure
- For those wavelengths for which the cavity length is an integral multiple of half the wavelength in the cavity – so that a round trip through the cavity is an integral multiple of the wavelength –all the light waves transmitted through the right facet add in phase.
- Such wavelengths are called the resonant wavelength of the cavity.
- In WDM systems, the separation between two adjacent wavelengths must be at least a FWHM in order to minimize crosstalk.



Longitudinal Modes

- Two conditions must be satisfied.
  - First, the wavelength must be within the bandwidth of the gain medium that is used.
  - Second condition is that the length of the cavity must be an integral multiple of half the wavelength in the cavity.
- Multiple-longitudinal mode (MLM) laser.
- MLM lasers have large spectral widths, typically around 10 nm.
- Likewise, a narrow spectral width is also needed to minimize crosstalk in WDM systems.
- Single-longitudinal mode oscillation can be achieved by using a filtering mechanism in the laser that selects the desired wavelength and provides loss at the other wavelengths.
- This ratio is typically more than 30 dB for practical SLM lasers.

Distributed-Feedback Lasers

- Light feedback can also be provided in a distributed manner by a series of closely spaced reflectors.
- The most common means of achieving this is by providing a periodic variation in the width of the cavity
- This wavelength gets preferentially amplified at the expense of the other wavelengths.
- By suitable design of the device, this effect can be used to suppress all other longitudinal mode whose wavelength is equal to twice the corrugation period.
- By varying the the corrugation period at the time of fabrication, different operating wavelengths can be obtained.

Longitudinal Modes

- That uses a corrugated wave guide to achieve single-longitudinal mode can be termed a distributed-feedback.
- When the corrugation is outside the gain region, the laser is called a distributed Bragg reflector (DBR) laser.
- DFB lasers are required in almost all high0speed transmission systems today.
- FP lasers are used for shorter-distance data communication applications.
- Reflections into a DFB laser cause its wavelength and power to fluctuate and are prevented by packaging the laser with an isolator in front of it.

Longitudinal Modes

- The laser is also usually packaged with a thermoelectric (TE) cooler and photodetector attached to its rear facet.
- TE cooler is necessary to maintain the laser at a constant operating temperature to prevent its wavelength from drifting.
- Temperature sensitivity .1 nm/ºC.
- The packaging of a DFB laser contributes a significant fraction of the overall cost of the device.

Longitudinal Modes

- For WDM systems, it is very useful to package multiple DFB lasers at different wavelengths inside a single package. This device can then serve as a multiwavelength light source or, alternatively, as a tunable laser.
- These lasers can all be grown on a single substrate in the form of an array.
- Suppression of oscillation at more than one longitudinal mode can also be achieved by using another cavity—called an external cavity—following the primary cavity where gain occurs.

Longitudinal Modes

- These lasers structures are used today primarily in optical test instruments and are one disadvantage of external cavity lasers is that they cannot be modulated directly at high speeds.
- LEDs are also not capable of producing high-output powers like lasers, and typical output powers are on the order of –20 dBm.
- Tunable lasers are highly desirable components for WDM networks for several reasons.
- Fixed-wavelength DFB lasers work very well for today's applications.

Direct and External Modulation

- Process of imposing data on the light stream is called modulation.
- Simplest and most widely used modulation scheme is called on-off keying (OOK), where the light stream is turned on or off, depending on whether the data bit is a 1 or 0.
- OOK modulated signals are usually realized in one of two ways:
- 1. By direct modulation of a semiconductor laser or an LED.
- 2. By using an external modulator.
- The direct modulation scheme is illustrated.

Direct and External Modulation

- Drive current into the semiconductor laser is set well above threshold for a 1bit and below (or slightly above) threshold for a 0 bit.
- Ratio of the output powers for the 1 and 0 bits is called the extinction ration.
- Direct modulation is simple and inexpensive .
- Major advantage of semiconductor lasers is that they can be directly modulated.
- Disadvantage of direct modulation is that the resulting pulses are considerably chirped.
- Chirp is a phenomenon wherein the carrier frequency of the transmitted pulse varies with time, and it causes a broadening of the transmitted spectrum.
- Chirped pulses have much poorer dispersion limits than unchirped pulses.

Direct and External Modulation

- Amount of chirping can be reduced by increasing the power of 0 bit so that the laser is always kept well above its threshold; the disadvantage is that this reduces the extinction ratio, which in turn, degrades the system performance.
- In practice, we can realize an extinction ratio of around 7 dB while maintaining reasonable chirp performance.
- This enhanced pulse broadening of chirped pulses is significant enough to warrant the use of external modulators in high-speed, dispersion-limited communication systems.
- An OOK external modulator is placed in front of a light source and turns the light signal on or off based on the data to be transmitted.

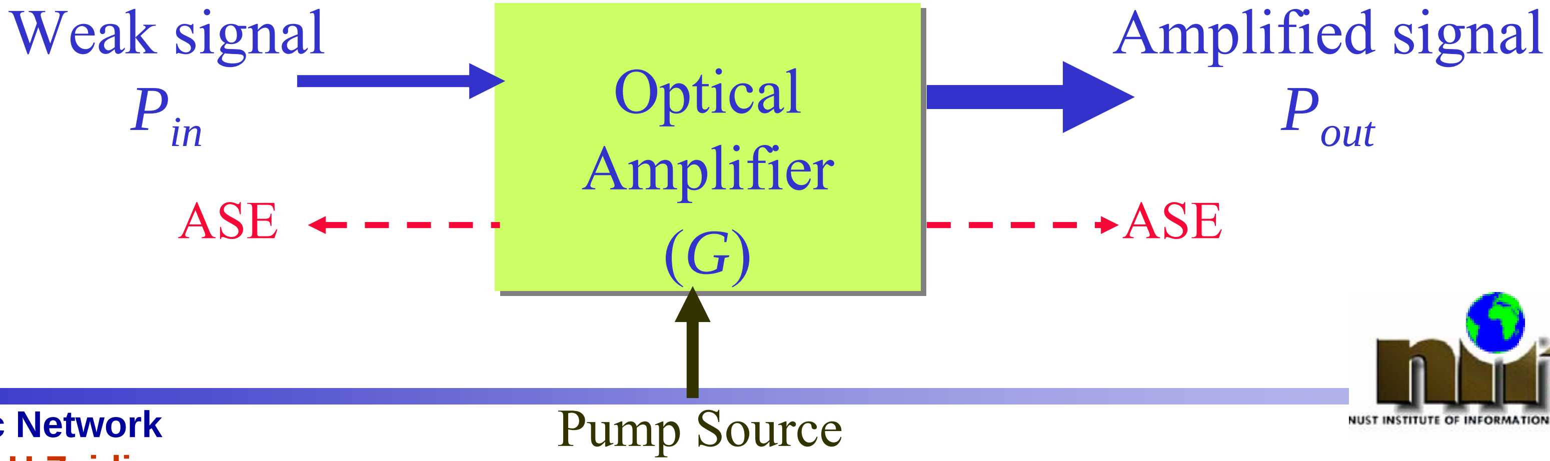
Direct and External Modulation

- Light source itself is continuously operated.
- This has the advantage of minimizing undesirable effects, particularly chirp.
- Several types of external modulators are commercially available and are increasingly being integrated with the laser itself inside a single package to reduce the packaging cost.
- In fact, transmitter packages that include a laser, external modulator, and wavelength stabilization circuits are becoming commercially available for use in WDM systems.
- External modulators become essential in transmitters for communication systems using solitons or return-t-zero (RZ)

Optical Amplifiers
and
Detectors

Optical Amplifiers

- Optical signal propagating in fiber suffers attenuation
- Optical power level of a signal must be periodically conditioned
- Optical amplifiers are a key component in long haul optical communication



Why the Need for Optical Amplification?

- Semiconductor devices can convert an optical signal into an electrical signal, amplify it and reconvert the signal back to an optical signal. However, this procedure has several disadvantages:
  - Costly
  - Require a large number over long distances
  - Noise is introduced after each conversion in analog signals (which cannot be reconstructed)
  - Restriction on bandwidth, wavelengths and type of optical signals being used, due to the electronics
- By amplifying signal in the optical domain many of these disadvantages would disappear!

NUST INSTITUTE OF INFORMATION TECHNOLOGY

Optical Amplifiers

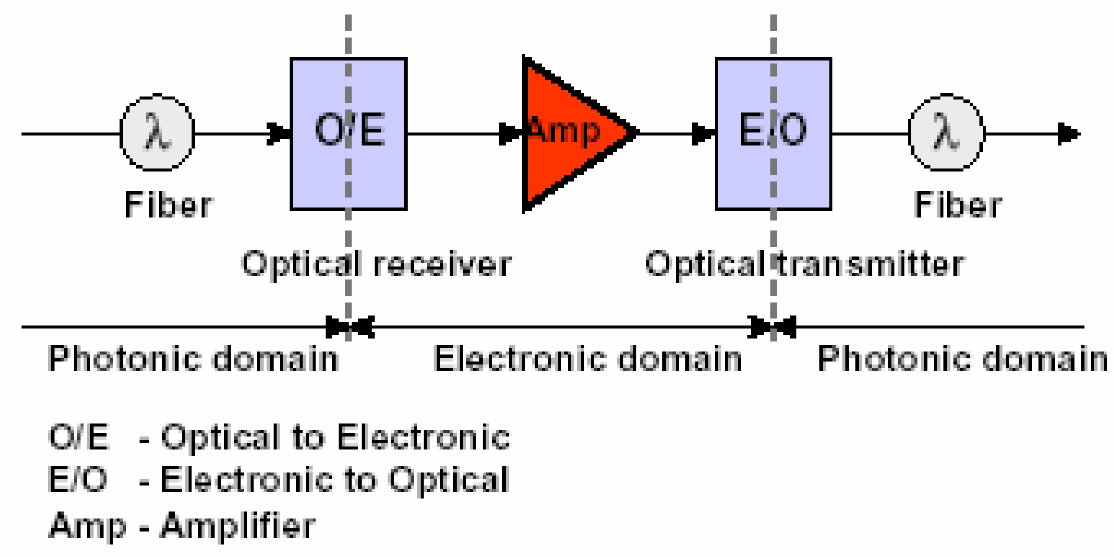
- An optical amplifier is characterized by:
  - **Gain** – ratio of output power to input power (in dB)
  - **Gain efficiency** – gain as a function of input power (dB/mW)
  - **Gain bandwidth** – range of wavelengths over which the amplifier is effective
  - **Gain saturation** – maximum output power, beyond which no amplification is reached
  - **Noise** – undesired signal due to physical processing in amplifier

Optical Amplifiers

- Types of amplifiers:
  - Electro optic regenerators
  - Erbium-doped optical amplifiers (EDFA)
  - Raman Amplifiers
  - Semiconductor optical amplifiers (SOA)

Electro Optical Amplifiers

- Optical signal is:
  - Received and transformed to an electronic signal
  - Amplified in electronic domain
  - Converted back into optical signal at same wavelength



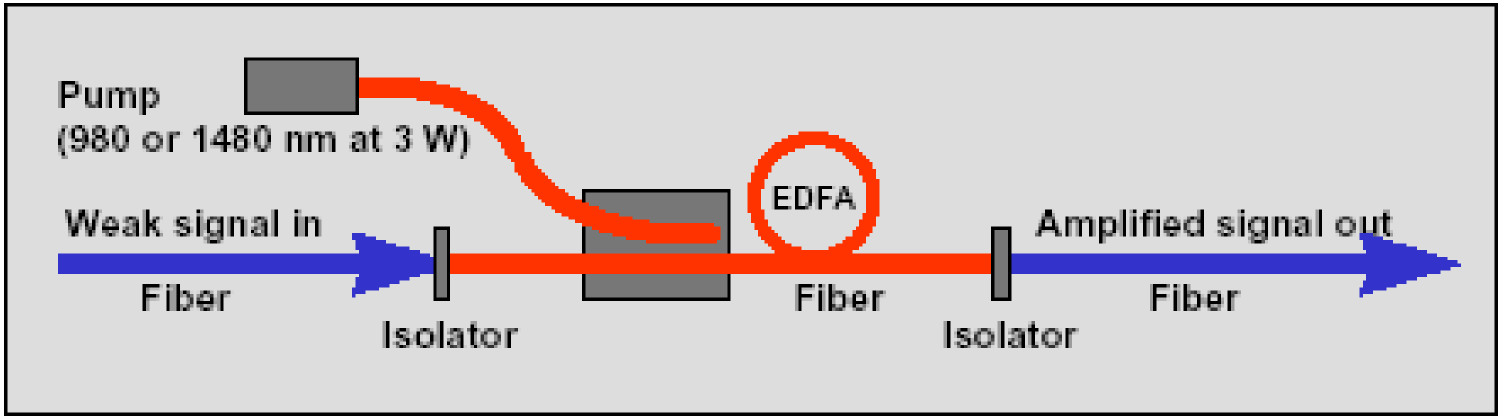
Erbium-doped Fiber Amplifier (EDFA)

- An erbium-doped fiber amplifier consists of:
  - A length of silica fiber, whose core is doped with rare earth element erbium.
  - A pump laser of 980 nm or 1480 nm.
  - Wavelength selective couplers & Isolators.

- Combination of several factors has made EDFA an attractive choice:
  - Availability of compact and reliable high-power semiconductor pump lasers.
  - It is an all fiber device, making it polarization independent and easy to couple light in and out of it.
  - Simplicity of device
  - It introduces no crosstalk when amplifying WDM signals.

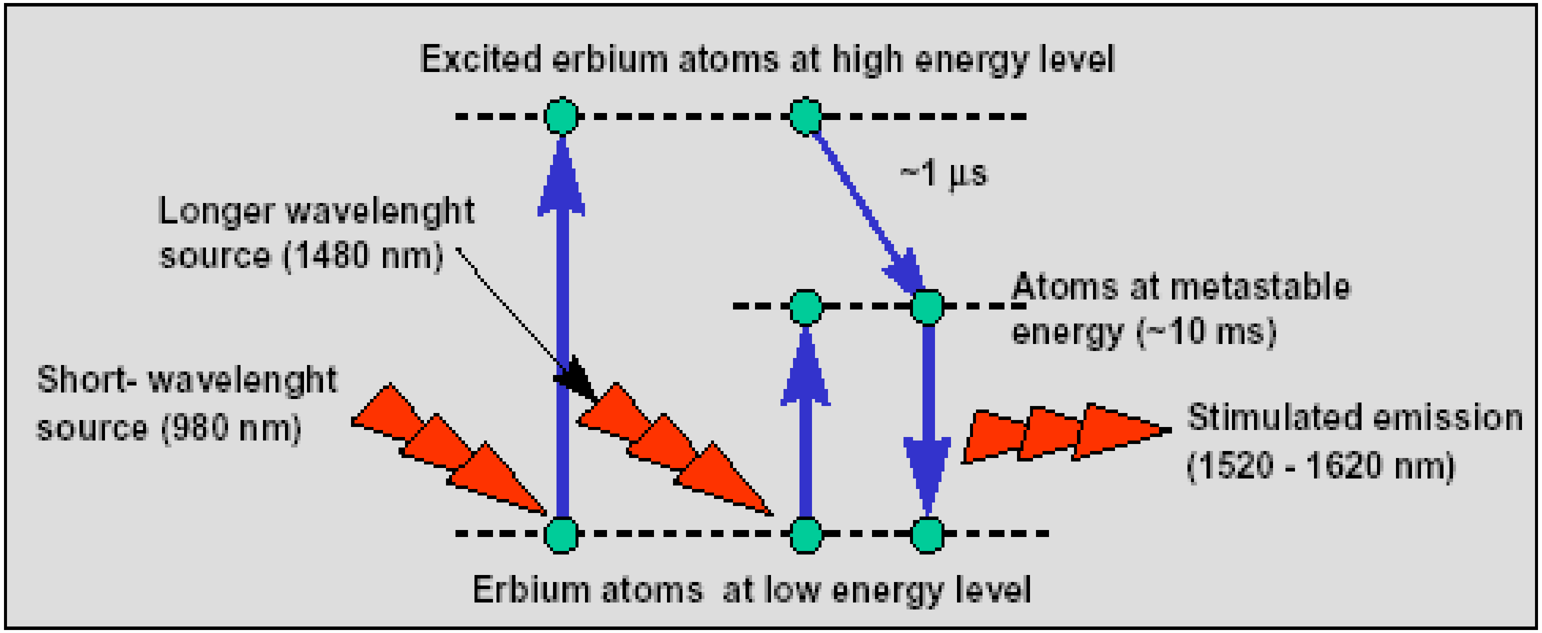
EDFA - Construction

- EDFA is a fiber segment, a few meters long, heavily doped with erbium (rare earth metal)
- Energy is provided by a pump laser beam



EDFA – Principle of Operation

- Amplification is achieved by quantum mechanical phenomena of stimulated emission
  - Erbium ions are excited to a high energy level by pump laser signal
  - They fall to a lower metastable (long lived, 10 ms) state
  - An arriving photon triggers (stimulates) a transition to ground level and another photon of same wavelength is emitted



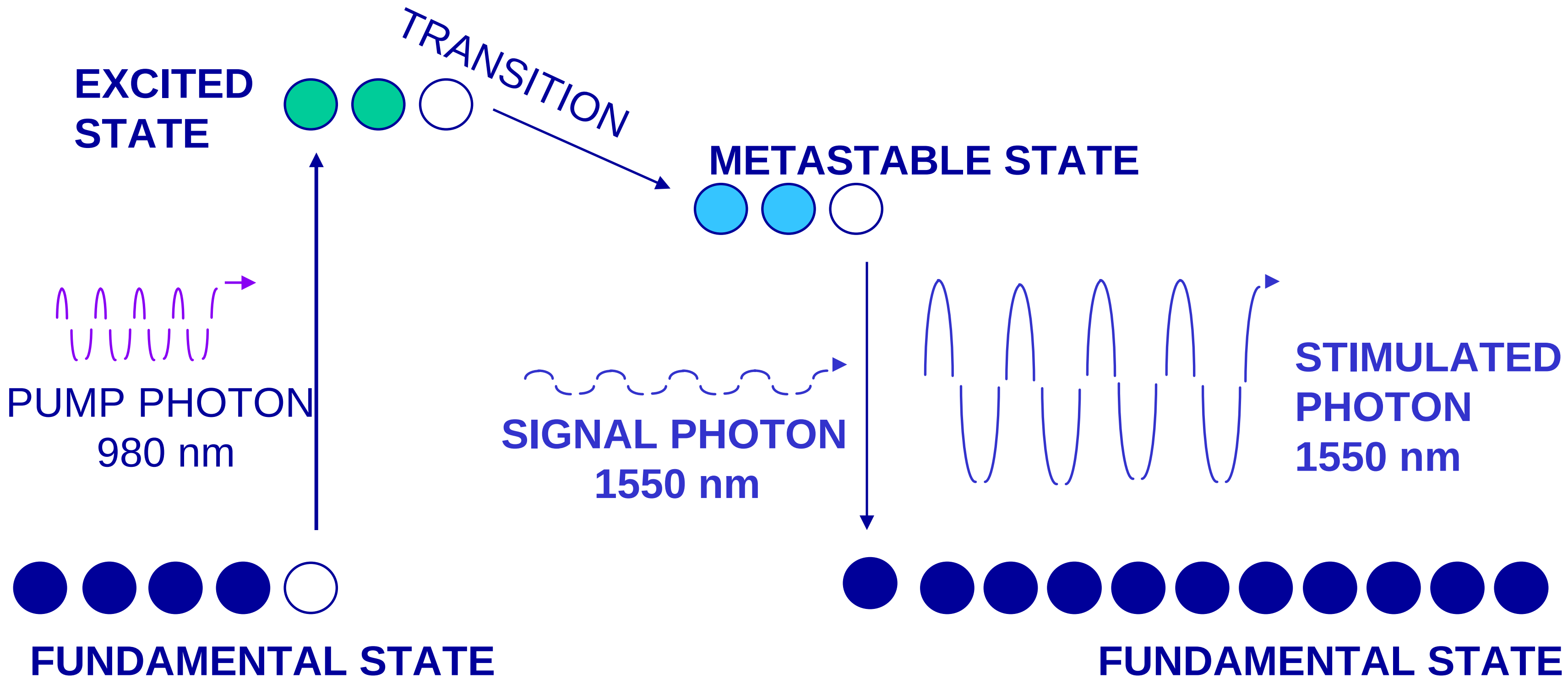
NUST INSTITUTE OF INFORMATION TECHNOLOGY

EDFA – Principle of Operation

- Stark Splitting
  - Isolated erbium ions have discrete energy levels.
  - On introduction into silica glass, the discrete energy level is distributed into multiple energy levels.
  - This process is called stark splitting.
  - It is the phenomena by which the energy levels of free erbium ions are split into a number of levels, or into energy bands, when the ions are introduced into the silica glass.
- Thermalization
  - The process by which the erbium ions are distributed with in the various energy levels constituting an energy band.

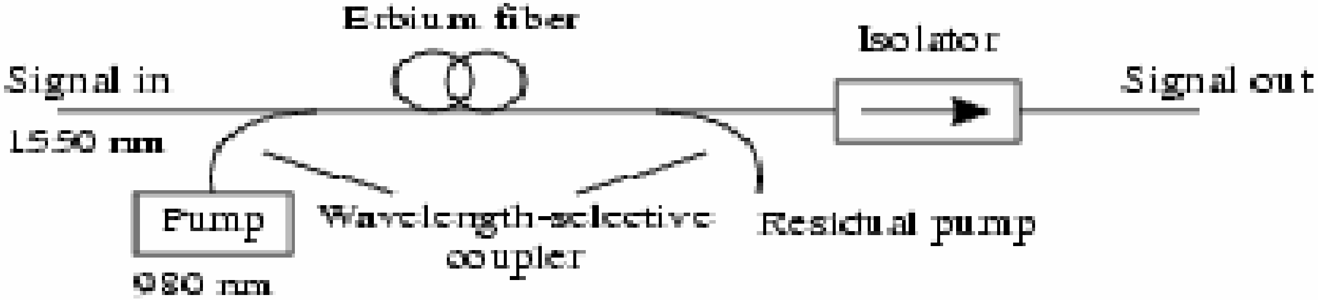
NUST INSTITUTE OF INFORMATION TECHNOLOGY

EDFA – Principle of Operation



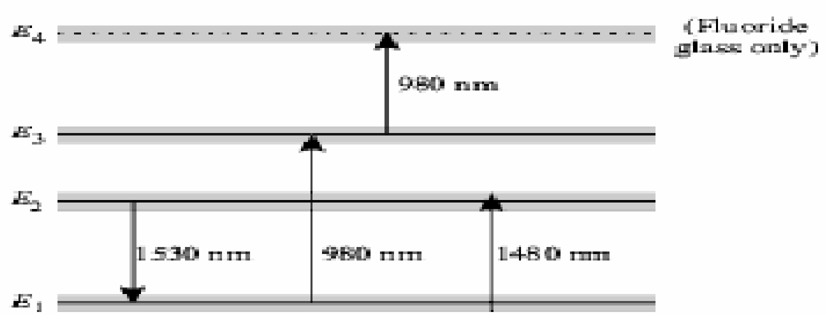
EDFA

- In the case of erbium ions in silica glass, the set of frequencies that can be amplified by stimulated emission from the E2 band to the E1 band corresponds to the wavelength range 1525-1570nm, a bandwidth of 50 nm, with a peak around.
- Pumping process is more efficient, that is, at 980 nm than these other wavelengths. The pump wavelength is 1480 nm.
- Pumping at 1480 nm is not as efficient as 980 nm pumping.
- Moreover, the degree of population inversion that can be achieved by 1480 nm pumping is lower.



EDFA

- The higher the population inversion, the lower the noise figure of the amplifier.
- Thus 980 nm pumping is preferred to realize low- noise amplifiers.
- However, higher-power pump lasers are available at 1480 nm, compared to 980nm, and thus 1480m, pumps find applications in amplifiers designed to yield high output powers.
- Another advantage to the 1480 nm pump is that the pump power can also propagate with low loss in the silica fiber that is used to carry the signals.
- The pump laser can be located remotely from the amplifier itself.
- This feature is used in some systems to avoid placing any active components in the middle of the link.



EDFA

- In thermal equilibrium
  - N1 > N2 > N3
- Population inversion condition for stimulated emission from E2 to E1 is
  - N2 > N1
- The energy difference between E1 and E3 corresponds to a wavelength of 980 nm.
- If optical power of 980 nm is applied into amplifier, a state transition is acquired from E1 to E3.
  - This process is called pumping.

EDFA

- Due to spontaneous emission the ions from E3 will transit to E2.
  - The time for ions to stay at E3 is only 1ųs.
- Ions, due to spontaneous emission will also transit from E2 to E1.
  - But the life time of this process is about 10ms.
- If the pump power is sufficiently large then the majority of ions will be found at E2.
  - Thus forming a population inversion between E2 and E1.
  - N2 > N1
- At this point, if a signal in 1525 – 1570 nm is injected into fiber, it will be amplified by stimulated emission from E2 to E1 level.

EDFA – Gain Flatness

- Population levels at different levels in a band are different.
  - Thus the gain becomes a function of the wavelength.
- The gain is different at different wavelengths.
- Such an EDFA, gives different degrees of amplification in a WDM system.
- To improve the flatness of gain we have different options:
  - Use of Fluoride glass fiber
  - Use of filter inside amplifier

NUST INSTITUTE OF INFORMATION TECHNOLOGY

EDFFAs – Gain Flatness

- Instead of Silica glass inside amplifier, fluoride glass fiber is used.
- Erbium-doped Fluoride Fiber Amplifiers
- The fluoride provides a naturally flattened gain spectrum.
- EDFFAs are nowadays commercially available.

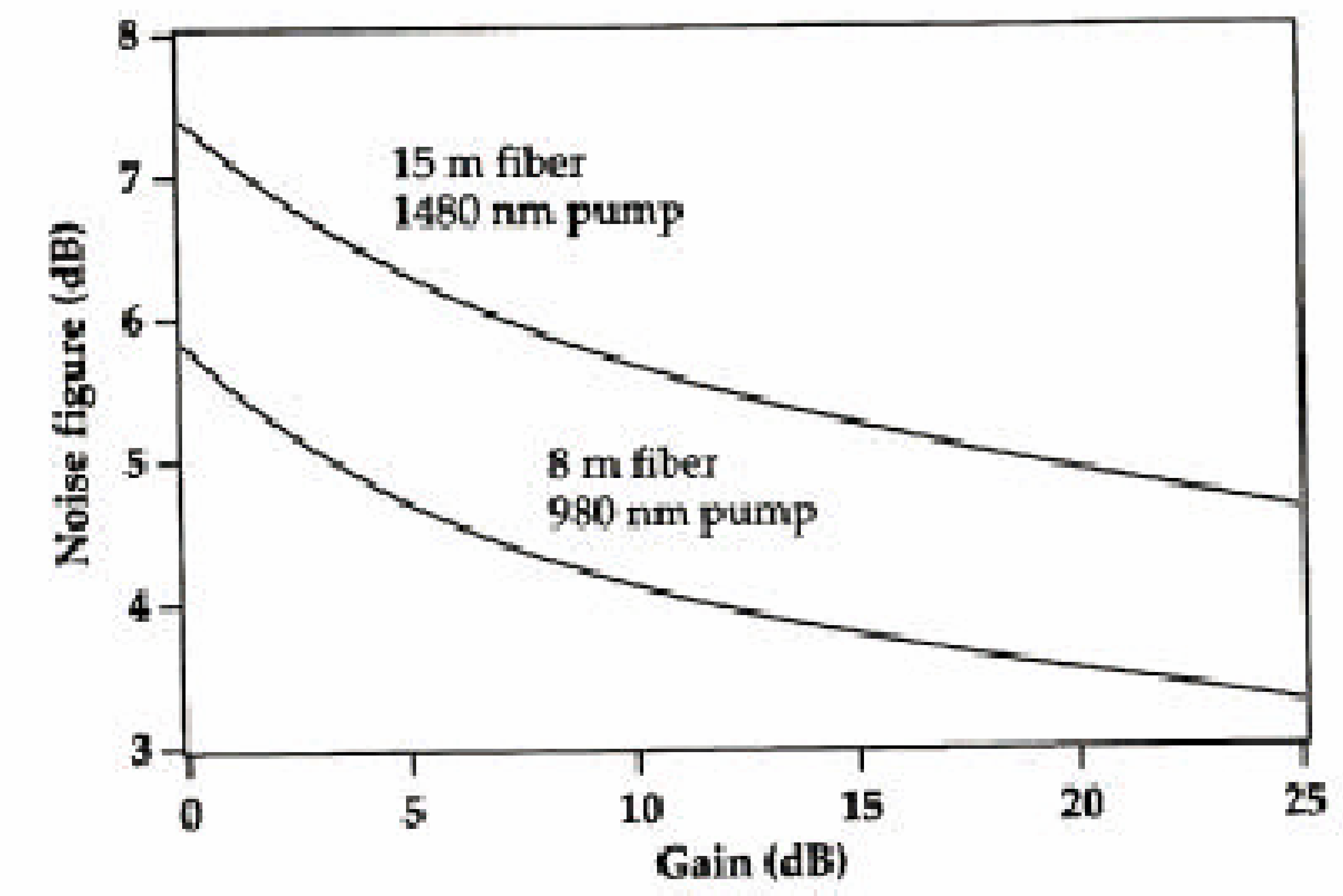
EDFFAs – Gain Flatness

- There are certain drawbacks associated to the EDFFAs
  - The noise performance is poorer in EDFFA as compared to EDFA.
    - Must be pumped at 1480 nm
    - Excited State Absorption
  - Fluoride fiber is itself difficult to handle.
    - Brittle
    - Difficult to splice
    - Susceptible to moisture

Filters – Gain Flatness

- Filters can be used to smoothen the high notches in the gain graph.
- Notch filters are normally used for this purpose.

EDFA – Principle of Operation



Different Wavelength bands

Band	Descriptor	Wavelength range (nm)
O-band	Original	1260 to 1360
E-band	Extended	1360 to 1460
S-band	Short	1460 to 1530
C-band	Conventional	1530 to 1565
L-band	Long	1565 to 1625
U-band	Ultra-long	1625 to 1675

L-Band EDFAs

- So far we have focused on EDFAs operating in the C-band (1530-1565nm).
- Erbium-doped fiber, however, has a relatively long tail to the gain shape extending well beyond this range to about 1605 nm.
- This has stimulated the development of systems in the so-called L-band from 1565 to 1625 nm.
- Gain spectrum of erbium is much flatter intrinsically in the L-band than in the C-band.
- This makes it easier to design gain-flattening filters for the L-band.
- Erbium gain coefficient in the L-band is about three times smaller than in the C-band.

L-Band EDFAs

- Pump powers required for L-band EDFAs are much higher than their C-band counterparts.
- Many of the other components used inside the amplifier, such as isolators and couplers, exhibit wavelength-dependent losses and are therefore specified differently for the L-band than for the C-band.