OPTICAL AMPLIFIERS

Conventional Repeater/Amplifier Performs:

1. Photon to electron conversion
2. Electrical amplification
3. Retiming
4. Pulse shaping
5. Electron to photon conversion

This process woks well for moderate speed single wavelength operation.

This process is fairly complex and expensive for high speed multiple wavelength systems.

Optical amplifiers operate **completely in the optical domain** to boost the power levels of multiple lightwave signals over spectral bands of 30 nm and more.

Three Fundamental Types of Optical Amplifiers:

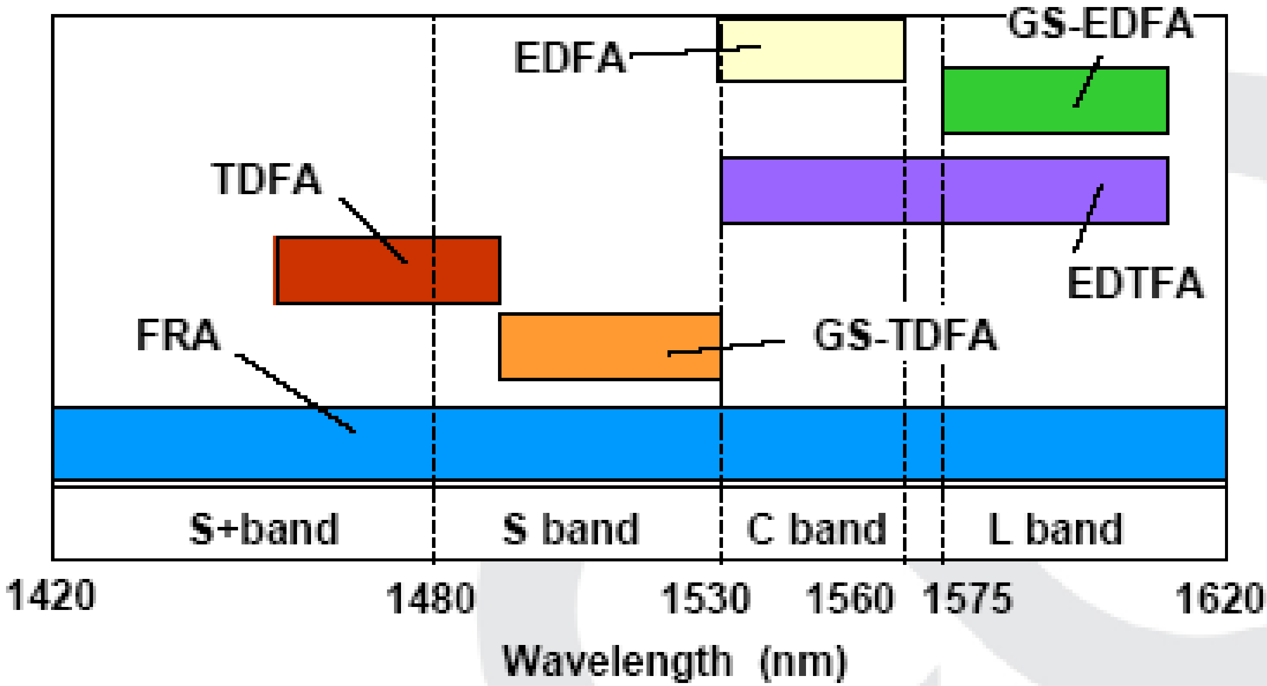
1. Semiconductor optical amplifiers (SOAs)
2. Doped Fiber amplifiers (DFAs) or
   REDFAs (Rare Earth Doped Fibre Amplifiers)
3. Raman amplifiers

SOAs are based on the same operating principles as laser diodes i.e external pumping principles and gain mechanisms.

EDFAs are widely used in the C-band (1530 to 1560) for optical communication networks.

Wideband optical amplifiers that operate over several wavelength bands simultaneously.

Optical fiber amplifier types:



EDFA : Erbium-Doped Fiber Amplifier (1530 - 1565 nm)
GS-EDFA : Gain-Shifted EDFA (1570 -1610 nm)
EDTFA : Telluride-Based EDFA (1530 - 1610 nm)
TDFA : Thulium-Doped Fluoride-Based Fiber Amplifier (1450 - 1490 nm)
FRA : Fiber Raman Amplifier (1420 - 1620 nm or more)

Basic Applications and Types of Optical Amplifiers

Used in diverse applications ranging from:

Ultra-long undersea links to **Short links acces network**.

In long distance undersea and terrestrial point to point links the traffic patterns are relatively stable, so that input power levels to an optical amplifier do not vary significantly.

Optical amplifier used in metro and access network need to be able to recovery quickly from rapid input power variations, due to the bursty nature of traffic.

General Applications

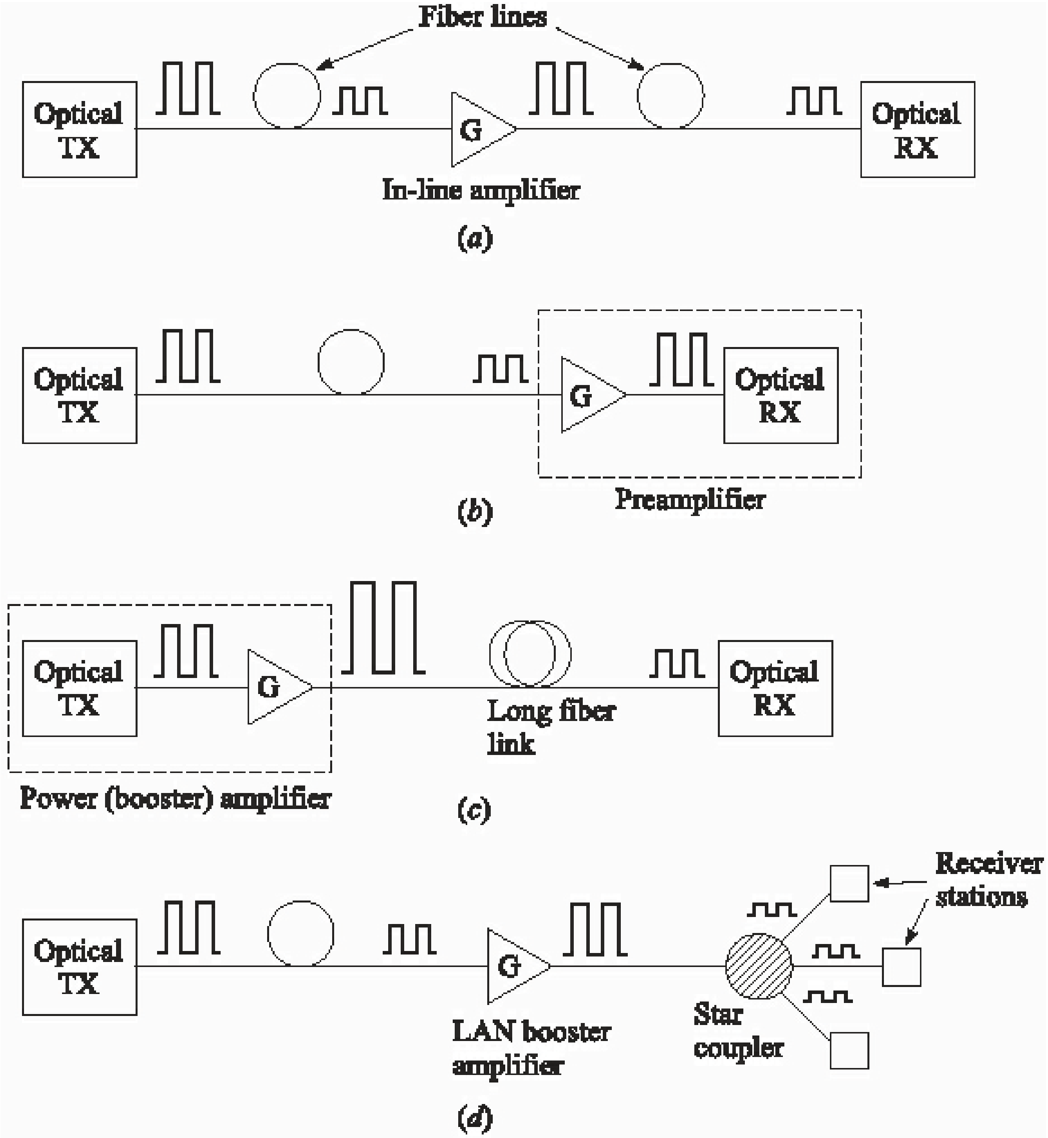
1. In-line optical amplifiers:

It can be used to compensate for transmission loss and to increase the distance between regenerative repeaters.

2. Preamplifier: Used as **front-end premplifier** for an optical receiver. Weak optical signal is amplified ahead of the photodetection process so that the signal-to-noise ratio degradation caused by thermal noise in the receiver electronics can be suppressed.

3. Power Amplifier: Placing an amplification device immediately **after the optical transmitter** gives a boost to the light level right at the beginning of a fiber link, and serves to increase the transmission distance by 10 to 100 km depending on the amplifier gain and fiber loss.

As an example, **using this boosting technique together with an optical preamplifier** at the receiving end can enable **continuous underwater transmission distances of 200 to 250 km.**



Four possible applications of optical amplifiers: (a) in-line amplifier to increase transmission distance (b) preamplifier to improve receiver sensitivity, (c) booster of transmitted power, (d) booster of signal level in a local area network.

Amplification Mechanism

1. For **stimulated emission** to occur, there must be a **population inversion** of carriers, which means that there are more electrons in an excited state than in the ground state.

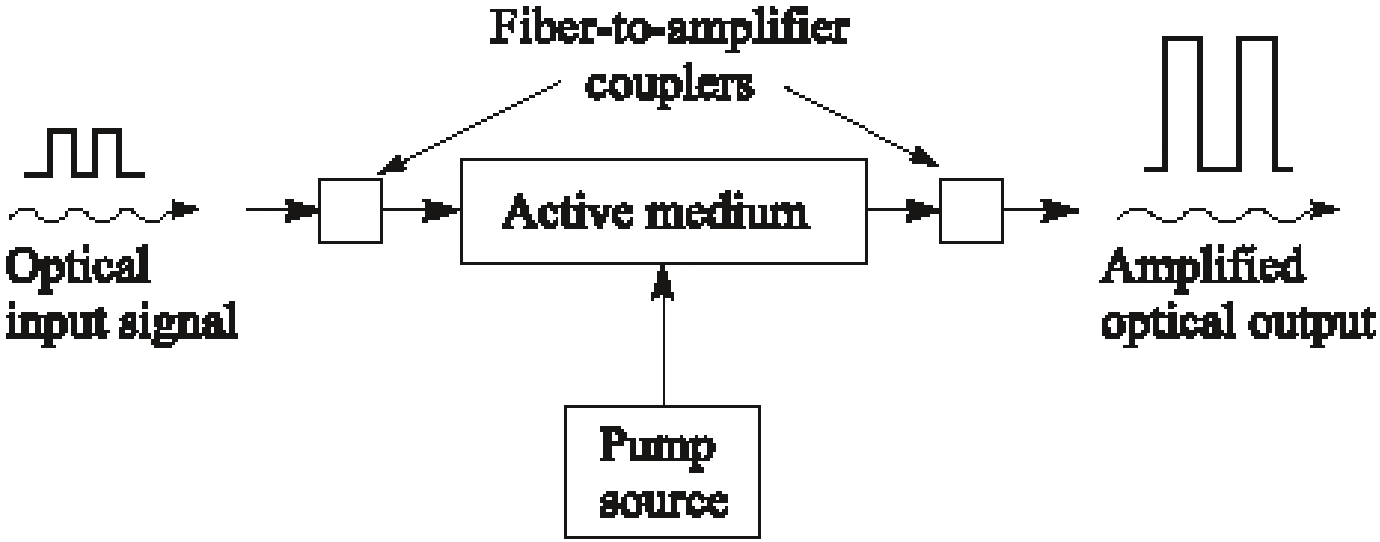
2. population inversion is achieved by supplying **external energy to boost (pump)** electrons to a higher energy level.

3. The pump supplies energy to electrons in an active medium, which **raises them to higher energy levels** to produce a population inversion.

4. An incoming signal photon will trigger these excited electrons to **drop to lower levels** through a stimulated emission process, thereby producing an amplified signal.

One of the most important parameters of an optical amplifier is the signal gain or amplifier gain G, which is defined as

$$G = P_{out}/P_{in}$$



Basic Operation of a generic optical amplifier

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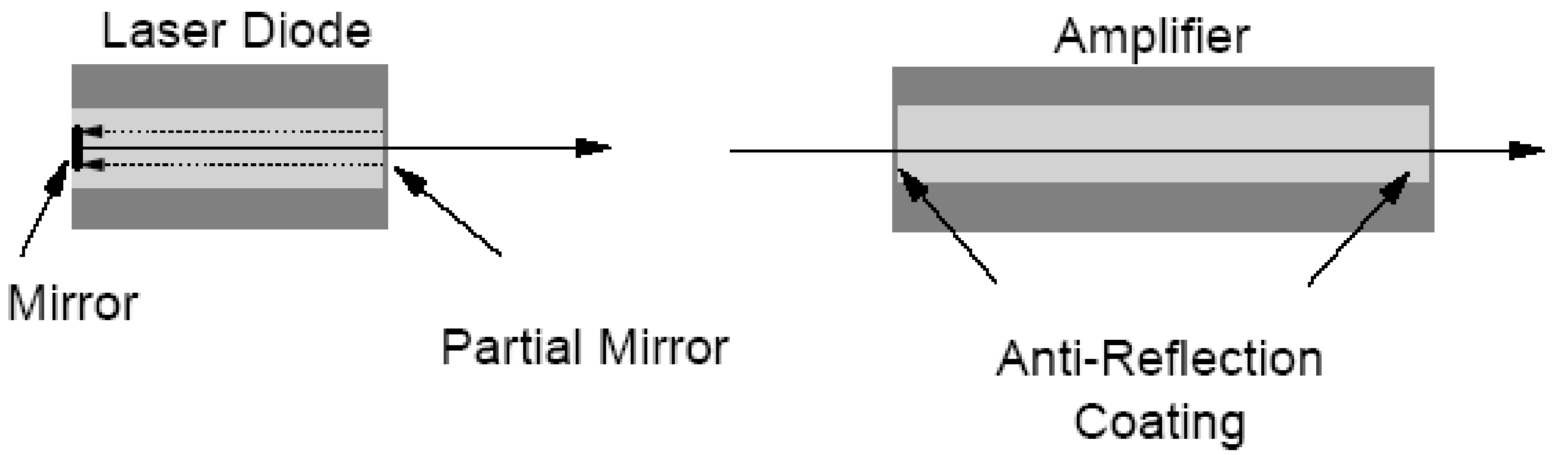
Semiconductor Optical Amplifiers



Semiconductor Optical Amplifier Relationship to Laser

Semiconductor Optical Amplifiers

SOAs can operate in every fiber wavelength band extending from **1280 nm in the O-band to 1650nm in the U-band** by varying the composition of the active InGaAsP material.

In the SOA the **significant difference** is that the optical signal travels through the device only once

It can boost incoming signal levels but **cannot generate a coherent** optical output by itself.

Facet reflectivity of **less than 0.01 percent** is necessary in an SOA to prevent oscillations

SOAs have severe limitations however:

1. They can't deliver very much power (only a few milliwatts). This is usually sufficient for single channel operation but in a WDM system you usually want up to a few milliwatts per channel.

2. Coupling the input fibre into the chip tends to be very lossy and hence reduces the effectiveness of the amplifier. The amplifier must have additional gain to overcome the loss on the input facet.

3. SOAs tend to be noisy.

4. They are highly polarisation sensitive.

5. They can produce severe crosstalk when multiple optical channels are amplified. This is mainly around the power level where the amplifier saturates but this is quite a low power.

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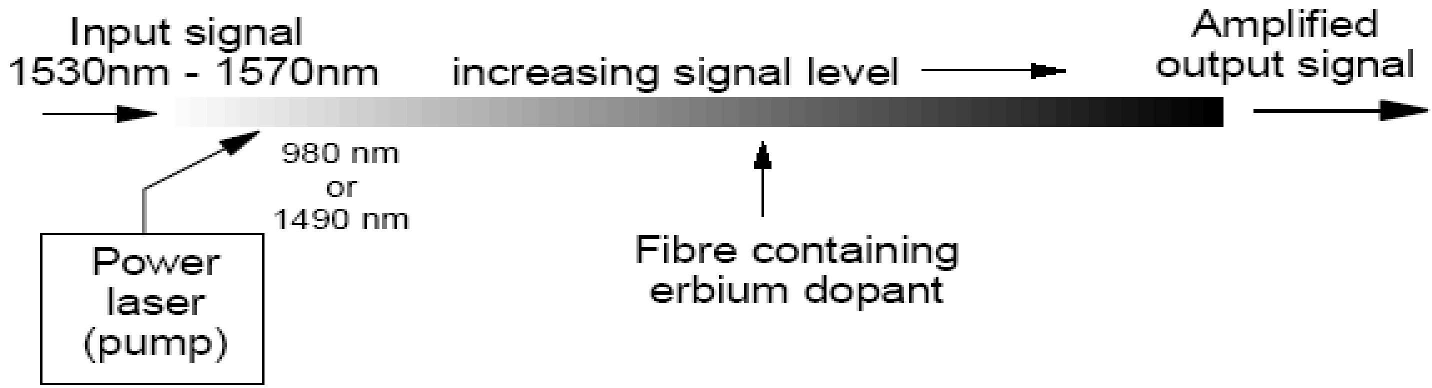
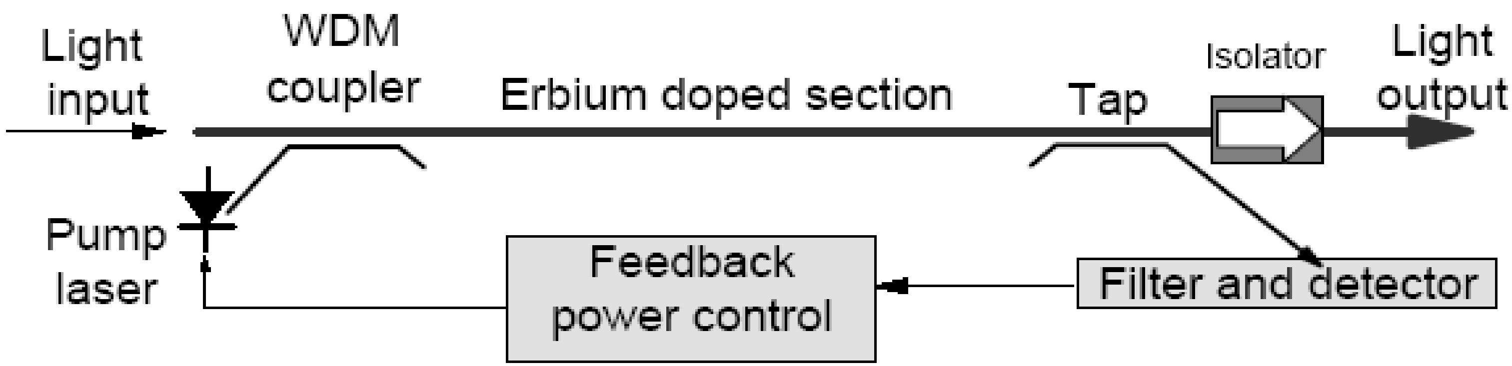
Erbium Doped Fiber Amplifiers





Erbium Doped Fiber Amplifiers

The most common material for **long-haul telecommunication applications** is a silica fiber doped with erbium, which is known as an erbium-doped fiber amplifier or EDFA.

Originally the operation of an EDFA by itself was limited to the **C-band (1530- to 1560-nm region).**
Recent improvements in erbium-doped fiber designs have allowed the extension of EDFAs into the **L-band.**

An Erbium Doped Fibre Amplifier consists of a short section of fibre which has a small controlled amount of the rare earth element erbium added to the glass in the form of an ion (Er^{3+}).

Erbium ions are able to exist in several energy states . When an erbium ion is in a high-energy state, a photon of light will stimulate it to give up some of its energy and return to a lower-energy (more stable) state.

Erbium Doped Fiber Amplifiers

EDFAs have a number of attractive technical characteristics:

1. Efficient pumping
2. Minimal polarisation sensitivity
3. Low insertion loss
4. High output power
5. Low noise
6. Very high sensitivity
7. Low distortion and minimal interchannel crosstalk

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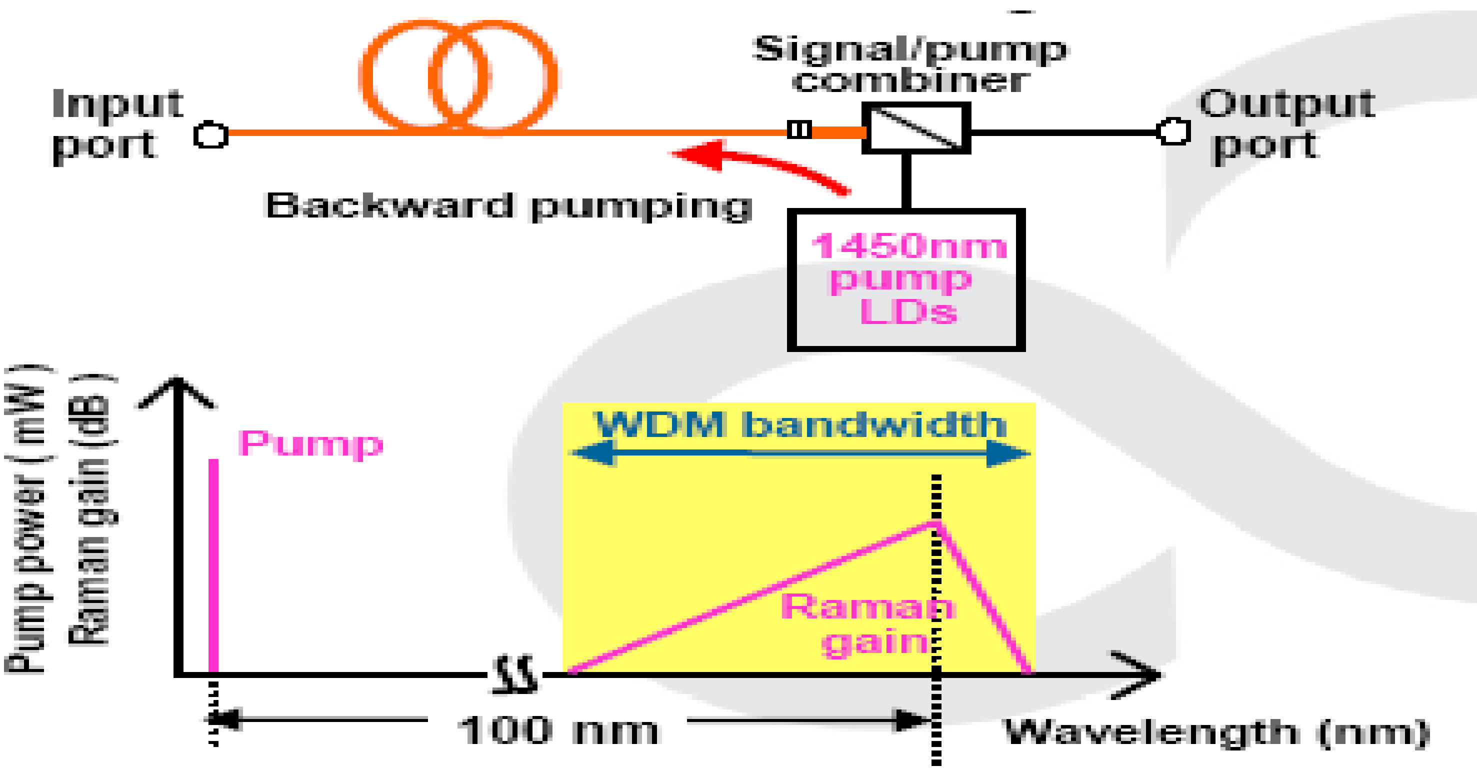
Raman Amplifiers

EDFA requires a <u>specially constructed optical fiber</u> for its operation.

Raman amplifier makes use of the <u>transmission fiber itself</u> as the amplification medium.



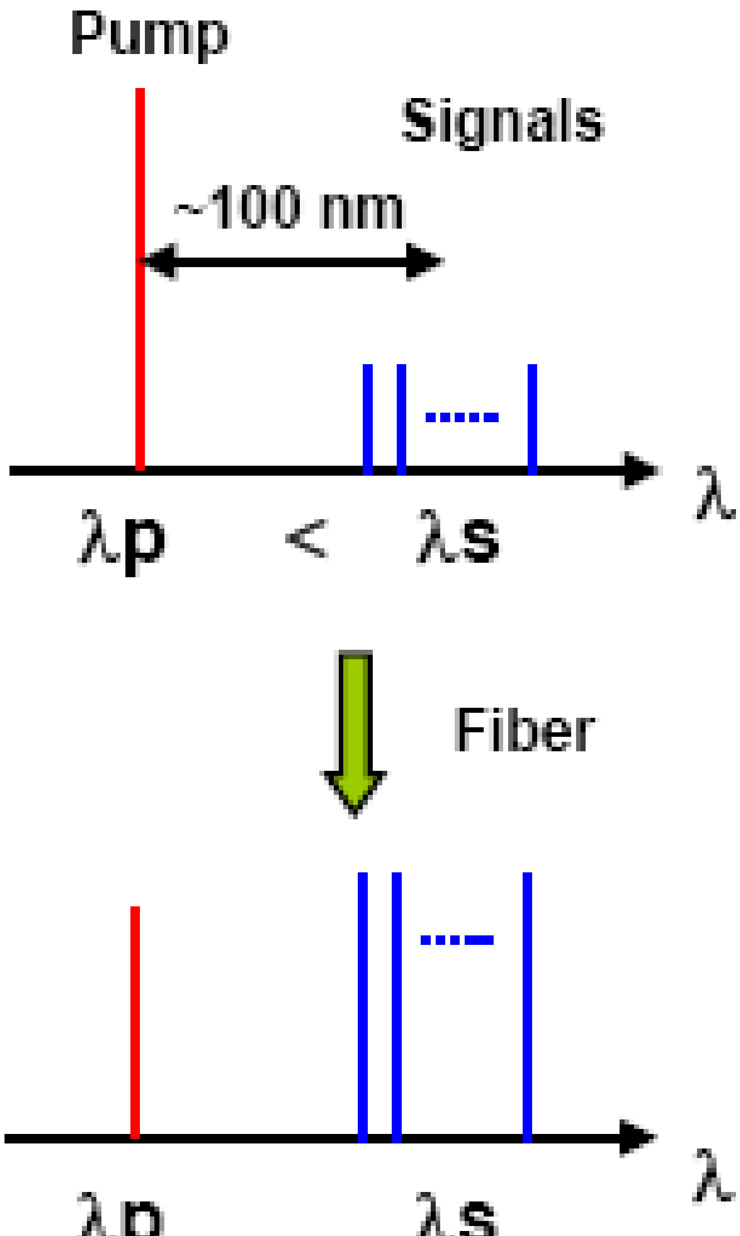
Raman amplifier is based on an effect:

- **Called stimulated Raman scattering (SRS).**
- **This effect is due to an interaction between an optical energy field and the vibration modes of the lattice structure in a material.**
- **An atom first absorbs a photon at a particular energy and then releases another photon at a lower energy (longer wavelength than that of absorbed photon).**

stokes shift:

The power transfer to higher wavelength occurs over a broad spectral range of **80 to 100nm**. The shift to a particular longer wavelength is referred to as stokes shift for that wavelength.

This process transfers optical energy from a strong laser pump beam to a weaker transmission signal that has a wavelength which is 80 to 100 nm higher than the pumping wavelength.



Pump
Signals
~100 nm
λ
λp
<
λs
Fiber
λ
λp
λs

Raman amplifier advantages

•Can use existing fiber as gain medium (distributed amplification)

•Can operate in any region of the spectrum

Raman amplifier disadvantages

•Require very high pump powers.

•Can be used only over long distances, since Raman effect is weak.

•Rayleigh scattering dominates, causing loss of pump power