



Optical Communications

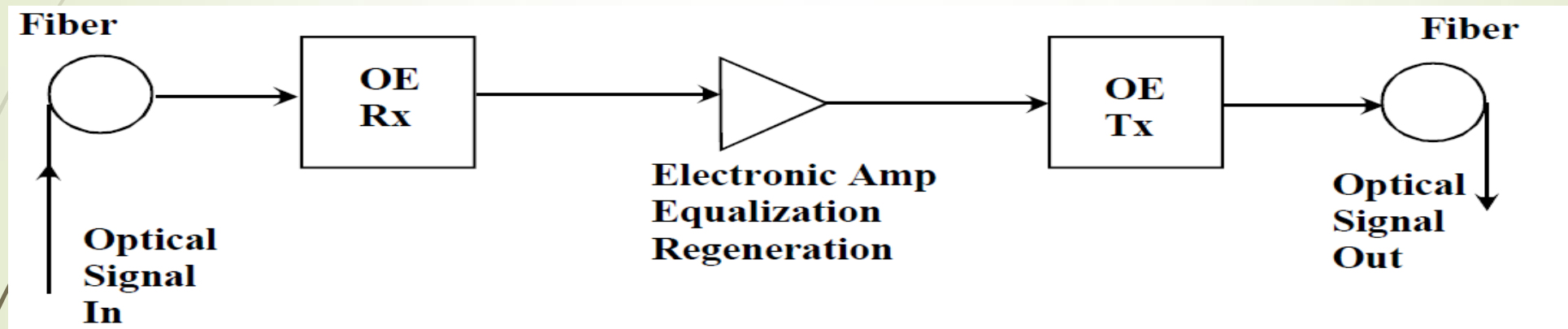
Lecture 6

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OPTICAL AMPLIFIERS

- In order to transmit signals over long distances (>100 km) it is necessary to compensate for attenuation losses within the fiber.
- Initially regeneration was used to overcome attenuation. It is the process of converting the weak optical signal to its electrical equivalent, then amplifying and reshaping it electronically, and retransmitting it on another laser.
- This process is generally known as optical-electrical-optical (OEO) conversion.

Optical Amplifier



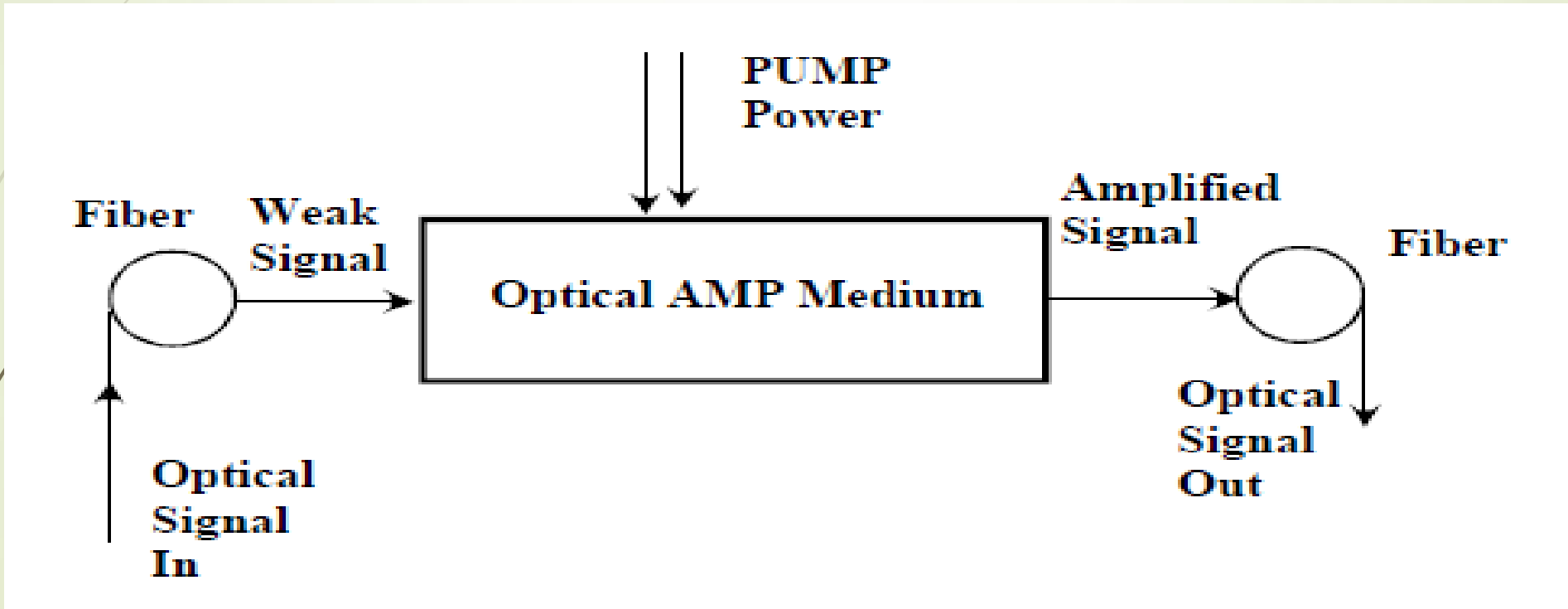
Regenerator



Optical Amplifier

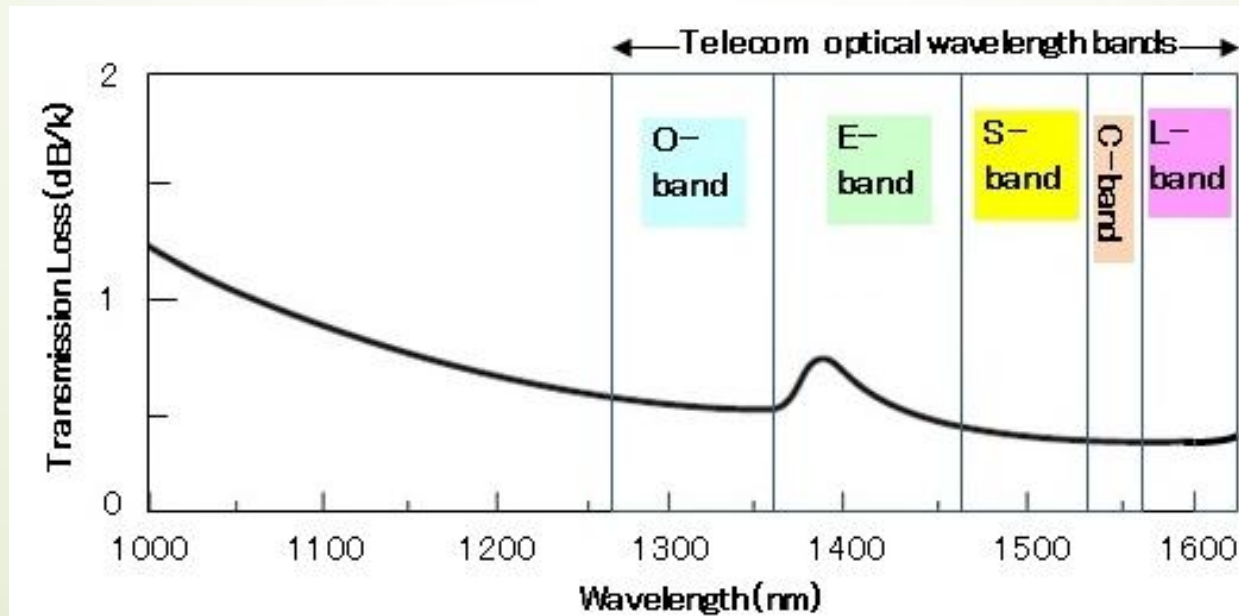
- Optical amplifiers boost signal level without the need to first convert it to an electrical signal.
- Several types of optical amplifiers have since been demonstrated to replace the OE – electronic regeneration systems.
- These systems eliminate the need for E-O and O-E conversions.
- This is one of the main reasons for the success of today's optical communications systems.
- The General form of Optical Amplifier is Illustrated on the next slide.

Optical Amplifiers



Optical Amplifiers

- ▶ Fiber-optic communication is mainly conducted in the wavelength region where optical fibers have small transmission loss.
- ▶ This low-loss wavelength region ranges from 1260 nm to 1625 nm, and is divided into five wavelength bands referred to as the O-, E-, S-, C- and L-bands, as shown in Figure.



Optical Amplifiers

- **Gain** is the factor by which the input signal is amplified and is measured as the ratio of output power to input power (in dB). A higher gain results in higher output optical signal.
- **Gain bandwidth** defines the range of bandwidth where the amplification functions. A wide gain bandwidth is desirable to amplify a wide range of signal wavelengths.
- **Saturation** output power is the maximum output power attainable after amplification beyond which no amplification is reached. It is important that the SOA has a high power saturation level to remain in the linear working region and to have higher dynamic range.

Optical Amplifiers

- Some types of OAs that have been demonstrated include:
- Semiconductor optical amplifiers (SOAs)
- Fiber Raman amplifiers
- Rare earth doped fiber amplifiers (erbium – EDFA 1500 nm)
- The most practical optical amplifiers to date include the SOA and EDFA types. New pumping methods and materials are also improving the performance of Raman amplifiers.

SOA

Characteristics of SOA types:

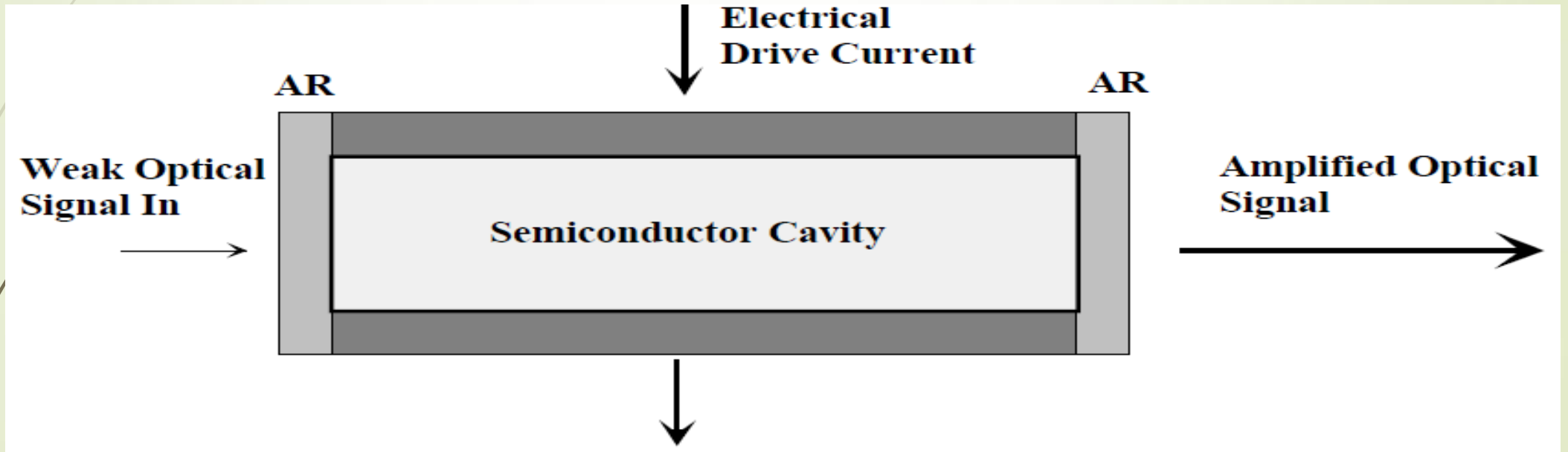
- Polarization dependent – require polarization maintaining fiber
- Relatively high gain ~20 dB
- Output saturation power 5-10 dBm
- Can operate at 800, 1300, and 1500 nm wavelength regions.
- Compact and easily integrated with other devices
- Can be integrated into arrays
- High noise figure and cross-talk levels.



SOA

- ▶ This last feature restricts the use of SOAs.
- ▶ Semiconductor Optical Amplifier (SOA) – similar to a laser cavity. Used as a discrete amplifiers. They can be integrated into arrays of amplifying switching and gating devices.
- ▶ Limited in operation below 10 Gb/s. (Higher rates are possible with lower gain.)

SOA



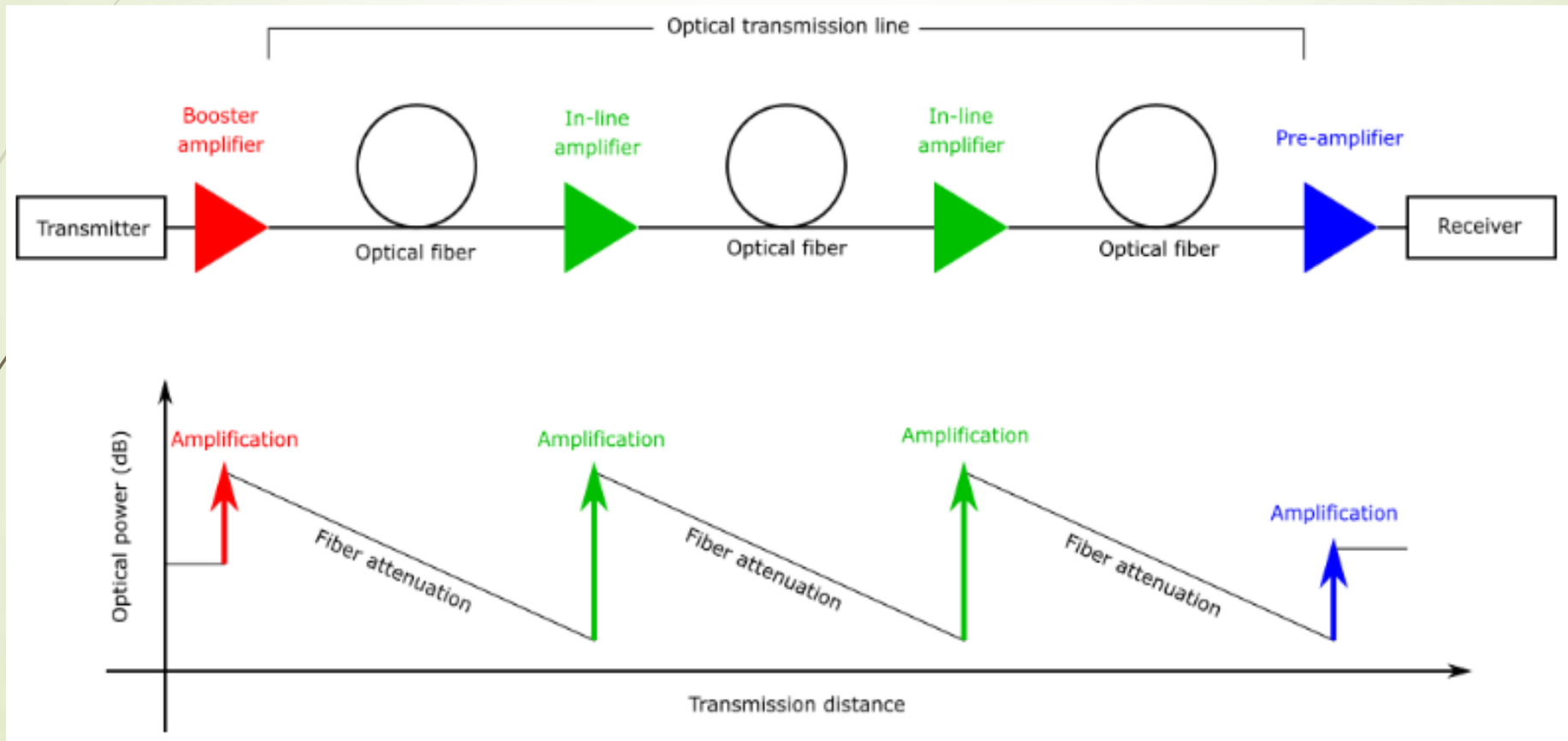
EDFA

- **Rare Earth Doped Fiber Amplifier Characteristics:**
- Rare earth doped fiber amplifiers are finding increasing importance in optical communications systems.
- The most important version is erbium doped fiber amplifiers (EDFAs) due to their ability to amplify signals at the low loss 1.55 μ m wavelength range.

EDFA

- EDFAs are used as a booster, inline, and pre-amplifier in an optical transmission line.
- The booster amplifier is placed just after the transmitter to increase the optical power launched to the transmission line.
- The inline amplifiers are placed in the transmission line, compensating the attenuation induced by the optical fiber.
- The pre-amplifier is placed just before the receiver, such that sufficient optical power is launched to the receiver.
- A typical distance between each of the EDFAs is several tens of kilometers.

EDFA



EDFA

Characteristics of EDFAs (advantages):

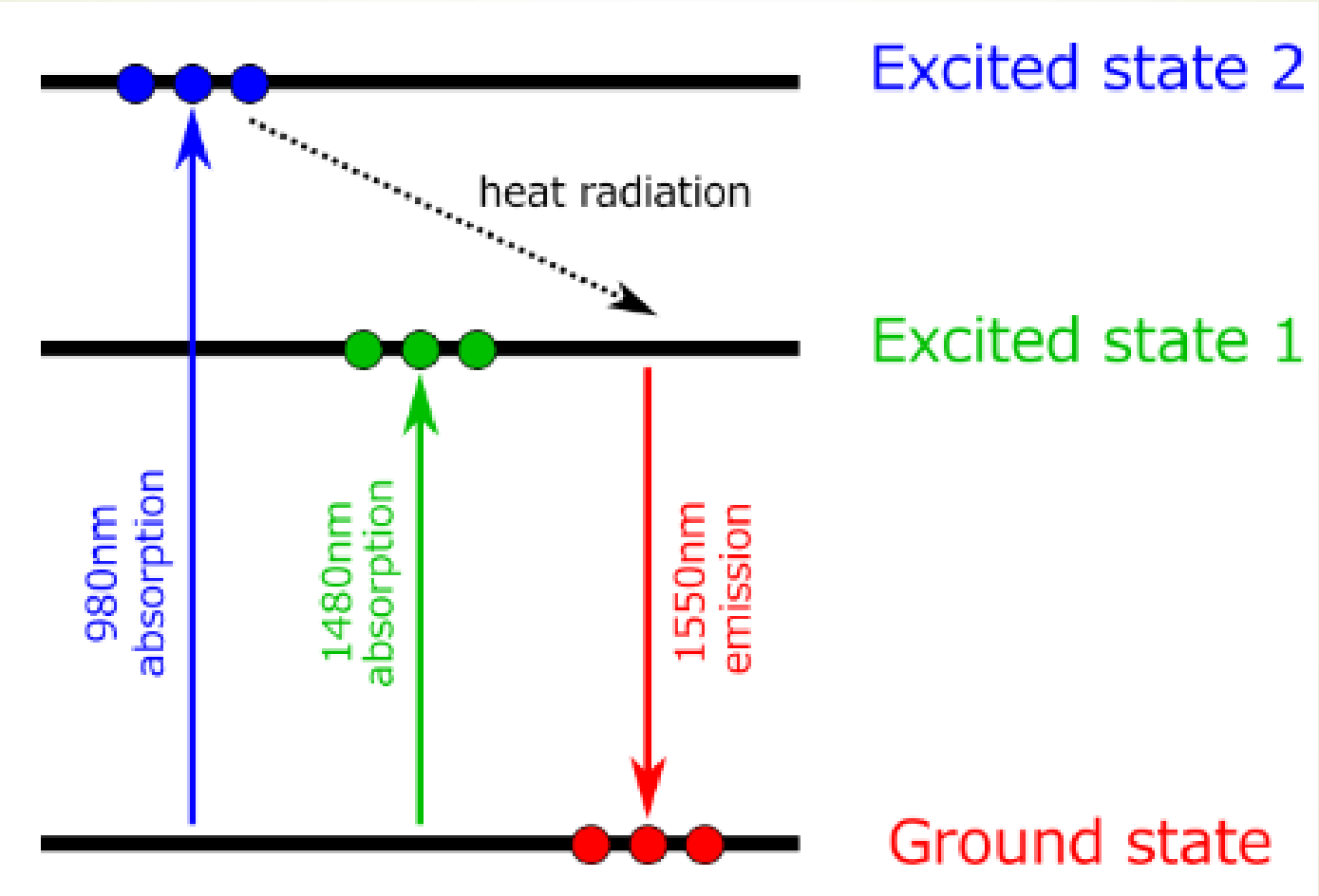
- High power transfer efficiency from pump to signal power ($> 50\%$).
- Wide spectral band amplification (>20 dB)
- Saturation output (10 to 25 dBm).
- Large dynamic range.
- Low noise figure.
- Polarization independent.
- Suitable for long-haul applications.

EDFA

Disadvantages of EDFAs:

- Relatively large devices (km lengths of fiber) – not easily integrated with other devices.
- ASE – amplified spontaneous emission. There is always some output even with no signal input due to some excitation of ions in the fiber – spontaneous noise.
- Cross-talk effects.

EDFA



EDFA

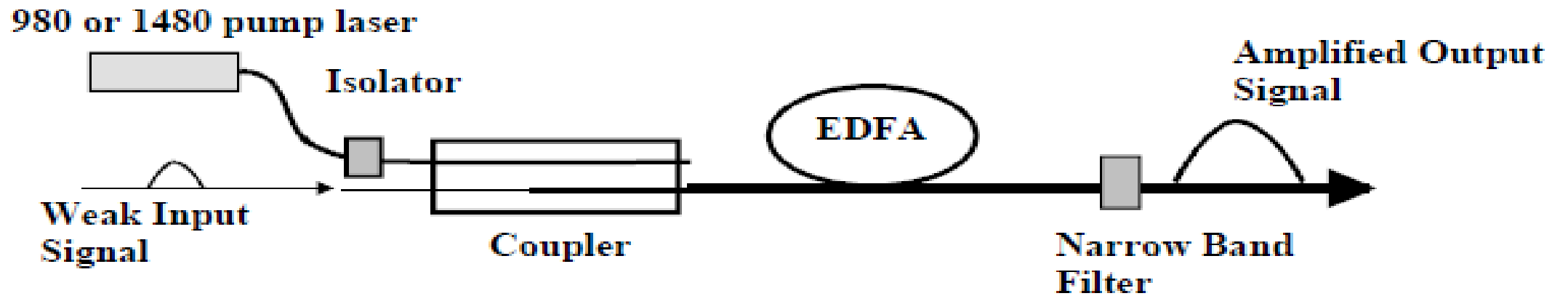
- Pumping is primarily done optically with the primary pump wavelengths at 1480 nm and 980 nm.
- When an EDFA is pumped at 1480 nm, Er ion doped in the fiber absorbs the pump light and is excited to an excited state 1.
- When sufficient pump power is launched to the fiber and population inversion is created between the ground state and Excited state 1, amplification by stimulated emission takes place at around 1550 nm.

EDFA

- ▶ When an EDFA is pumped at 980 nm, Er ion absorbs the pump light and is excited to another excited state (Excited state 2 in Figure). The lifetime of the Excited state 2 is relatively short, and as a result, the Er ion is immediately relaxed to the Excited state 1 by radiating heat.
- ▶ This relaxation process creates the population inversion between the ground level and Excited state 1, and amplification takes place at around 1550 nm.
- ▶ Semiconductor lasers have been developed for both pump wavelengths.

EDFA

General EDFA Amplifier Configuration:



EDFA

- The gain coefficient can be expressed as:

$$g(\omega) = \frac{g_0}{1 + (\omega - \omega_0)^2 T_2^2 + P / P_s}$$

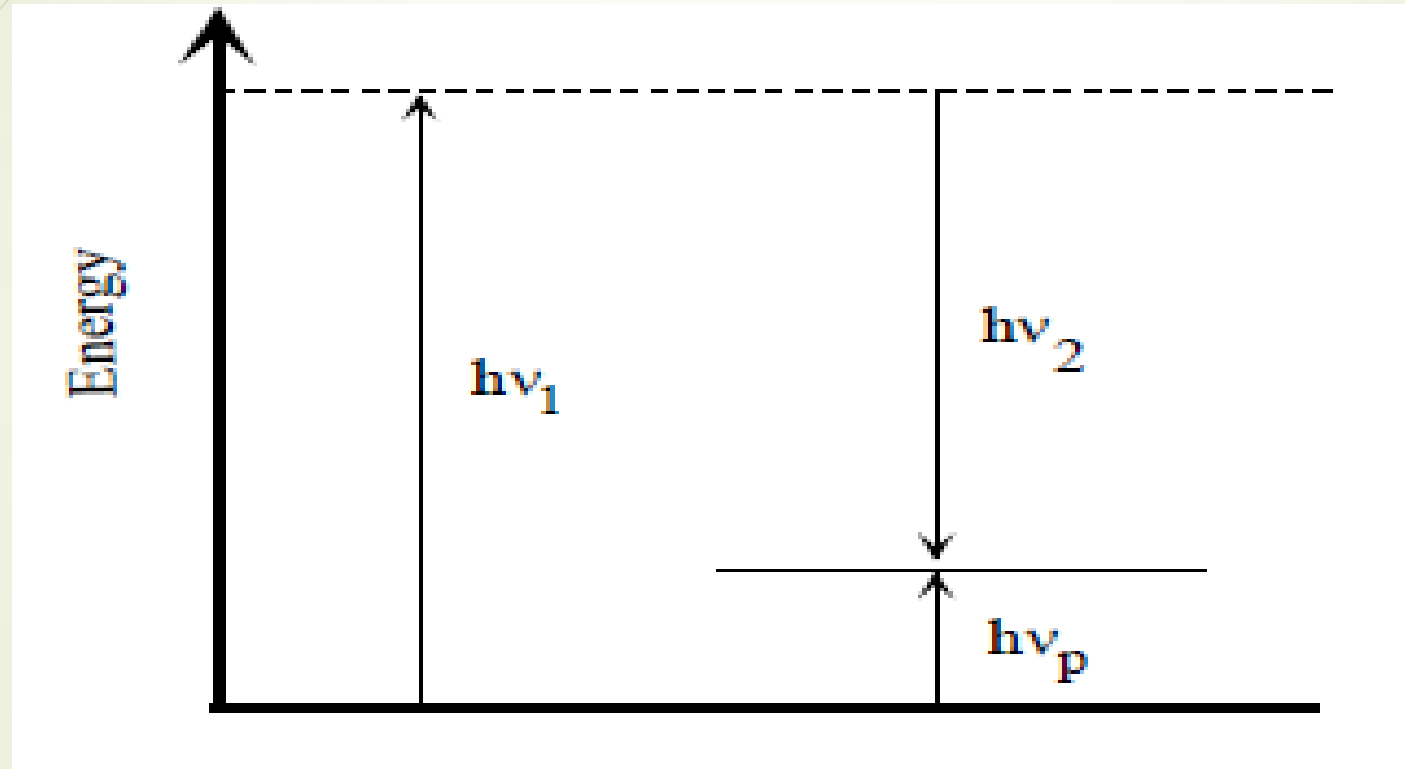
- g_0 is the peak gain, “ ω ” is the optical frequency of the incident signal.
- ω_0 is the transition frequency, P is the optical power of the incident signal.
- T_2 is the dipole relaxation time, and P_s is the saturation power.

RAMAN AMPLIFIERS

- A fiber-based Raman amplifier uses *stimulated Raman scattering* (SRS) occurring in silica fibers when an intense pump beam propagates through it.
- Raman scattering is an elastic scattering mechanism. Does not require a population inversion.
- A photon with energy $h\nu_1$ traveling through a material can excite a vibration transition of the material forming an optical photon with energy $h\nu_2$ and a photon with slightly reduced energy $h\nu_p$ given by

$$\nu_2 = \nu_1 - \nu_p$$

RA



RA

- SRS differs from stimulated emission in one fundamental aspect. Whereas in the case of stimulated emission an incident photon stimulates emission of another identical photon without losing its energy.
- In the case of SRS the incident pump photon gives up its energy to create another photon of reduced energy at a lower frequency (inelastic scattering).
- The remaining energy is absorbed by the medium in the form of molecular vibrations (optical phonons).
- Raman scattering is weak effect. It occurs through a slight modulation of the refractive index through molecular vibrations of the material.

RA

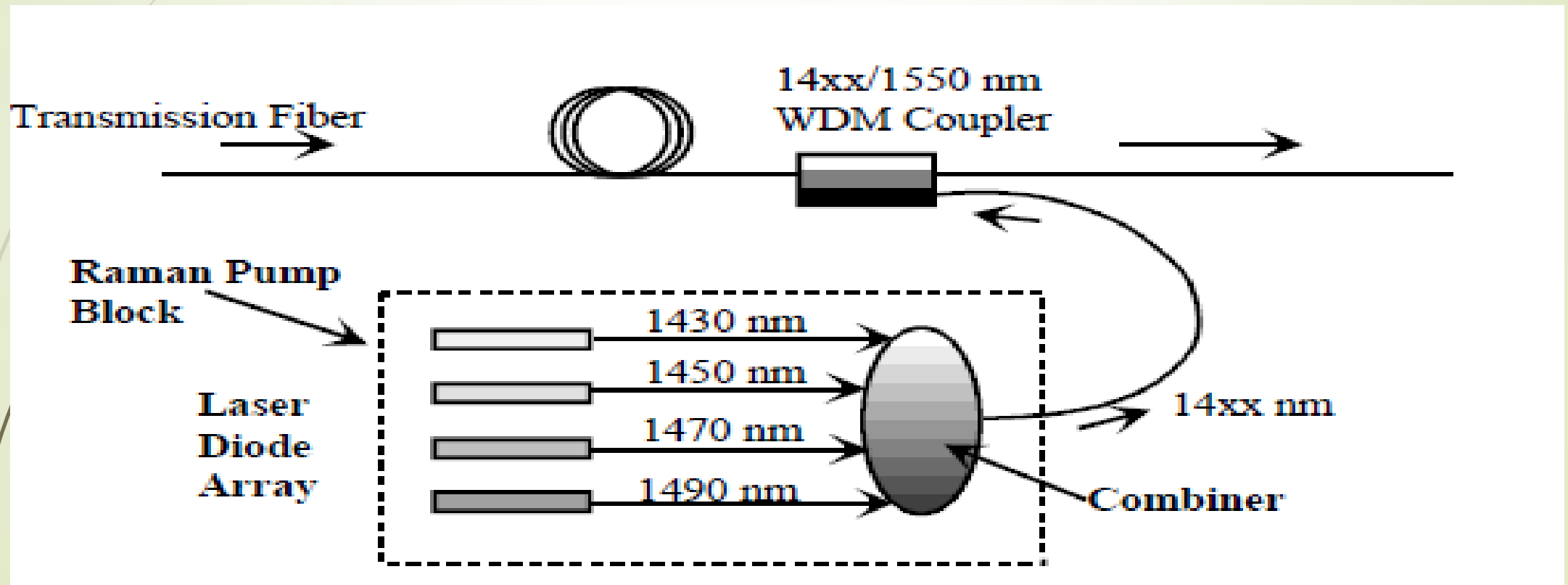
- At low illumination levels the Raman process results in low scattering levels.
- Spontaneous Raman Scattering. The molecules contributing to the process are vibrating independently and the scattered light is non-directional.
- Stimulated Raman Scattering (SRS). At higher intensity levels the generated photons begin to act in phase or coherently – i.e. the molecules oscillate as an array of vibrating oscillators. This gives rise to SRS.
- SRS can be a problem but it can also be used as a signal amplification process.
- On the negative side it contributes to dispersion and places an operational limit on the amount of power that can be transmitted through a fiber.

RA

Pump Arrangement to Extend the Range for Stimulated Raman Amplification:

- An array of laser diodes can be used to provide the Raman pump. The beams are combined and then coupled to the transmission fiber.
- The pump beams can counter propagate to the direction of the signal beams.

RA





End Of Slides