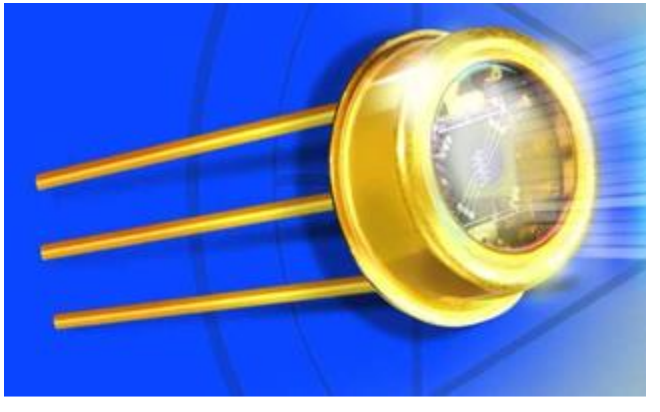
Optical Detectors

Optical **Detectors**

- Optical detector is an essential component of an optical receiver which converts received optical signal into an electrical signal.

- Photodetectors can influance the performance of a fiber optic communication link.



Requirements of Optical detector

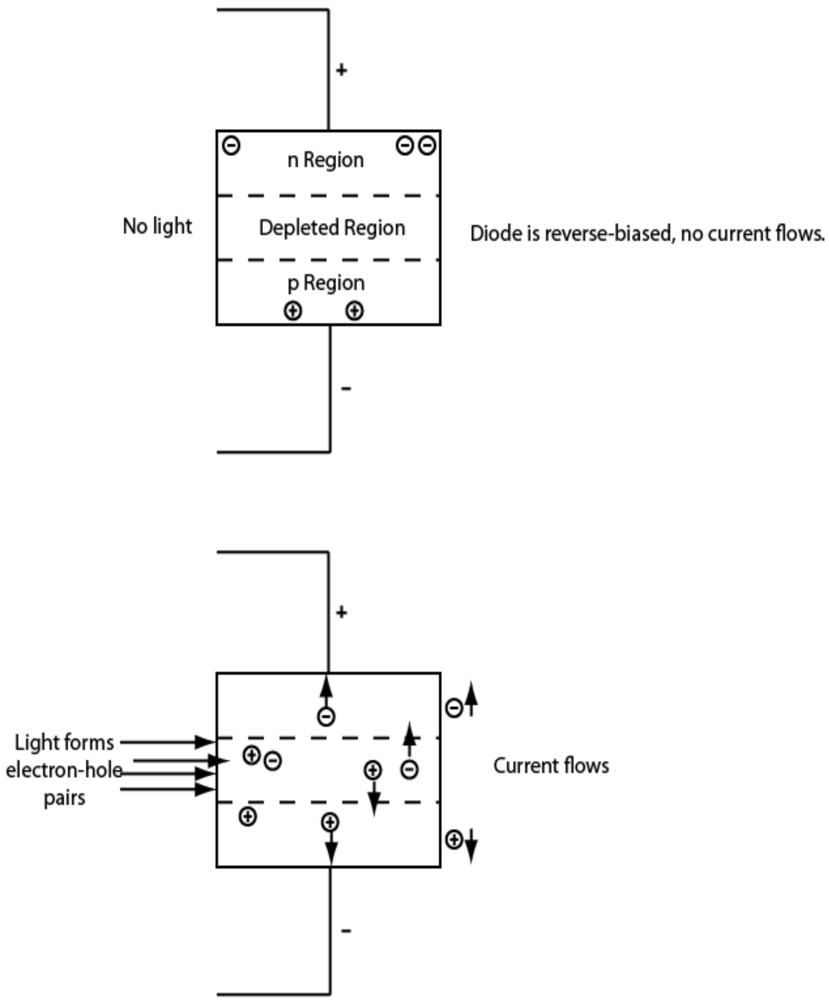
- ✓ High sensitivity at the operating wavelength
- ✓ High Fidelity
- ✓ Large electrical response to the optical signal
- ✓ Short response time to obtain a suitable bandwidth
- ✓ A minimum noise introduced by the detector
- ✓ Stability of performance characteristics
- ✓ Small Size
- ✓ Low bias voltage
- ✓ High reliability
- ✓ Low cost

Type of Optical Detectors

- p-n photodiodes
- p-i-n photodiodes(PIN Structure)
- Avalanche photodiodes(APD)

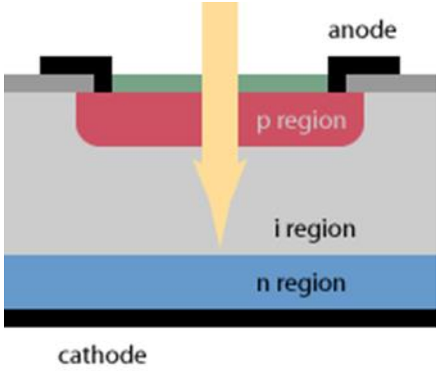
PN Photodiode

A reverse bias p-n junction consists of a region, known as depletion region Electron-hole pairs are created through absorption when such p-n junction is illuminated with light on one side Because of the large built-in electric field, electrons and holes generated inside the depletion region accelerate opposite directions and drift to n and p sides respectively. The resulting flow of current is proportional to the incident optical power A reverse bias pn junction acts as a photodetector and is referred as pn photodiode



PIN photodiode

- PIN photodiode has an intrinsic semiconductor region sandwiched between a p-doped and an n-doped region .
- PIN photodiode is reverse-biased so that intrinsic (i) region has no free charges, its resistance is high.
- Since the electric field is high in the i region, any electron-hole pairs generated by optical radiation in this region are immediately swept away by the field.
- The resulting flow of current is proportional to the incident optical power



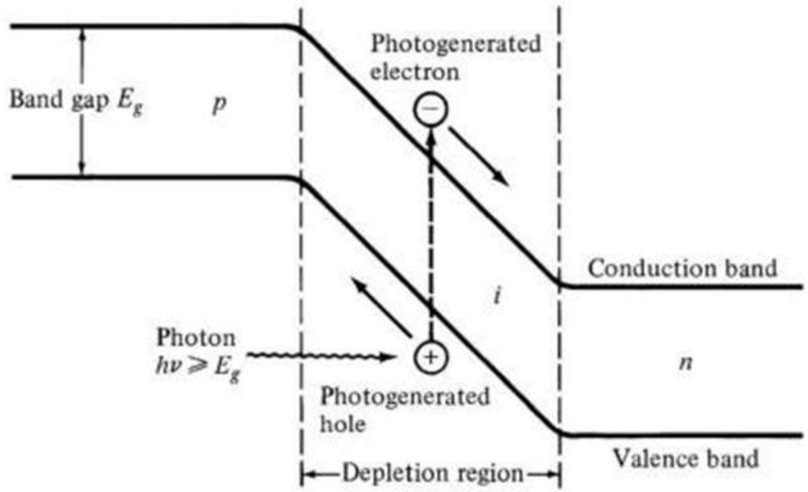
Advantages of P-I-N photodiode

- Intrinsic layer is thick, so more number of incident photons enter into this layer and generate electron hole pair, so results in the high quantum efficiency of the device.

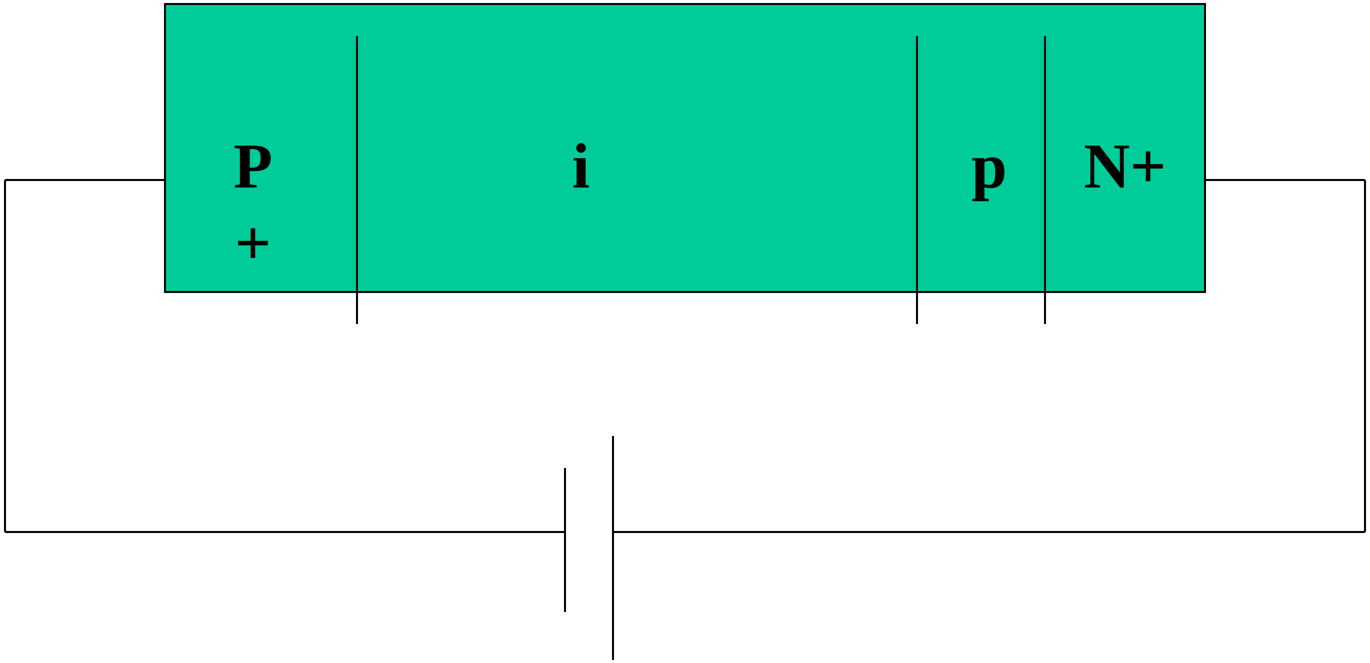
- Reverse biasing voltage is small (usually 50) because the thickness of the depletion region is controlled by the thickness of the intrinsic layer, not by reverse voltage.

- High bandwidth (Efforts to improve the bandwidth of 110 Ghz).

p-i-n energy-band diagram



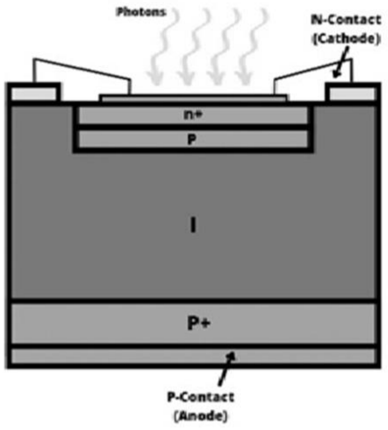
Avalanche Photodiode



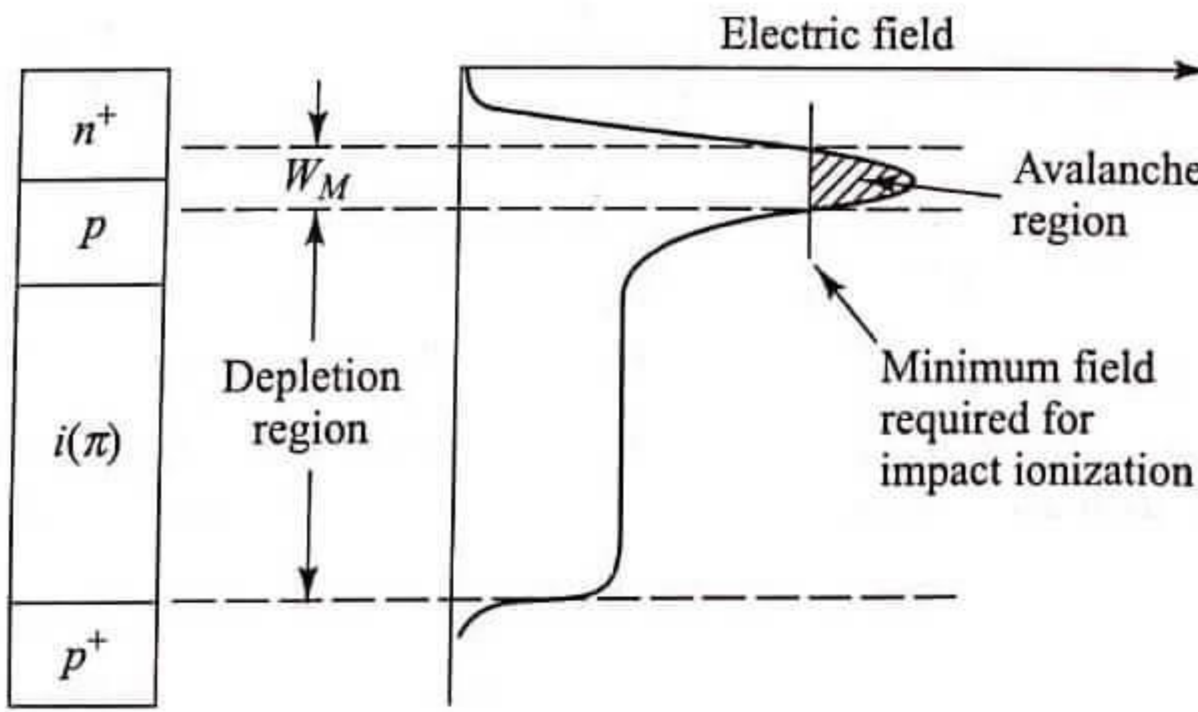
Avalanche photodiodes(APD)

The diode which uses the avalanche method to provide extra performance as compared to other diodes is known as avalanche photodiode.

Avalanche breakdown occurs mainly once the photodiode is subjected to maximum reverse voltage. This voltage enhances the electric field beyond the depletion layer. When incident light penetrates the p+ region then it gets absorbed within the extremely resistive p region then electron-hole pairs are generated.
Charge carriers drift including their saturation velocity to the p n+ region wherever a high electric field exists. When the velocity is highest, then charge carriers will collide through other atoms & produce new electron-hole pairs. A huge charge carrier's pair will result in high photocurrent.



The reach-through avalanche photodiode (RAPD) is composed of a high-resistivity p-type material deposited as an epitaxial layer on a pt (heavily doped p-type) substrate. A p-type diffusion or ion implant is then made in the high-resistivity material, followed by the construction of an nt (heavily doped n-type) layer.



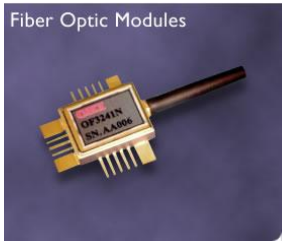
A P D

- Drawback of P-I-N photodiode is that it need of an amplifier to magnify the photocurrent produced by the photodiode.

- The quantum efficiency of the APD is M times larger than that of a P-I-N photo diode.

R(APD)=M x R (PIN)

M depends upon



1 Accelerating voltage

2 Thickness of the gain region

3 Ratio of electrons to holes participating in the ionization process.

- M ranges from 10 to 500.

Avalanche Photodiodes (APDs)

- High resistivity p-doped layer increases electric field across absorbing region

- High-energy electron-hole pairs ionize other sites to multiply the current -Leads to greater sensitivity

Characteristics of Photodetector

Quantum Efficiency(η)

Photodetector's sensitivity can be measured in two concepts: quantum efficiency and responsivity.

It is defined as the ratio of the number of electron hole pairs generated to the total number of incident photons.

$$\text{Quantum Efficiency} = \frac{\text{Electrons Out}}{\text{Photons input}}$$

It can by calculated by

$$\eta = (1 - R)\xi(1 - e^{-\alpha\omega})$$

R is the reflection coefficient at the air-semiconductor surface
ξ is the fraction of the e-h pairs contributes to the photo current
α is the absorption coefficient
ω is the distance where optical power is absorbed

Responsivity

The photo current I_p is directly proportional to the incident optical power P_{in}

$$I_p = RP_{in}$$

Where R is resposivity of photodetector in units of A/W

$$R = \frac{output\ photo\ current}{incident\ optical\ power} = \frac{I_p}{P_{in}}$$

Responsivity is the ratio of the electrical output to the optical input.

Responsivity

Responsivity is the ratio of electrical output from the detector to the input optical power.

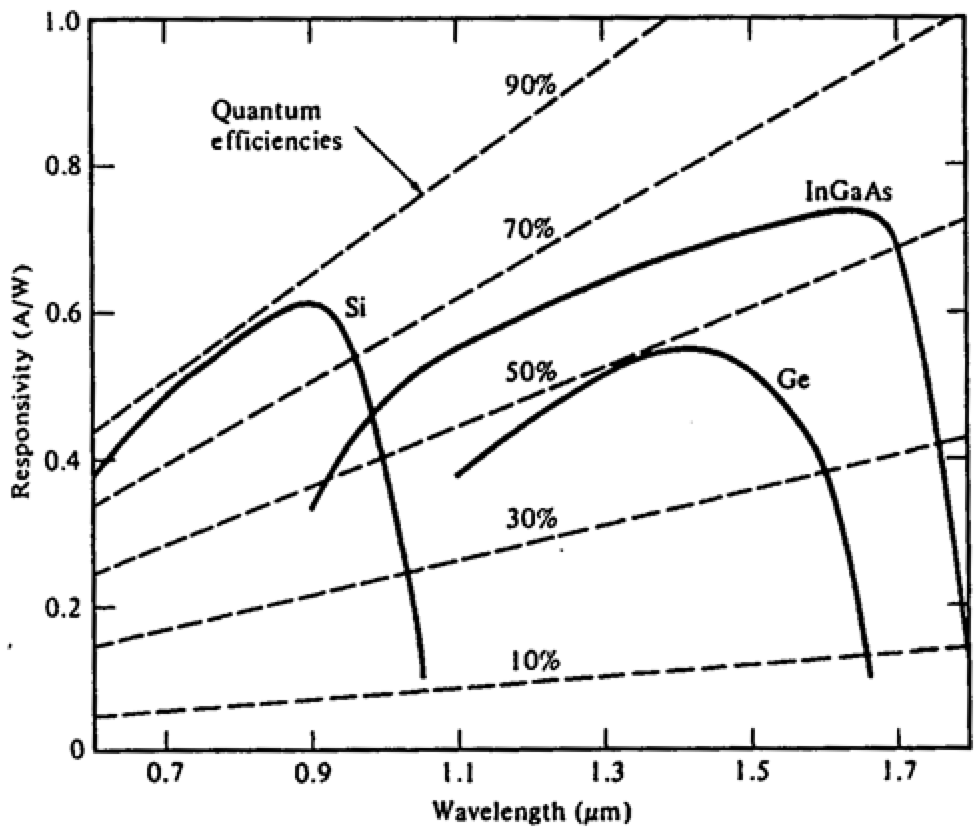
If the output current varies proportionally to the input, this is measured as amps per watt (A/W). Since in fiber optic communication systems, input powers are usually in microwatt level, responsivity is often expressed as uA/uW.

The responsivity ρ is the photo current generated per unit optical power. The following formula shows how to calculate responsivity.

$$\rho = \frac{\lambda_0}{1.24}\eta$$

where
λ_0 is measured in micrometer
η is the quantum efficiency

The figure shows the spectral dependence of responsivity and quantum efficiency for different semiconductor materials.



Speed of Response

The speed of response and bandwidth of a photodetector depend on three factors.

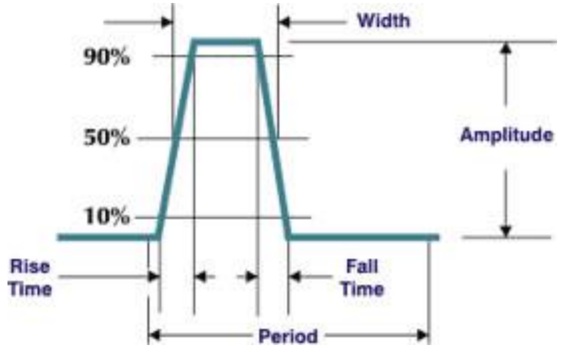
- The transit time of the photo-generated carriers through the depletion region
- The electrical frequency response as determined by the RC time constant, which depends on the diode's capacitance
- The slow diffusion of carriers generated outside the depletion region

Rise Time

Rise time is the time the output signal takes to rise from 10% to 90% of the peak value after the input is turned on instantaneously.

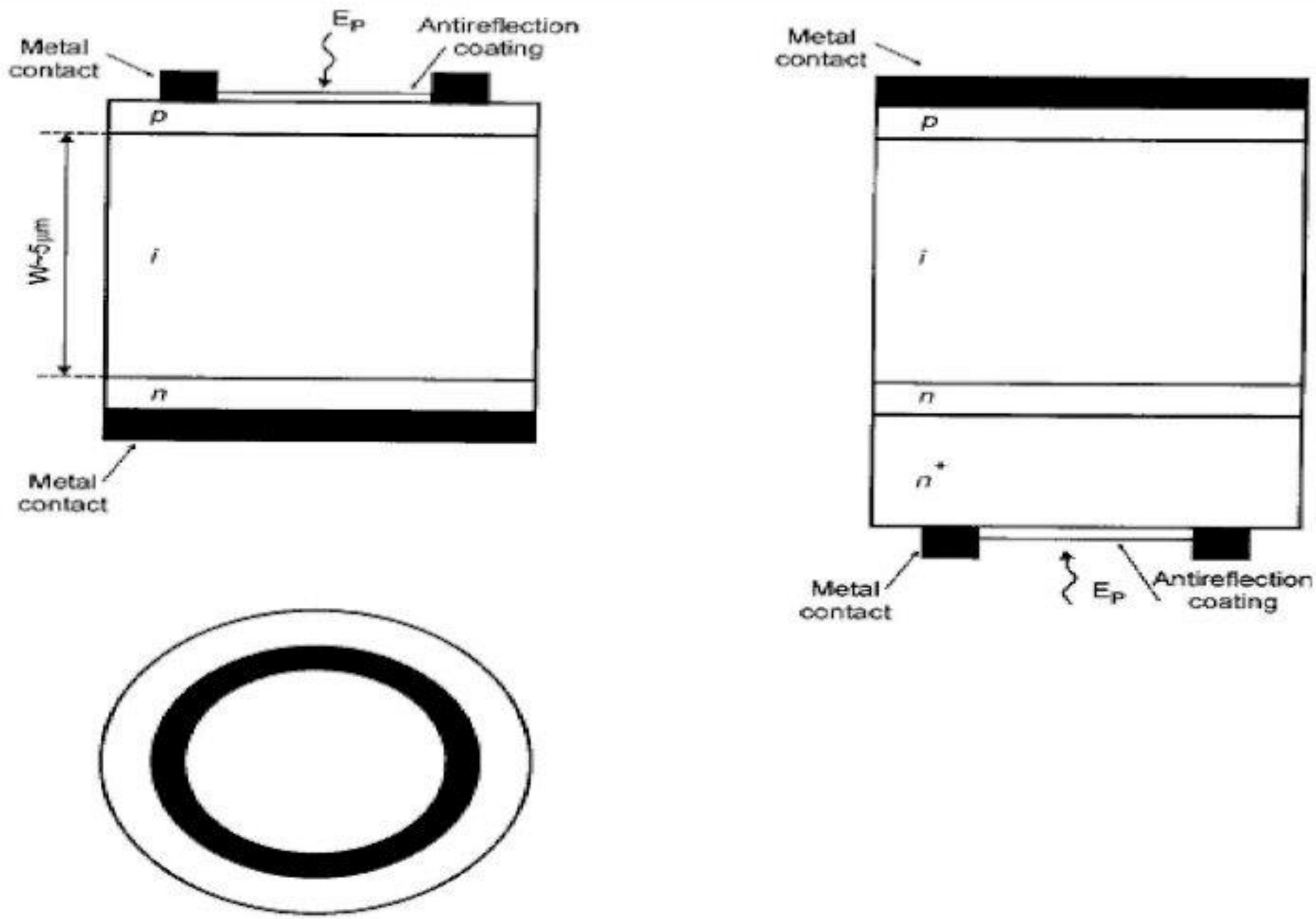
Fall Time

Fall time is the the time the output signal takes to drop from 90% to 10% of the peak value after the input is turned off abruptly.



Dark Current

Dark current is the current through the photodiode in the absence of light, when it is operated in photoconductive mode. The dark current includes photocurrent generated by background radiation and the saturation current of the semiconductor junction.



Metal contact
E_P
Antireflection coating
p
W~5μm
i
n
Metal contact
Metal contact
p
i
n
n+
Metal contact
E_P
Antireflection coating

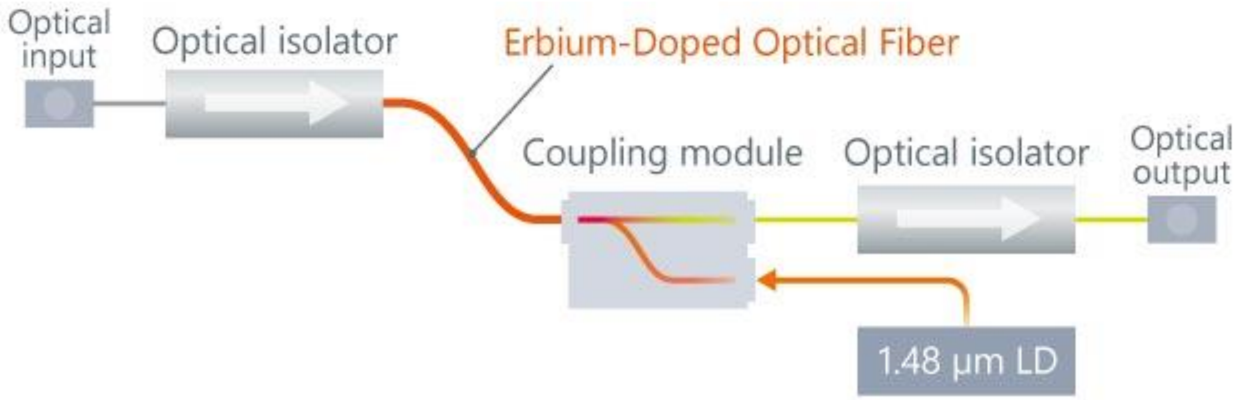
a)

b)

Optical Amplifier

An optical amplifier amplifies light as it is without converting the optical signal to an electrical signal, and is an extremely important device that supports the long-distance optical communication networks .
The major types of optical amplifiers include an **EDFA and SOA**.

EDFA (Erbium Doped Fiber Amplifier)



SOA (Semiconductor Optical Amplifier)